

Modular Dynamic Modeling Investigation of Multi-Stage Planetary Gears for Space Manipulator Joints

Fei Ren^{1, a, *}, Taoli Yang², Ansheng Li¹, Guiqin Shi¹, Chao Wu¹, Zhiqiang Guo¹, Rumin Zhu¹, Ning Wang³

¹ Zhengzhou University of Light Industry, Zhengzhou 450002, China

² PetroChina Tarim Oilfield Company, Korla 841000, XinJiang, China

³ Underground Space Design and Research Institute, China Railway Engineering Equipment Group Co. Ltd, Zhengzhou 450016, China

^{a, *} Corresponding author e-mail: renfei2010phd@163.com

Abstract. In order to overcome the shortcomings of the traditional modeling method, a modular modeling approach for the space manipulator joint transmission system in this paper is proposed. In the first place, the multi-stage planetary transmission system for the space manipulator joint is divided into several sub-modules, and the sub-modules of each level are established by considering the factors such as meshing stiffness, meshing errors and so on. In the second place, the dynamic differential equations of the multi-stage planetary transmission system for the space manipulator joint are obtained through the integration of each level modules. The proposed modular modeling approach is convenient for the dynamic behavior analysis and the quick choice of transmission scheme.

Keywords: Space Manipulator Joints, Multi-Stage Planetary Gears, Modular, Dynamic Modeling

1. Introduction

The planetary gear transmission (PGT) joint has large capacity, high reliability and long service life. However, to achieve a higher transmission ratio, the multi-stage planetary gear transmission is required. Domestic and international research on the dynamic characteristics of the multi-stage planetary gear transmission system is concentrated in the aviation and marine fields[1-5].

All above literatures are based on the whole system, and the dynamic model of the system is established. If the system transmission form is changed, the corresponding dynamic model need be re-established. The above modeling method is called the traditional integrated modeling. This modeling method is not convenient for quickly selecting the transmission scheme through dynamic performance analysis. The model is not universal, not only complicated and time consuming, but also prone to errors during the reconstruction of the model.

In order to overcome the shortcomings of the traditional modeling approach, the modular modeling idea in this paper is presented to establish a generalized modular dynamic model of the space manipulator joint transmission system, which is not limited to a certain transmission form and helpful for the rapid selection of transmission schemes and the study of dynamic characteristics.



2. Transmission Scheme of Gear trains for Space Manipulator Joints

The multi-stage 2K-H planetary transmission connected in series is adopted in this study. The schematic diagram of the transmission scheme is shown in Fig. 1. Each stage of the 2K-H planetary transmission consists of a sun gear s , N_i uniform planet gear p , a ring gear r and a planet carrier c . The planet carrier of the upper stage is connected to the sun gear of the next stage. The input and output members of the system are the sun gear of the first transmission stage and the planet carrier of the N -th stage, respectively.

