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Research on Tortional Vibration Characteristics of Series Spring Damper for Hybrid Electric Vehicle

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Abstract

In this paper, the torsional vibration characteristics of series spring torsional damper for hybrid electric vehicle are studied. Firstly, dynamic software is used to build the physical simulation model of the hybrid transmission system under the direct drive acceleration condition, and the modal analysis of the transmission system is carried out, and the local mode of the series spring torsional damper is found. Through the torsional vibration analysis and real vehicle test of the hybrid power train, the influence of the local mode of the series spring torsional damper on the torsional vibration of the power train is confirmed, local modes can amplify the torsional vibration response of the drive train and cause the gear rattle problem. Secondly, the sensitivity analysis is carried out to find out the key influencing factors. Finally, the improved torsional damper is simulated to confirm the improvement effect. The conclusion provides a reference for the optimization of the series spring torsional damper.

Keywords: series spring torsional damper; series parallel hybrid; torsional vibration characteristics; angular acceleration

Introduction

At present, the torsional vibration damper used in the transmission system of hybrid vehicles mainly include clutch driven disc torsional vibration damper (CTD) and dual-mass flywheel torsional vibration damper DMF [1]. It is generally believed that DMF is generally adopted in the power system with high torque and above, if the gearbox gear rattle is more sensitive, and the damping capacity is improved by taking advantage of the DMF with large secondary flywheel inertia and the low stiffness of the vibration damping spring in the large rotation working range [2]. However, the DMF has a complex structure and high manufacturing cost. And in the high speed section of the engine, due to the large load on the radial of the damping spring, the dynamic damping caused by friction increases significantly under the condition of large centrifugal force and deformation, thus reducing the vibration isolation level of the high speed section. The CTD is simple in structure, low in cost, and does not have the problem of dynamic damping increase caused by large centrifugal force and deformation of the damping spring in the high speed section of the engine. However, due to structural limitations, the torsion angle of the CTD is usually small [3], and the reduction of spring stiffness is limited in the high-torque power system, thus limiting its application. Under this background, the new type of torsional vibration damper increases the torsional angle of the vibration damper by the way of series damping spring, so as to take into account the torsional capacity and damping capacity of the vibration damper, so that it is suitable for high torque power system.

Aiming at the research on torsional vibration of hybrid powertrain, Li Zhi [4] studied the torsional characteristics of a hybrid powertrain through simulation and test, and optimized the damping parameters of the torsional vibration damper. Yan Minggang [5] studied the parameter optimization of torsional vibration damper for a certain hybrid power transmission system.

The above research on the torsional vibration characteristics of the transmission system does not see the torsional vibration characteristics of the series spring torsional vibration damper. In this paper, a series spring vibration damper used in the development of a hybrid transmission is taken as an example, the torsional vibration modeling analysis and test of the vehicle hybrid power transmission system are carried out, the key stiffness, inertia and other parameters are simulated and verified, and the torsional vibration characteristics of the series spring vibration damper are studied.

Introduction of Hybrid Powertrain with Series Spring Vibration Damper

Figure 1 shows the transmission system configuration of a series-parallel hybrid electric vehicle. The hybrid model adopts engine front-drive arrangement, matching torsional vibration damper between the engine and the hybrid gearbox, which is used to reduce the torsional vibration transmitted by the engine to the hybrid gearbox, and reduce the gear rattle caused by the light-load (or no-load) gear backlash inside the hybrid gearbox.

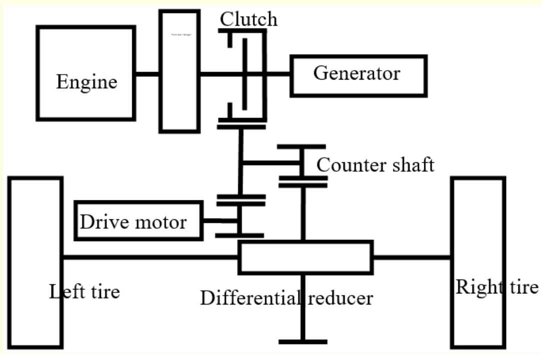


Figure 1: Structure diagram of series and parallel mixed power train.

Compared with traditional vehicles, the series-parallel hybrid power system has multiple power coupling and more excitation sources. The change of transmission system structure, fast motor torque response, frequent engine start and stop, fast clutch combination and separation, and light or no-load motor in direct drive condition of the engine are prone to vibration and noise problems of the transmission system [6].

Introduction to the Principle of Hybrid Power System

This series parallel hybrid power system adopts dual motor configuration, transmission input shaft and generator shaft coaxial arrangement, generator shaft and intermediate shaft through the clutch control engine power transfer to the half shaft, the drive motor arranged in the differential reduction intermediate shaft gear side, through the clutch engagement and separation to achieve pure electricity, parking power generation, series driving, direct driving and hybrid driving modes.

