Parameter optimization and analysis of electric vehicle power transmission system based on PSO

Zhifei Yang, Guoqiang Chen, Ruidong Xu, Shaobin Lv, Xiaofeng Li

School of Mechanical and Power Engineering

Henan Polytechnic University

Jiaozuo, 454003, China

Abstract: *Aiming at the problem of the torsional vibration in the vehicle transmission system, the particle swarm optimization algorithm was used to optimize the model parameter. According to the mechanical model of the electric vehicle transmission system, the dynamic equation of the transmission system is derived, and the simulation model of the transmission system is established. The particle swarm optimizationalgorithm is used to optimize the damping parameter in the model, and the simulation verification is performed. The simulation results show that the angular velocity and angular acceleration peaks of the motor shaft are reduced by 20.56% and 15.56% respectively, the angular velocity and angular acceleration peaks of the decelerator differential assembly are reduced by 20.37% and 15.56% respectively, and the angular velocity and angular acceleration peaks of the transmission half shaft are reduced by 18.75% and 23.67% respectively. The optimized peak has been significantly reduced by comparing the results, and the overall vibration amplitude has also been reduced. The model established in this paper has certain versatility, and the parameter modification is also convenient. This modeling and optimization analysis method provides a theoretical foundation for solving the torsional vibration problem of the vehicle transmission system.*

Key words: *electric vehicle; power transmission system; torsional vibration; PSO*

I. INTRODUCTION

Currently, people have conducted extensive research on the lightweight and fuel consumption of the vehicle, and the overall performance of the vehicle has been significantly improved[1-6]. However, the vibration and noise may also be caused when the vehicle performance is improved. The important system related to the vibration and noise is the power transmission system[7]. The torsional vibration of the power transmission system is one of the vehicle vibration forms, and is also an important factor in evaluating the performance of the vehicle. The noise generated by torsional vibration not only affects the ride comfort, but also may cause an interruption in the power transmission system of the vehicle. Therefore, to establish the electric vehicle power transmission model and study the torsional vibration phenomenon is of great significance for reducing the torsional vibration noise of the vehicle.

According to the mechanical model of the electric vehicle power transmission system, the dynamic equation of the transmission system is derived and the simulation model of the transmission system is established. The particle swarm optimization algorithmis used to optimize the damping parameter in the model, and the simulation verification is carried out. The results show that the peak value of angular velocity and angular acceleration of the motor shaft, the differential assembly and the transmission half shaft decreases significantly, and the overall vibration amplitude is also reduced. The noise of the power transmission system is reduced, and the driving stability of the vehicle is improved.

II. MODEL ESTABLISHMENT

The electric vehicle studied in this paper adopts the power transmission mode of the front pre-driver. The centralized drive motor of the power transmission system is integrated with the decelerator differential assembly, and then the wheels are driven by the left and right half shafts to drive the vehicle[4]. According to the local distribution and integration mode of transmission system components, the modularization method is used to divide the transmission system into seven sub-modules, which includes the motor, the motor shaft, the decelerator differential assembly, the left and right half shaft, and left and right wheel. The model of the power transmission system is shown in Figure 1.

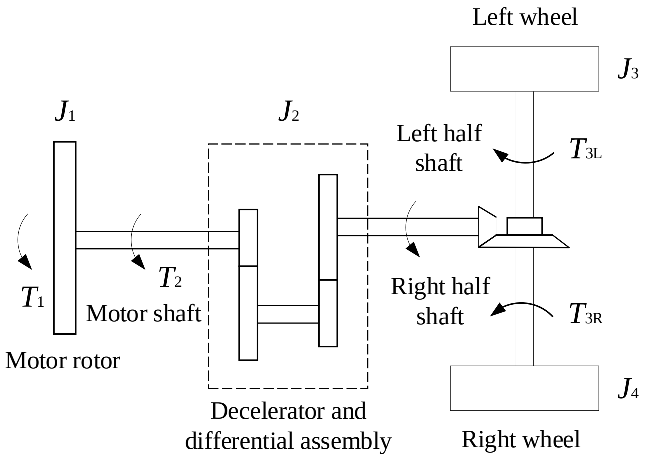

Figure 1 Model of the power transmission system

where, T_1 is the output torque of the motor; T_2 is the torque transmitted by the motor shaft; T_{3L}, T_{3R} is the torque transmitted by the left and right half shafts respectively; J_1 is the equivalent rotational inertia of the motor rotor; J_2 is the equivalent rotational inertia of the decelerator differential assembly; J_3, J_4 is the equivalent rotational inertia of the left and right wheels respectively.

The dynamic equations of the transmission system componentsare established through the Lagrange dynamic equation[1,3,6].