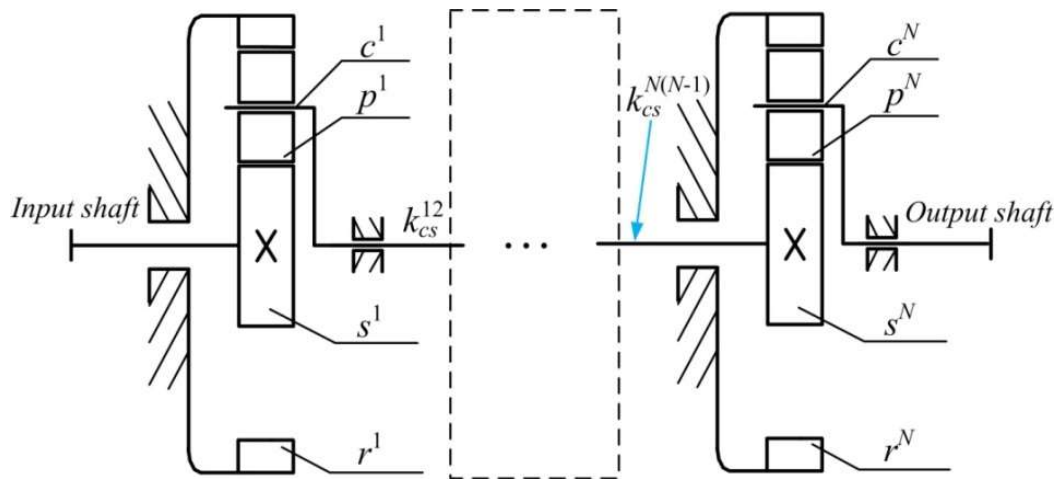


Fig. 1 Schematic diagram of the multi-stage planetary gear transmission scheme for space manipulator joints

3. Modular Dynamic Modeling of Multi-Stage Planetary Gears for Space Manipulator Joints

3.1. Computational Model

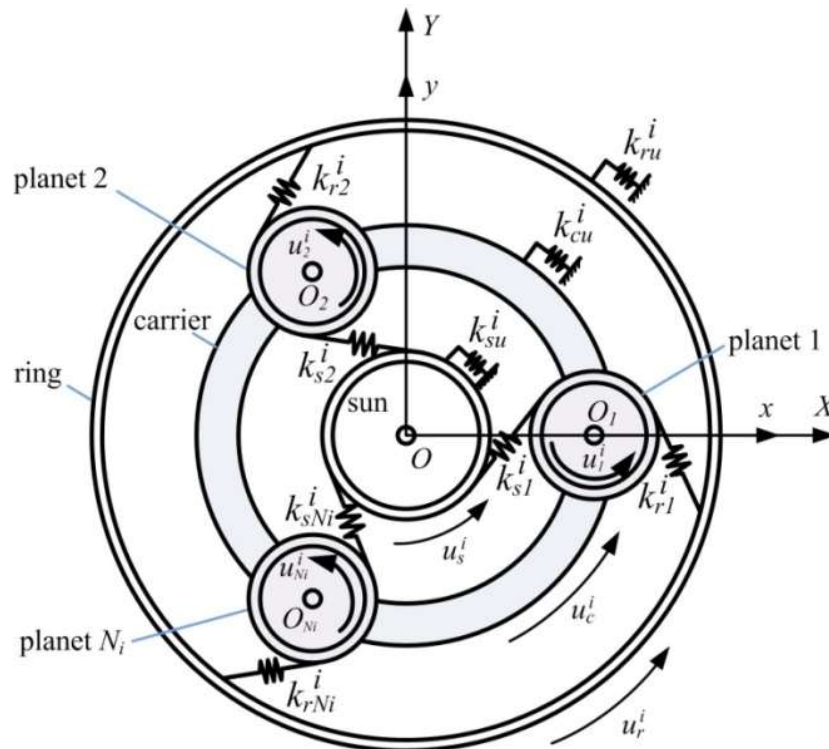


Fig. 2 Lumped-parameter model of single-stage 2K-H planetary transmission

Fig. 2 shows the pure torsional lumped-parameter model of the i -th stage 2K-H planetary transmission for the multi-stage planetary gear transmission system. In the model depicted in Fig.2, OXY is a static coordinate system. Oxy is a moving coordinate frame. u_c^i, u_r^i, u_s^i , and u_n^i ($n = 1, 2, \dots, N_i$) are the torsional vibration displacements of the carrier, ring gear, sun gear and j -th planet gear of the i -th transmission stage in the u direction. The relative mesh deformations of the internal and external mesh pair along each LOA in the i -th stage ($i=1, 2, \dots, N$) can be expressed as $\delta_{rn}^i = (u_r^i - u_n^i - u_c^i \cdot \cos \alpha_r^i) + e_{rn}^i(t)$, $\delta_{sn}^i = (u_n^i + u_s^i - u_c^i \cdot \cos \alpha_s^i) + e_{sn}^i(t)$, respectively. Since the composition of each transmission stage in the transmission scheme for space manipulator joints is the same, only a single-stage calculation model is given in Fig. 2.