Electric mode: the clutch is disengaged, the engine is turned off, and the electricity from the power battery drives the vehicle through the driving motor.

Parking power generation mode: the clutch is separated, the engine runs to drive the generator to generate power to charge the battery or accessories consumption, and the drive motor does not work.

Series driving mode: the clutch is separated, the engine drives the generator to generate electricity, and the electricity emitted by the generator drives the motor to drive the vehicle or charges the battery.

Direct drive mode: The clutch is combined, the engine drives the vehicle directly through the direct drive gear, and the generator and drive motor do not work.

Hybrid driving mode: the clutch is combined, the engine drives the vehicle directly through the direct drive gear, and the generator and drive motor coordinate the torque according to the driver's needs, battery power and engine operating load.

The Structure and Principle of Series Spring Vibration Damper are Introduced

The traditional structure of the torsional vibration damper is shown in Figure 2. The main structure is divided into driving disc, spring, driven disc and the damping mechanism between the driving disc and driven disc. The principle of vibration isolation can be simplified into a mass spring model, as shown in Figure 3. Limited by the straight spring, the torsion angle of the traditional torsional vibration damper generally does not exceed 20°.

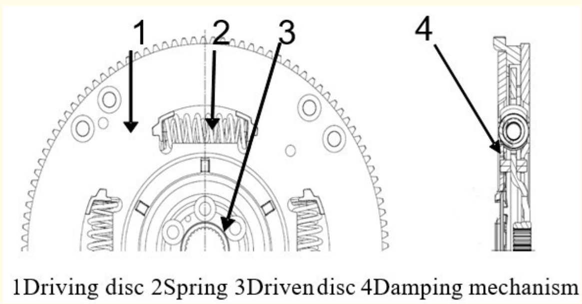


Figure 2: Structure diagram of traditional torsional vibration damper.

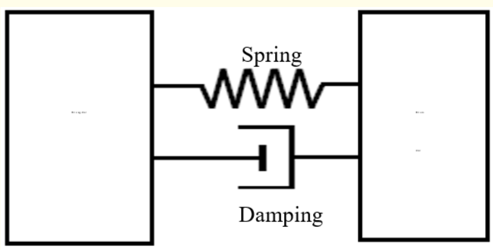


Figure 3: Schematic diagram of traditional torsional vibration damper.

The structure of the series spring vibration damper is shown in Figure 4. In order to increase the torsion Angle, it is necessary to increase the stroke of the damping window of the torsional vibration damper. In the case of using a straight spring, the angle can be increased by about 10°~20° through the spring series. It is necessary to use a transfer plate to fix and connect the spring between the series springs. The transfer plate is fixed on the driving plate through the sliding pin and rotates with the compression and extension process of the damping spring. There is no damping mechanism between the transfer disc and the driving disc, and there is a damping mechanism between the driving disc and the driven disc. The principle of vibration isolation can be simplified to the spring mass combination model as shown in Figure 5.

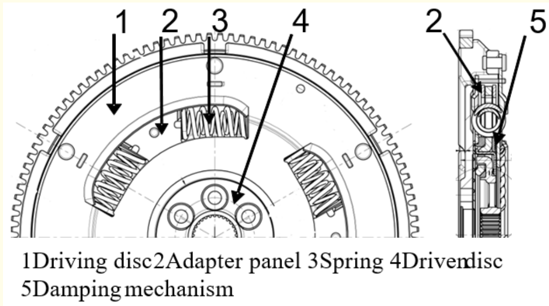


Figure 4: Structure diagram of series spring torsional vibration damper.

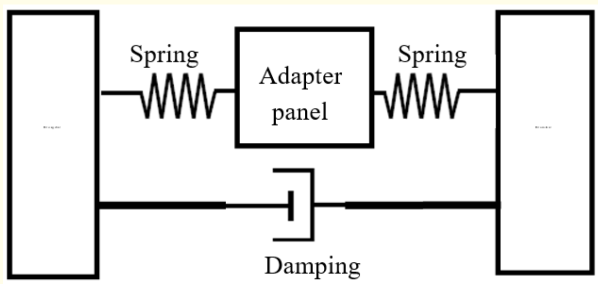


Figure 5: Schematic diagram of series spring torsional vibration damper.