The dynamic equation of the motor rotor is expressed as

$$T_1 - T_2 = J_1\ddot{\theta}_1 + c_1\dot{\theta}_1 \quad (1)$$

The dynamic equation of the motor shaft is expressed as

$$T_2 = k_1(\theta_1 - \theta_2) + c_2(\dot{\theta}_1 - \dot{\theta}_2) \quad (2)$$

The dynamic equation of the decelerator differential assembly is expressed as

$$\begin{cases} T_2 - T_3 = J_2\ddot{\theta}_2 + c_3\dot{\theta}_2 \\ n = \dfrac{\dot{\theta}_2}{\dot{\theta}_3} \end{cases} \quad (3)$$

The dynamic equations of the driving half shaft are expressed as

$$T_{3\mathrm{L}} = k_2(\theta_3 - \theta_4) + c_4(\dot{\theta}_3 - \dot{\theta}_4) \quad (4)$$

$$T_{3\mathrm{R}} = k_3(\theta_3 - \theta_6) + c_4(\dot{\theta}_3 - \dot{\theta}_6) \quad (5)$$

The dynamic equations of the driving wheel are expressed as

$$T_{3\mathrm{L}} = J_3\ddot{\theta}_4 + c_5\dot{\theta}_4 + k_4(\theta_4 - \theta_5) \quad (6)$$

$$T_{3\mathrm{R}} = J_4\ddot{\theta}_6 + c_5\dot{\theta}_6 + k_5(\theta_6 - \theta_7) \quad (7)$$

where, k_1 is the equivalent torsional stiffness of the motor shaft; k_2, k_3 is the equivalent torsional stiffness of the left and right half axes respectively; k_4, k_5 is the equivalent torsional stiffness of the left and right wheels respectively; c_1 is the equivalent damping coefficient of the motor rotor; c_2 is the equivalent damping coefficient of the motor shaft; c_3 is the equivalent damping coefficient of the decelerator differential assembly; c_4 is the equivalent damping coefficient of the half shaft; c_5 is the equivalent damping coefficient of the wheels; n is the total transmission ratio of the decelerator differential assembly; $\theta_i, \dot{\theta}_i, \ddot{\theta}_i$ are the angular displacement, angular velocity and angular acceleration of transmission component i respectively, i=1,2,…7. The parameter values of the power transmission system components are shown in Table 1.

Table 1 Parameter values of the power transmission system

$J/(\mathrm{kg\cdot m^2})$		$c/(\mathrm{N\cdot m\cdot s\cdot rad^{-1}})$		$k/(\mathrm{N\cdot m\cdot rad^{-1}})$	
J_1	0.047	c_1	0.5	k_1	43250
J_2	0.0215	c_2	0.1	k_2	6342
J_3	2.1	c_3	1.0	k_3	6342
J_4	2.1	c_4	2.0	k_4	4750
--	--	c_5	10.0	k_5	4750

III. SIMULATION AND ANALYSIS OF PARTICLE SWARM OPTIMIZATION

The particle swarm optimization (PSO) algorithmis a swarm intelligence algorithm proposed by Kennedy and Eberhart in 1995 based on the study of group behavior of the bird and fish. The idea is derived from the artificial life and evolutionary computation theory, which mimics the bird flight foraging behavior and achieves optimal groups through bird cluster collaboration[8-10]. The PSO algorithmis a branch of evolutionary computation and an iterative optimization tool. The system is initialized into a set of random solutions, and the optimal values are searched by iteration. The basic principle and mechanism of the PSO algorithmare relatively simple. The algorithm evolves to the global optimal solution only by updating the speed and position, does not require gradient information, has few adjustable parameters, runs efficiently and is easy to implement[11,12]. The basic principles are shown in Figure 2.

