Vibration Characterizations of motor-gear-rotor system with considering the lateral-torsional-axial coupling effect

Wenyu Bai
College of Mechanical Engineering
Zhejiang University of Technology
HangZhou,PR China
bauyo@zjut.edu.cn

Hongyu Xi
College of Mechanical Engineering
Zhejiang University of Technology
HangZhou,PR China
15157655293@163.com

Xiaohang Zhang
College of Mechanical Engineering
Zhejiang University of Technology
HangZhou,PR China
1277574786@qq.com

Zhouxin Wu
College of Mechanical Engineering
Zhejiang University of Technology
HangZhou,PR China
WZX16JY@outlook.com

Linbin Zhang
College of Mechanical Engineering
Zhejiang University of Technology
HangZhou,PR China
lbz@zjut.edu.cn

Abstract

To investigate the dynamic responses of high-speed motor-gear transmission system in the electric vehicle, the non-linear coupled lateral-torsional-axial vibration model of motor-gear-rotor coupling system is developed based on the engagement of gears under various excitations. Firstly, the electromagnetic radial and tangential forces of the permanent magnetic synchronous machine are analyzed by finite element method, and the influences of the extracted electromagnetic radial and tangential force with considering the slot effect and magnetic saturation effect is presented. Furthermore, the dynamic characteristics of the motor-gear-rotor coupling system with the effects of the time-varying mesh stiffness, electromagnetic excitations and gear eccentricity are analyzed. The simulation results reveal the phenomenon that torsional vibration displacements are larger than those in lateral and axial directions, which is more obvious than the model without motor coupling. Meanwhile, the vibrations due to the time-varying mesh stiffness, gear eccentricity, slot effect and magnetic saturation effect are distinguished at different operation speed. Additionally, nonlinear motions are observed due to the electromagnetic excitations, including limit cycles and jumping phenomena for the motor rotor and gears. The research results lay a foundation for dynamic characteristics and fault diagnosis of the high-speed motor-gear transmission system for the electric vehicle.

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Introduction:

Permanent magnet synchronous motors (PMSM) have been widely used in electric vehicles (EV) because of its inherent quietness and high efficiency. The NVH problem of electric vehicles includes not only the Permanent magnet synchronous motors, but also the gearbox. The powertrain of an electric vehicle is shown in Figure 1, And a mechanism diagram suitable for electric vehicle powertrain is shown in Figure 2. The fixed coordinate system Ai-xiyizi(i=1,2) is established in the ideal center Ai of the driving and driven gear, and the fixed coordinate system Bi-xiyizi(i =1~4) is established in the ideal center Bi of the bearing. The rotation center coordinates of the main and driven gears are O1(x1, y1, z1) and O2(x2, y2, z2) respectively, and the centroid coordinates are G1(x_{g1}, y_{g1}, z_{g1}) and G2(x_{g2}, y_{g2}, z_{g2}). And the dynamic meshing model of the gear rotor system is shown in Fig. 3.

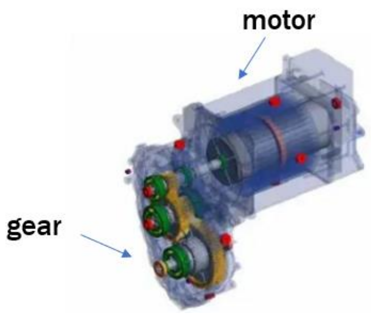

Fig. 1. Structure of the electric powertrain.

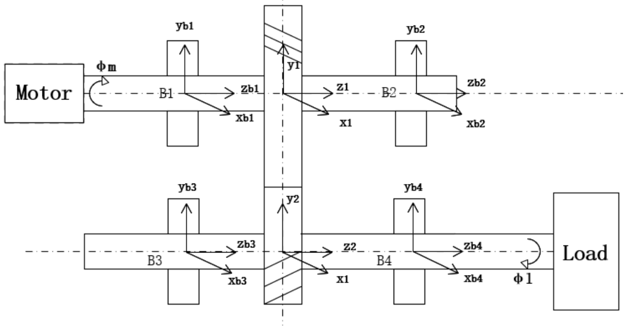

Fig. 2. Gear - rotor transmission system static model.

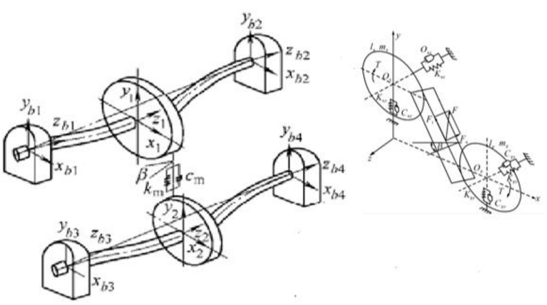

Fig. 3. Dynamic model of gear-rotor transmission system.

Results:

1.Using JMAG-Designer 2D finite element simulation, the torque curve of motor is extracted, as shown in Figure 1. And the extracted torque will act on the non-linear coupled lateral-torsional-axial vibration model, the subsequent simulation will also confirm the coupling effects between motor and gear.

