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Effect of fluid film wave bearings on attenuation of gear mesh noise and vibration

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ABSTRACT

The attenuation of the gear mesh noise/vibration by fluid film wave bearings relative to rolling element bearings was experimentally investigated. Tests were performed on a gearbox that can accommodate both rolling element bearings and wave bearings. It was found that at specific speeds and torques, the wave bearings could significantly reduce the noise/vibration compared to rolling element bearings. Because the gear noise is accompanied by noise from other sources, a method was developed to extract from the original signal only the mesh harmonic components.

The wave bearing dynamic coefficients were also predicted. It was found that adjusting the wave bearing parameters could considerably increase the capacity of the wave bearings to attenuate the gear mesh noise and vibration.

1. Introduction

The helicopter transmissions, which connect the high-speed engines to the low speed rotors, are expected to reduce the shaft rotational speed in the range from 25:1 to 100:1 [1]. At the same time, the transmission components must be as light as possible. One of the major problems encountered when designing high speed and high power density transmissions is the transmission noise and vibration. The primary source of the noise and vibration is the dynamic force of the gear mesh. The dynamic forces generate torsional, axial, and transverse vibrations of the gear shaft [2]. The vibrations are transferred to the bearings that support the shaft, generating lateral and vertical displacements at the support bearing locations. The vibration and noise then travels primarily by structural paths into the helicopter cabin. Measurements performed in helicopter's cabins showed that the gear generated noise can be over 100 dB in a helicopter cabin [3]. In addition, the noise predominant frequencies are in the most sensitive regions of hearing spectrum, contributing to crew and passenger fatigue and hearing loss [4].

In recent years, efforts have been made to find design methods to reduce the influence of the gear mesh on the noise and vibration of geared transmissions. Modifications to gear profiles can reduce, but not eliminate, transmission error at the source, particularly since the gears must operate over a range of torque levels, not just at a single design torque. Vibration isolators are generally not used in rotorcraft due to shaft alignment requirements and the large torque at engine startup [5]. Noise absorption treatments can be applied to cabin surfaces to reduce noise radiation into the cabin; however, absorbers add weight and cannot be applied to windows.

Another way proposed to reduce the gear mesh noise and vibration was to replace the rolling element bearings, traditionally used to support the gear shafts, with fluid film wave bearings. The objective of this paper is to compare the attenuation effects of wave bearings and rolling element bearings in transmitting gearbox noise and vibration.

2. Wave bearing concept

The wave bearing was introduced by Dimofte [6,7], as an alternative to the plain journal bearing. Unlike the plain circular bearing, the wave bearing has a slight, continuous variation of its profile. The variation is such that a continuous waved profile is circumscribed onto the non-rotating bearing surface. To exemplify the concept, a comparison between a wave bearing having circumscribed a three-wave profile and a plain journal bearing is presented in Fig. 1. The wave amplitude and the clearance are greatly exaggerated in Fig. 1. The most important geometrical parameters of a wave bearing can be seen in Fig. 2. The radial clearance C is defined as the difference between the radius of the mean circle of the waves R_{med} and the radius, R, of the rotor. The radial clearance is usually less than one thousandth of the rotor radius while the wave amplitude is usually a fraction (0.03–0.5) of the clearance. The ratio between the wave amplitude and

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Nomenclature

B_{xx}, B_{xy}, B_{yx}, B_{yy}	bearing damping coefficients, Ns/m
C	bearing clearance, m
e_w	wave amplitude, m
f_m	tooth passing frequency, Hz
f_s	rotating frequency of the shaft, Hz
h	fluid film thickness, m
K_{xx}, K_{xy}, K_{yx}, K_{yy}	bearing stiffness coefficients, N/m
N_g	number of the gear teeth
n_w	number of the waves
x_r, y_r	coordinates of the rotor center, m
$x[n]$	discrete time domain signal
$X[k]$	complex Fourier coefficients
θ	angular coordinate, rad
γ	wave position angle, rad

clearance is usually called wave amplitude ratio. The wave amplitude ratio is a very important parameter of the bearing because the performance of the wave bearing is strongly influenced by it [8,9]. The performance of a wave bearing also depends on the number of the waves, and on the position of the waves relative to

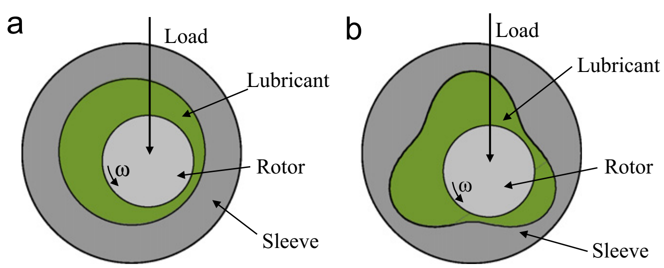

Fig. 1. Comparison between (a) the plain journal bearing and (b) the wave journal bearing.