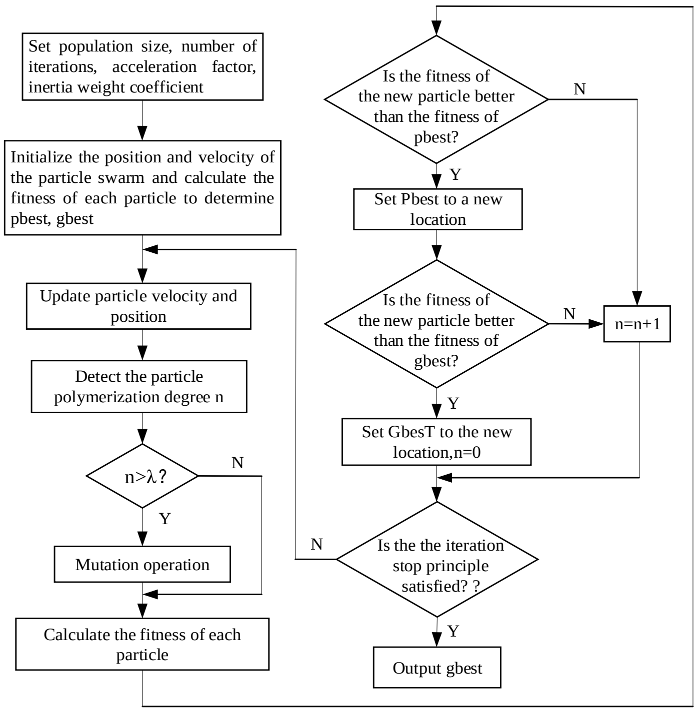

Figure 2 Particle swarm algorithm flow

According to the dynamic equation of the power transmission system, the Simulink simulation model is shown in Figure 3. The input of the model is $150\mathrm{N \cdot m}$ pulse torque added to the motor rotor, which is used to simulate the working condition of the vehicle at the beginning. The simulation time is set to 2s, and the fourth-order Runge-Kutta algorithm is used to solve the problem.

The main reason for the vibration of the vehicle transmission system is the transmission of gears and the rotation of shafts. The transmission of gears mainly concentrate in the decelerator differential assembly. The rotation of shafts mainly includes the rotation of the motor shaft and the transmission half shaft. In this paper, the optimization objective function including the angular velocity of the motor shaft, the decelerator differential assembly and the transmission half shaft is established as the output of the PSO algorithm fitness value.

The optimized objective function is established as

$$J = \sqrt{\frac{1}{T}\int_0^T (q_1\omega_2^2 + q_2\omega_3^2 + q_3\omega_4^2)\mathrm{dt}} \quad (8)$$

where, q_1, q_2 and q_3 are the weighting coefficients; ω_2, ω_3 and ω_4 are the torsional angular velocity of the motor shaft, the decelerator differential assembly and the transmission half shaft respectively.

The damping of each component in the model has important influence on the torsional vibration of the power transmission system. Because the system characteristics are relatively complex and the damping coefficient is difficult to obtain, the model damping coefficient is taken as the optimization object in this paper.

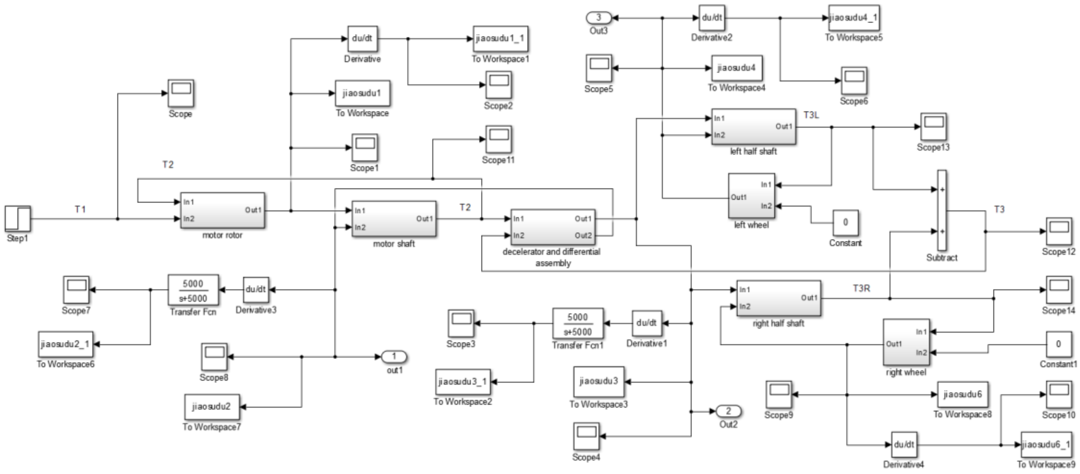

Figure 3 Simulink model of power transmission system

The population size of the PSO algorithm is 50, the cognitive coefficient is 1.5, the social coefficient is 2,the inertia weight coefficient is 0.5,and the maximum number of the iteration is 300. The fitness convergence curve of the PSO algorithmis shown in Figure 4.

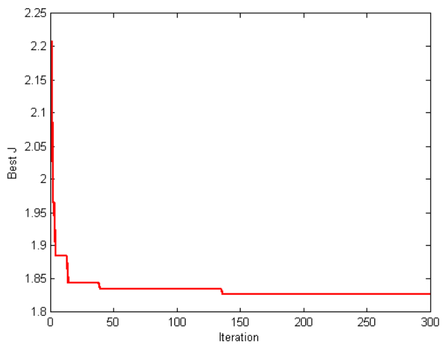

Figure 4 Fitness convergence curve of PSO

The PSO algorithmcan make the optimization objective function continue to approach the optimal solution. When the root mean square value of the objective function satisfies the iteration stop principle, the optimal damping coefficient is shown in Table 2.