3.2. Modular Modeling Approach

In this paper, the modular modeling method is adopted to divide the overall model of the transmission system into four-level modules. A generalized dynamic model of the planetary gear transmission system is established via the call of different levels of modules. The specific component of each module model is as following:

3.2.1. Construction of one-level module model. The one-level module is a pair of gear meshing, including internal meshing (i.e. ring and planet gear meshing) and external meshing (sun and planet gear meshing). Based on the torsional dynamic model presented in Fig. 2, considering time-varying mesh stiffness and comprehensive mesh errors, the dynamic model for a pair of gear is constructed.

3.2.2. Construction of two-level module model. The two-level module includes multiple pairs of gear meshing module as well as the planet carrier and multi-planet module. The multiple pairs of gear meshing modules include the meshing of the sun gear with a plurality of planet gears as well as the ring gear and a plurality of planet gears, and the number of planet gears is limited by the assembly conditions. Taking the planet carrier and multiple planet gears as the whole research object, the dynamic model of the carrier and multi-planet module can be established.

3.2.3. Construction of three-level module model. The three-level module can be constructed by the call of one-level and two-level module. The three-level module model is the dynamic model of a certain single-stage transmission in a multi-stage planetary gear transmission system. The single-stage planetary transmission system is not limited to a certain type of planetary transmission, and can be selected and selected in the upper level modules according to design requirements. The single-stage planetary transmission system is not limited to a certain type of planetary transmission, and can be selected in the upper level modules in the light of design requirements. Through calling the upper two modules, the dynamic model of the i -th stage in the multi-stage planetary transmission can be constructed as follows.

$$M_i \cdot \ddot{q}_i + (K_{mi} + K_{bi}) \cdot q_i = T_i + F_i \quad (1)$$

3.2.4. Construction of four-level module model. Considering the coupling connection among each transmission stage, and calling the first three modules in turn, the four-level module model can be constructed, that is, the nonlinear dynamic differential equations of the multi-stage planetary gear transmission system is able to be set up as follows.

$$M \cdot \ddot{q} + (K_m + K_b) \cdot q = T + F \quad (2)$$

Where q is the displacement vector; M is the mass matrix; K_m is the mesh stiffness matrix; K_b is the support stiffness matrix; T is the external exciting force vector; F is the internal exciting force vector.

4. Summary

Different from the traditional overall modeling method, adopting the modular idea, the system is divided into four sub-modules. Through integrating each level sub-modules, a modular generalized dynamic model of multi-stage planetary transmission system is established to fast select the transmission scheme by facilitate the dynamic analysis of the system. The proposed modular dynamic model can utilized for the analysis of PGTs with arbitrary number of planets and arbitrary stages.

Acknowledgements

The authors appreciate the financial support from the Scientific and Technological Research Project of Henan Province (Grant Nos. 172102210056, 182102210154, 172102110208), the Doctoral Scientific Research Funds of Zhengzhou University of Light Industry (Grant No. 2015BSJJ030) and the National Natural Science Foundation (Grant Nos. 31802138, U1404515).

References

- [1] F. Ren, G.F. Luo, G.Q. Shi, X.L. Wu, N. Wang, Influence of manufacturing errors on dynamic floating characteristics for herringbone planetary gears, *Nonlinear Dynam.* 93(2018) 361-372.
- [2] F. Ren, D.T. Qin, T.C. Lim, S.K. Lyu, Study on dynamic characteristics and load sharing of a herringbone planetary gear with manufacturing errors, *Int J Precis Eng Man.* 15(2014) 1925-1934.
- [3] D.T. Qin, Z.M. Xiao, J.H. Wang, Dynamic characteristics of multi-stage planetary gears of shield tunneling machine based on planet mesh phasing analysis, *J Mech Eng.* 47(2011) 20-29. (in Chinese)
- [4] Y.C. Guo, R.G. Parker, Sensitivity of general compound planetary gear natural frequencies and vibration modes to model parameters, *J Vib Acoust.* 132(2010) 1-13.
- [5] H.Y. Bao, R.P. Zhu. Analysis of dynamic load sharing in a two-stage planet gear train, *J. Aero. Pow.* 20(2005) 937-943. (in Chinese)