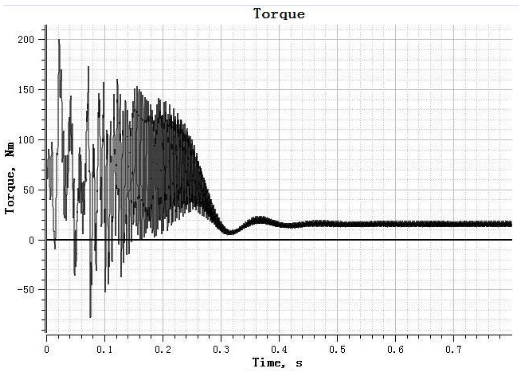

Fig. 4. Motor torque curve.

2. In this paper, the vibration response of the system is preliminarily calculated when the speed of the driving gear is n1=1485r/min. The motor - gear coupling effects are the most obvious on bearing b1, and the vibration displacements in three directions of bearing b1 are analyzed here. Fig. 5, Fig. 6 and Fig. 7 respectively show the displacements in X, Y and Z directions.

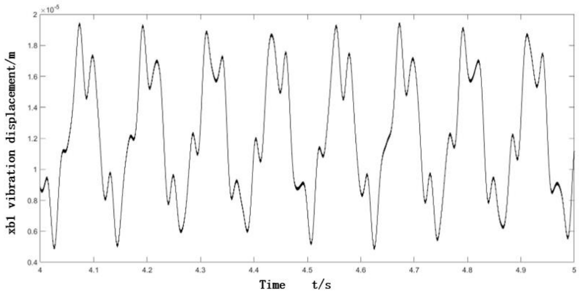

Fig. 5. No1 bearing displacement curve in X direction.

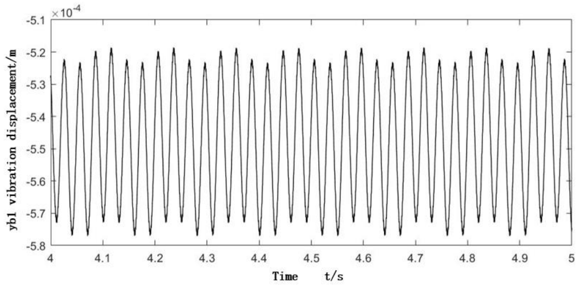

Fig. 6. No1 bearing displacement curve in Y direction.

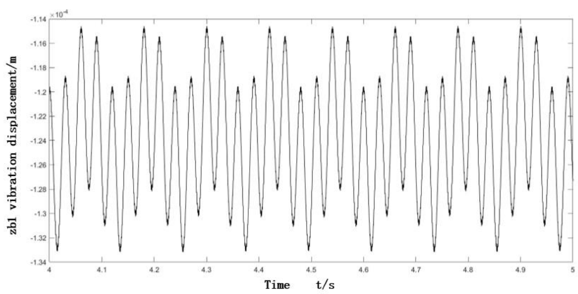

Fig. 7. No1 bearing displacement curve in Z direction.

3. Limit cycles and jump phenomena for the motor rotor and gears are analyzed in this paper. Due to the coexistence of electromagnetic excitations and bearing excitations, jump phenomena will appear. As the non-linear coupled lateral-torsional-axial vibration model is a nonlinear system, the motion characteristics of drive shaft gear center is shown in Fig. 8, the driving gear vibration are clearly dominated by the nonlinear limit cycle motion induced by the magatic motor forces and bearing excitations.

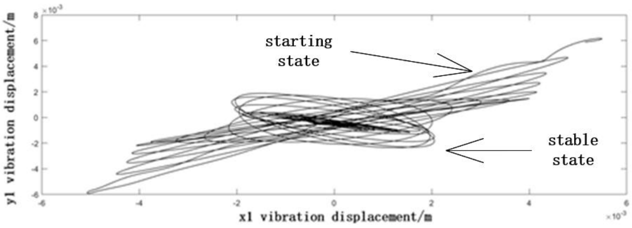

Fig. 8. Limit cycle motion.

Conclusion:

1. Compared with other models, the non-linear coupled lateral-torsional-axial vibration model takes more

nonlinearity factors into account. Due to the lateral-torsional coupling effects of helical gear system, the torsional vibration displacement in the transmission system is obviously larger than the lateral and axial vibration displacement. With the increasing of speed, the vibration displacement increases significantly, and the frequency amplitude fluctuates obviously.

2. Nonlinear motions are observed due to the electromagnetic excitations, including limit cycles. Limit cycle vibrations occur in this model, the results due to the dominance of the tangential component of the dynamic magnetic force over the bearing damping.

3. Further research will be conducted of the nonlinear phenomena of the electric driving system, and the corresponding results of this research can be applied to electric driving system of vehicles.

Highlights:

1. The influences of the extracted electromagnetic radial and tangential force with considering the slot effect and magnetic saturation effect is presented.
2. The dynamic characteristics of the motor-gear-rotor coupling system with the effects of the time-varying mesh stiffness, electromagnetic excitations and gear eccentricity are analyzed by the new coupling model.
3. Nonlinear motions are observed due to the electromagnetic excitations, including limit cycles and jumping phenomena for the motor rotor and gears.
4. The results of this research can be applied to electric vehicles.

First Author

Wenyu Bai is currently a lecturer at the college of mechanical engineering, Zhejiang University of Technology, Hangzhou, China. He received his B.S. degree, M.S. degree and Ph.D. degree of mechanical engineering from Chongqing University, China. From 2016 to 2018, he was a visiting Ph.D. student at the University of Cincinnati and the University of Texas at Arlington, USA sponsored by China Scholarship Council. His research interests include, electric drive system design, manufacturing and dynamics analysis.