Table 2 Optimization parameters of the damping coefficient

damping coefficient	c_1	c_2	c_3	c_4	c_5
Numerical value ($N \cdot m \cdot s \cdot rad^{-1}$)	1.9943	0.1943	2.0000	4.4198	18.9668

The damping coefficient obtained by the PSO algorithm is substituted into the Simulink model for simulation analysis. The analysis results before and after the optimization of the torsion angular velocity and angular acceleration of the motor shaft are shown in Figure 5 and Figure 6. The analysis results before and after the optimization of the torsion angular velocity and angular acceleration of the decelerator differential assembly are shown in Figure 7 and Figure 8. The analysis results before and after the optimization of the torsion angular velocity and angular acceleration of the driving half shaft are shown in Figure 9 and Figure 10.

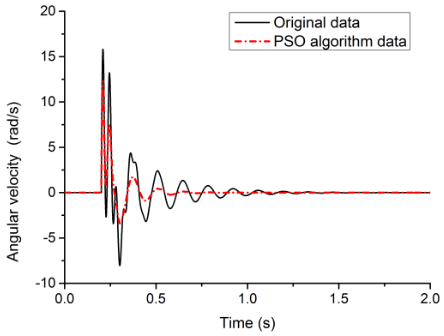

Figure 5 Angular velocity variation curve of the motor shaft

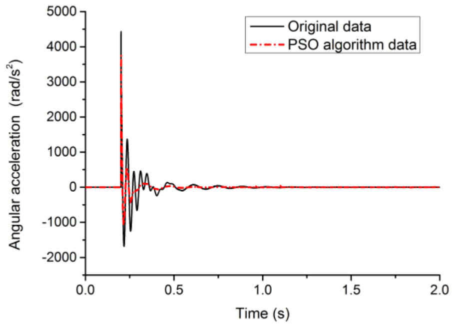

Figure 6 Angular acceleration variation curve of the motor shaft

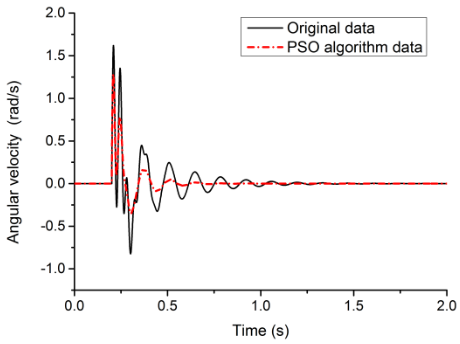

Figure 7 Angular velocity variation curve of the decelerator differential assembly

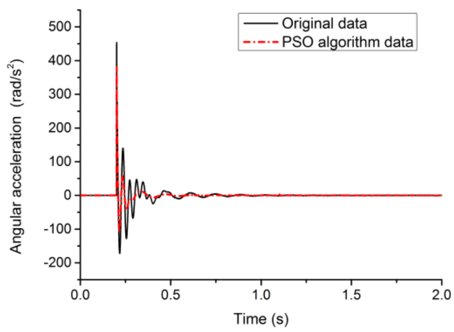

Figure 8 Angular acceleration variation curve of the decelerator differential assembly