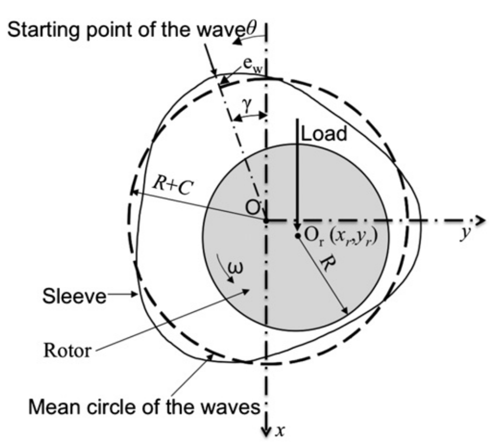

Fig. 2. Geometry of a wave bearing.

the direction of the load. Theoretical and experimental studies indicate that the best performance is obtained by a three-wave bearing having one of the points with maximum wave on the direction of the load [6].

The load capacity of a wave bearing is due to the rotation of the rotor and the variation of film thickness along the circumference. In a system of reference O fixed with respect to the sleeve (Fig. 2), the film thickness can be expressed as

$$h = C + e_w \cos[n_w(\theta - \gamma)] + x_r \cos\theta + y_r \sin\theta \quad (1)$$

where θ is the angular coordinate starting from the negative O axis, γ is the angle between the starting point of the waves and the vertical axis and (x_r, y_r) are the coordinates of the rotor center. The wave bearing has an improved stability compared to the plain journal bearing. In addition, because the geometry of the wave bearing is very close to the geometry of the plain circular bearing, the load capacity of the wave bearing is close to that of the plain journal bearing and superior to the load capacity of other types of journal fluid bearings.

3. Experimental rig and instrumentation

3.1. Experimental rig

A simple spur gearbox that can accommodate both rolling element bearings and wave bearings to support the shafts was used to experimentally investigate the attenuation effects on the gear mesh noise and vibration of the wave journal bearings compared to rolling element bearings. The rolling element configuration employs two 205-size deep groove ball bearings (bearings nos. 1 and 4) to support the coupling end of each shaft and two 205-size cylindrical roller bearings (bearings nos. 2 and 3) to support the free ends of the shafts (Fig. 3). Four wave-bearings having a diameter of 32 mm and a length of 22 mm directly replace the ball and roller bearings for the wave bearing configuration. The clearances of the wave bearings nos. 1, 2, 3,

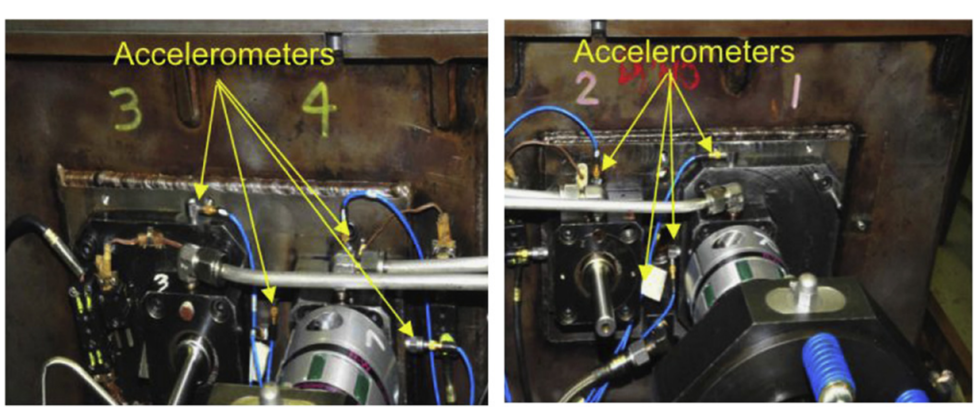

Fig. 3. Side views of the gearbox: input side (right) and output side (left).