Nonlinear Torsional Vibration Modeling and Characteristic Study of Planetary Gear Train Processing Device

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A nonlinear torsional vibration model with meshing errors, time varying meshing stiffness, damping coefficients, and gear backlashes was presented to analyse the nonlinear dynamic behaviour of the planetary gear train system, which was used to machine the Circular-Arc-Tooth-Trace cylindrical gear. Its dimensionless equations of the system were derived, and the solution of the equations was carried out by using the method of numerical integration. The bifurcation diagrams indicated that the system had abundant bifurcation properties with the dimensionless speed, and the damping ratios of meshing pairs could influence the vibration amplitudes and bifurcation characteristic greatly. The phase plane plots and Poincar maps revealed that the motion state of the system would through the regions such as harmonic response, non-harmonic response, 2T-periodic harmonic response, 4T-periodic harmonic response, quasi-harmonic response, and chaotic response. The chaotic regions will cause the system failure and instabilities, so these regions should be avoided.

1. INTRODUCTION

The planetary gear was used in the processing device for machining the Circular-Arc-Tooth-Trace cylindrical gear (CATT gear—it is a new type gear) due to its advantages, such as compactness, large torque-to-weight ratio, large transmission ratios, reduced vibrations, and translational property.[1] The processing device consists of planetary gear sets that have translational and rotary motions, which can form the ideal tooth profile of the CATT gear,[2] and its vibration influences the correct manufacturing of the tooth profile. That is the reason why this paper focuses on the vibration of the planetary gear transmission system. The structures of the processing device of the CATT gear are shown in Figs. 1 and 2. Similarly, there have been numerous studies about the vibration of planetary gears in recent decades. The factors influencing the vibration- and noise-related dynamic responses of planetary gear systems have been investigated by many researchers. Velex and Flamand,[3] Kahraman and Blankenship,[4] and Lin and Parker[5] investigated the time-varying mesh stiffness. Kahraman, Parker, et al. analysed the natural modes of planetary gears with unequally spaced planets and an elastic ring gear.[6,7] Ericson and Parker[8,9] investigated the effects of torque on the dynamic behavior and system parameters of planetary gears by experimental measurement and finite element analysis, and the study provided good methods for the CATT gear research. The transmission errors, the spacing, and backlash-related nonlinear dynamics were the main focus in much published research.[10–12] Xihui, Liang, et al.[13] investigated the vibration properties of a planetary gear set and evaluated the mesh stiffness effectively. Li, Wu, and Zhang[14] formulated a nonlinear time-varying dynamic model for a multi-stage planetary gear train. However, these published studies investigated the vibration based on the conventional planetary gears. Fewer studies are available about the investigations on the translational planetary gear train.

Although many models in previous research are different from this planetary gear set, some studies can provide many available methods, as in some of the work referenced in this paper. A. Kahraman used a family of torsional dynamic models of compound gear sets to predict the free vibration characteristics under different kinematic configurations resulting in different speed ratios, but he investigated the planetary gear sets without nonlinear models.[15] Robert G. Parker examined the effectiveness of planet phasing to suppress planetary gear vibration in certain harmonics of the mesh frequency based on the physical forces acting at the sun-planet and ring-planet meshes.[16] This research proposed a method to suppress the vibration of the planetary gears. J. Lin and R. G. Parker also investigated the natural frequency and vibration mode sensitivities to system parameters for both tuned and mistuned planetary gears.[17,18] V. K. Ambarisha, et al. investigated the complex, nonlinear dynamic behaviour of spur planetary gears using two models: a lumped-parameter model and a finite element model.[19] In this paper, mesh phasing rules to suppress rotational and translational vibrations in planetary gears were valid even when nonlinearity formed tooth contact loss occurs. Sun Zhimin, et al. used a clearance-type nonlinear dynamic model of a 2K-H planetary gear train to analyse the nonlinear dynamic behaviour of the gear train excited by a static transmission error in addition to a mean torque.[20] His research results indicate that the backlash induces complicated nonlinear dynamic behaviour in the 2K-H planetary gear train. Simi-