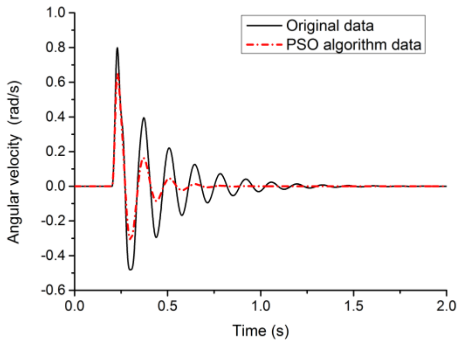

Figure 9 Angular velocity variation curve of the driving half shaft

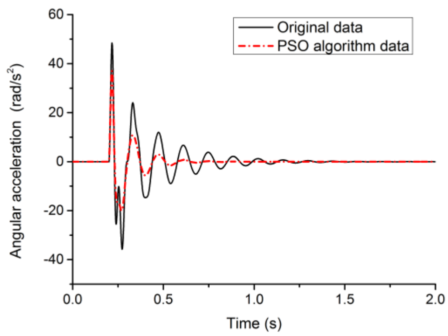

Figure 10 Angular acceleration variation curve of the driving half shaft

As can be seen from Figures 5 to 10, the torsional vibration peaks of all parts of the transmission system have been reduced to some extent. The peak values of the angular and angular accelerations of the motor shaft are 15.81 rad/s and 4433.05 rad/s^2 while the peaks optimized by the PSO algorithm are 12.56 rad/s and 3743.08 rad/s^2, which are reduced by 20.56% and 15.56% respectively. The peak values of the angular and angular accelerations of the decelerator differential assembly are 1.62 rad/s and 453.97 rad/s^2 while the peaks optimized by the PSO algorithm are 1.29 rad/s and 383.32 rad/s^2, which are reduced by 20.37% and 15.56% respectively. The peak values of the angular and angular accelerations of the transmission half shaft are 0.80 rad/s and 48.45 rad/s^2 while the peaks optimized by the PSO algorithm are 0.65 rad/s and 36.98 rad/s^2, which are reduced by 18.75% and 23.67% respectively. Therefore, after the parameter of the electric vehicle power transmission system are optimized by the PSO algorithm, the peak value of the torsional vibration of each component is significantly reduced, which has a significant effect on improving the ride comfort of the vehicle.

IV. CONCLUSION

According to the mechanical model of the electric vehicle power transmission system, the dynamic equations of the transmission system are derived and the simulation model is established. The PSO algorithm is used to optimize the angular velocity and angular acceleration of the motor shaft, the decelerator differential assembly and the transmission half shaft, and the simulation verification is carried out. The optimized peak has been significantly reduced through comparison, and the overall vibration amplitude has also been reduced. The model established in this paper has certain versatility, and the parameter modification is also convenient. This modeling and optimization analysis method provides a theoretical foundation for solving the torsional vibration problem of the vehicle power transmission system.

V. ACKNOWLEDGMENT

This work is supported by the National Natural Science Foundation of China (No. U1304525), the Key Scientific and Technological Project of Henan Province (No.172102310664) and the Fundamental Research Funds for the Universities of Henan Province (No. NSFRF170913). The author would like to thank the anonymous reviewers for their valuable work.

REFERENCES

[1] Zaiwen Xu, Haiqiao Wan, and Dongdong Huang, "Modeling and simulation analysis of vehicle transmission torsional vibration", Journal of Hefei university of Technology(Natural Science), 2012,35(1):13-16.

[2] Hao Wu, Fang Wang, "Optimization and simulation of torsional vibration of vehicle transmission system based on improved genetic algorithm", Chinese Journal of Construction Machinery, 2017,15(2):141-146.

[3] Dejiu Zhang, Haisheng Yu, and Jianwu Zhang, "Analysis and control of torsional vibration in HEV," Drive System Technique, 2014,28(4):3-8.

[4] Peng Yu, Tong Zhang, and Ling Sun, "Powertrain torsion vibration of a central-driven pure EV," Journal of Vibration and Shock, 2015,34(10):121-127.

[5] Liang Zou, Xiaolin Tang, and Haisheng Yu, "Analyses on the torsional vibration and noise of transmission system in hybrid electric cars," Automotive Engineering, 2014,36(6):709-714.

[6] Tiantang Song, Xiwen Wang, and Lianhua Lin, "Analysis of torsional vibration characteristics of transmission system for two-speed electric vehicle," Drive System Technique, 2017,31(1):3-9.

[7] Guo, Yanjie. "Dynamic modeling and characteristic analysis on dynamic wireless charging system of electric vehicle", Automation of Electric Power Systems, 2017,41(2):73-78.

[8] Mahdad, Belkacem. "Solving practical power system problems using hierarchical interactive PSO strategy considering SVC controllers", Journal of Intelligent and Fuzzy Systems, 2014,27(1):451-463.

[9] Berrouk, Fateh. "Optimal Power Flow For Multi-FACTS Power System Using Hybrid PSO-PS Algorithms", Journal of Control, Automation and Electrical Systems, 2018,29(2):177-191.

[10] Mondal, D. "Investigation of small signal stability performance of a multimachine power system employing PSO based TCSC controller", Journal of Electrical Systems, 2012,8(1):23-34.

[11] Ram Jethmalani, C.H. "Auxiliary hybrid PSO-BPNN-based transmission system loss estimation in generation scheduling", IEEE Transactions on Industrial Informatics, 2017,13(4):1692-1703.

[12] Falehi, Ali Darvish. "Dynamic stability enhancement of interconnected multi-source power systems using hierarchical ANFIS controller-TCSC based on multi-objective PSO", Frontiers of Information Technology and Electronic Engineering, 2017,18(3):394-409.