Spiral Bevel Gears nonlinear dynamics: chaotic response existence in multi degree of freedom systems

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Abstract. The present study investigates the dynamic behavior of the spiral bevel gears (SBGs) by developing two degrees of freedom dynamic model (2 DOF) to four degrees of freedom (4 DOF) which involves the rotational shaft stiffness. The governing equations of motion are derived based on a nonlinear time-varying model. The nonlinearity and time dependency emanate from the backlash and contact ratio of the pinion and the gear, respectively. Depending on the working conditions, it could be happened that the system experience a backside contact which is an undesirable phenomenon in gear systems. A comparison between two systems, i.e., 2 DOF and 4 DOF, is done to understand what kind of phenomena are neglected by decreasing the DOF. The root mean square (RMS) diagrams and bifurcation diagrams are employed to analyze the vibration response of the system. The interesting point is that the simplification in dynamic model could lead to a different dynamic response respect to the reality.

Introduction

Bevel gears are using for the power transmission systems with limited space. Without bevel gears, the drive motors, gearboxes, and driven equipment may locate on the linear position, consequently the total space of the driving equipment is vast. For high-speed gearboxes using spiral bevel gears (SBGs) instead straight bevel gears is essential due to the high level of vibration magnitude. Bevel gears are applicable in different engineering fields, e.g., aerospace, terrestrial vehicles, and in heavy industries whenever it is required to transmit a high load between nonparallel shafts [1]. In Ref. [2], Samani et al. investigated nonlinear vibration of the SBG with a novel tooth surface modification. However, they showed that the considered higher-order transmission error method is not able to decrease the vibration level for the considered frequency ratios. The effectiveness of squeeze film dampers for passive vibration control of SBGs is evaluated by Chen et al., [3]. Figure 1 represented the dynamic model, which is used for simulation. The translational degrees of freedom for both, driver and driven gears are constrained in all directions as well as the rotations. the gears can only rotate around their axes. By considering the shaft rotational stiffness, the dynamic model becomes 4 DOF, i.e., two rotational DOF for the pinion and the gear, and two degrees of freedom for the load and the motor. The nonlinear differential equations with time-varying mesh stiffness are solved via numerical integration based on an adaptive step-size implicit Runge-Kutta scheme.

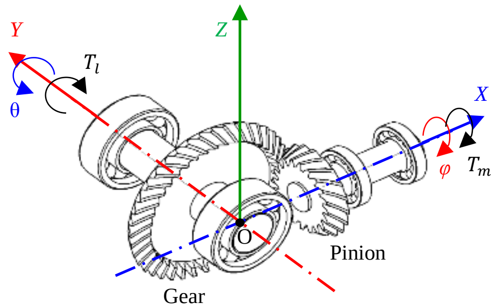

Figure 1: The dynamic model of a gear system with rotational degrees of freedom.

Results and discussion

The systems, regardless of the number of DOF experienced three types of contact: drive-side contact, separation tooth, and undesirable backside contact. By comparing the response of the dynamic models with 2-DOF and 4-DOF, the dynamic behavior of the system altered. The vibration amplitude, RMS, considering 2-DOF is higher than the system with 4-DOF at primary and super-harmonic frequency ratios. Besides, the maximum magnitude of vibration happens during backside contact. Vice versa, close to the primary resonance, the 4-DOF system represented chaotic response, while 2-DOF presents 4T harmonic response. At $\omega_m/\omega_n = 0.46$, the 2-DOF system presents chaotic response for a narrow range of frequency while it is eliminated in 4-DOF system.

References

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