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# A coupling dynamics analysis method for a multistage planetary gear system

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ABSTRACT

The lumped parameter and finite element methods (FEM) are two relatively common modeling approaches for the coupling vibration analysis of the planetary gear system. In order to overcome the lack of fidelity of the lumped parameter models and the high computational cost of finite element models, and in order to obtain accurate vibration response predictions to understand the coupling vibration mechanism in the planetary gear system, a comprehensive, fully coupled, dynamic modeling method is proposed by applying a virtual equivalent shaft element. The continuous planetary gear transmission system is divided into numerous shafting elements. The dynamic model of the planetary gear system is constructed applying these shafting elements, including the shaft segments and flexible ring gear, and as well as the flexible planet carrier. The proposed method is implemented on a two-stage planetary gear system, and it is verified by comparing the results to the calculations using existing lumped parameter and FEM. The quasi-static and dynamic modeling results are presented to study the dynamic behavior and coupling characteristics in-depth. The proposed method can be used to guide the design of high reliability and low vibration planetary gear systems.

## 1. Introduction

Planetary gear transmission has many advantages, such as its compactness, light weight, heavy carrying capacity, large transmission ratio, and high-transmission efficiency. Hence, it is extensively used in both high-speed, large power, and low-speed, high-torque applications, such as spacecrafts, gas turbines, blowers, compressors, marine main reducers, cars, tanks, engineering machinery, lifting transportation, and other related machineries [1]. Sometimes, due to poor operating conditions and complex loading that subject the transmission systems to variable loads, strong vibrations and large impact forces induce damaging vibration in the machinery leading to premature failure of the transmission system. For this reason, the dynamics and vibration characteristics of the planetary gear system has increasingly attracted extensive attention [2–4] because of the desire to design a highly reliable, low-vibration planetary gear system.

Currently, the lumped parameter method and finite element methods (FEM) are two common modeling approaches applied to the analysis of coupling vibration in the planetary gear system. Presently, the lumped parameter method applied to model multistage planetary gear dynamics assumes that the gear, shaft, and bearing, are concentrated points. Additionally, the complex coupling effect between the elastic shaft elements is represented by simple bending and torsional stiffnesses. These assumptions often render the

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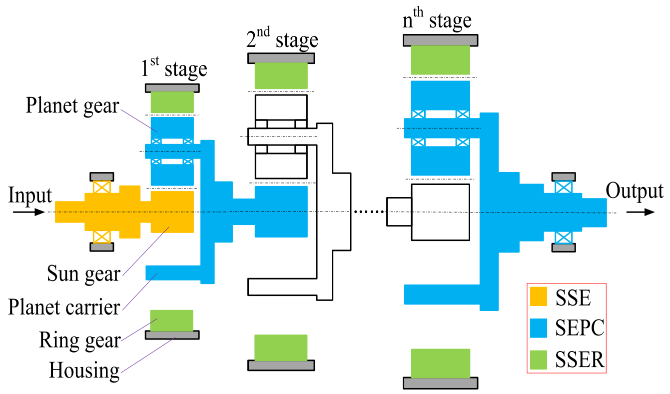


**Fig. 1.** Division of multistage planetary gear system into three forms of shafting elements.

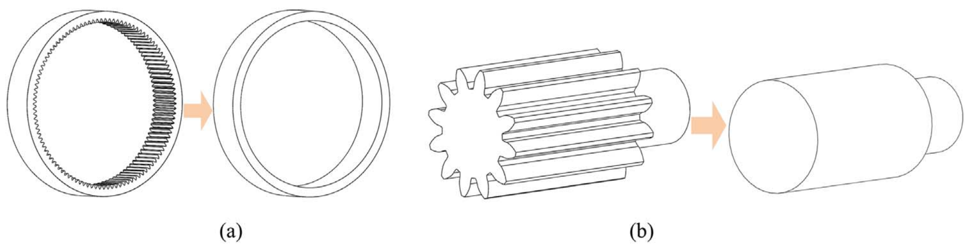


**Fig. 2.** Example of an equivalent virtual shaft segment of the (a) ring gear, and (b) gear shaft.

lumped parameter models less accurate because they are not able to reliably distinguish between the shaft section and bearing, and are not able to account for the flexibilities of the ring gear and the planetary carrier [5–7]. However, the large deformation of the structure will directly affect the transmission performance especially under heavy load condition and the deformation of structures should not be ignored.

In contrast, the FEM is generally able to analyze the vibration response of the planetary gear system at the expense of a steep computational burden. Several recent applications of finite elements in gearing studies are discussed next. Kahraman et al. [8] investigated the effect of dynamics on gear stresses as a function of gear rim thickness and the number of planets. Abousleiman and Velex [9] analyzed the three-dimensional dynamic behavior of planetary/epicyclic spur and helical gears by applying a hybrid finite element/lumped parameter model. Parker et al. [10] studied the dynamic response of a planetary gear using a semi-analytical finite element formulation that incorporated precise representation of the tooth geometry and contact forces. Ambarisha and Parker [11] also examined the complex, nonlinear dynamic behavior of spur planetary gears using both a lumped-parameter model and a finite element model. Kahraman and Vijayakar [12] investigated the effect of the internal gear flexibility on the quasi-static behavior of a planetary gear set by using a finite element/semi-analytical, nonlinear contact mechanics formulation. However, the dynamic analysis results of the planetary gear system could be more accurate as the elastic deformation of components is considered through the application of the finite element model. Certainly, it will lead to a high computational cost, and a complex modeling process due to the large number of degrees of freedom.

The low-fidelity problem of the lumped parameter method and the large computational burden of the FEM are the main shortcomings of these two existing modeling approaches. In order to accurately model the dynamic performance reliably and efficiently to understand the coupling vibration mechanism in the multistage planetary gear system, a novel coupling vibration analysis approach is put forward in this study, based on the virtual equivalent shaft element. In the proposed approach, the continuous planetary gear transmission system is divided into many shafting elements. The overall dynamic model of the planetary gear system is composed of these shafting elements, including shaft segments and flexible ring gear as well as a flexible planet carrier. This method provides full consideration of the coupling relationship amongst the major structural components in the analysis of the planetary gear dynamic characteristics.

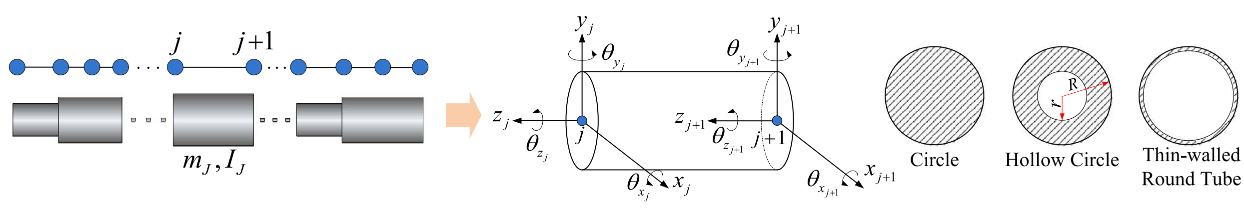


**Fig. 3.** Simple shafting element model.