Simulation Analysis and Test of Torsional Vibration of Drive Train

Establish the Simulation Physical Model

In view of the direct drive condition of the engine, the problem of gear knocking is easy to occur in the drive motor under no-load condition. Based on the structure of serial-parallel hybrid power train, the torsional vibration simulation model of the transmission system in direct drive mode was established by using dynamics software. The torsional vibration model of classical mechanics was used to study the torsional vibration analysis of the transmission system, and the substructure of the transmission train was equivalent to the inertial element, spring element and damping element. The model makes the following assumptions: ①ignore the friction torque of bearings and gears; ② ignore the damping on the shafting ③ ignore the gear clearance ④ the motor is in a zero torque state in direct drive mode, which is equivalent to the mechanical inertia and ignores the electromagnetic torque.

The Simulation Model of Series Spring Damper is Established

When the series spring damper model is established, the inertia of the driving disc and the driven disc and the series spring transfer disc are calculated respectively. There is no damping between the series spring transfer disc and the driving disc and the driven disc, and the damping element is set between the driving disc and the driven disc. The built simulation analysis model is shown in Figure 6. The parameter values of each component in the figure are shown in Table 1.

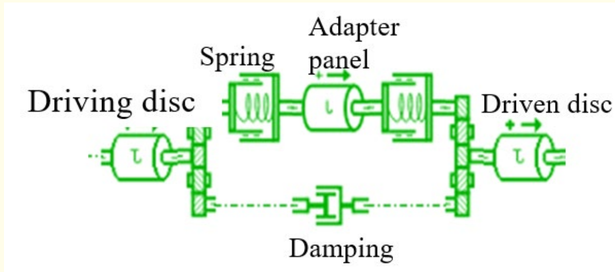


Figure 6: Simulation model of series spring torsional vibration damper.

Items	***Numerical value***
Driving disc	0.105kg*m^2
Adapter panel	0.004kg*m^2
Driven disc	0.006 kg*m^2
Spring stiffnes	790Nm/rad
Damping factor	4.78Nm/(rad/s)

Table 1: Parameters of series spring torsional vibration damper.

Simulation Modeling of Series Parallel Hybrid Transmission

The simulation model of series-parallel hybrid transmission is shown in Figure 7. The torsional stiffness parameters of each shafting are shown in Table 2, the moment of inertia parameters of each component are shown in Table 3, and the transmission ratio information is as follows: the generator shaft-intermediate shaft speed ratio is 1.033, the drive motor shaft-intermediate shaft speed ratio is 2.864, and the differential deceleration ratio is 3.087.

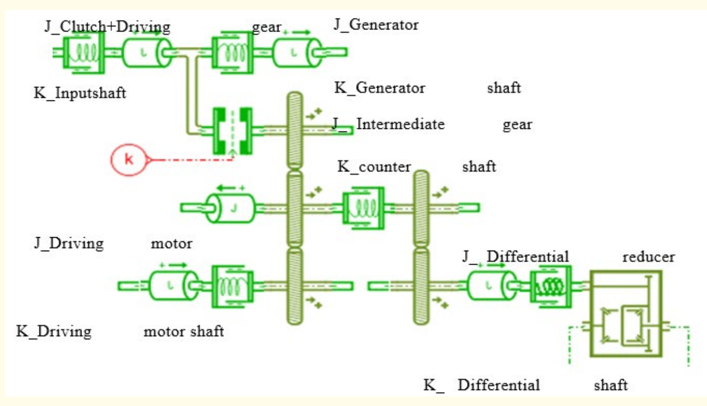


Figure 7: Simulation model of series-parallel hybrid transmission.

Items	Torsional rigidity (N*m/rad)
K_Input shaft	28648
K_Generator shaft	586000
K_Counter shaft	496000
K_Drive motor shaft	63025
K_Differential shaft	1000000

Table 2: Torsional stiffness parameters of hybrid transmission.

Items	Rotational inertia（kg*m^2）
J_Clutch+Drive gear	0.019
J_Generator	0.129
J_Counter shaft	0.006
J_Drive motor	0.036
J_Differential	0.041

Table 3: moment of inertia parameters of hybrid transmission.

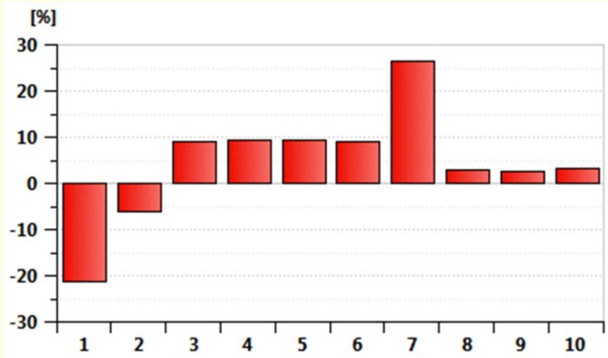
Items	Numerical value
Rotational inertia of engine	0.03 kg*m^2
Rotational inertia of left shaft	0.054 kg*m^2
Rotational inertia of right shaft	0.074 kg*m^2
Rotational inertia of tyre	1.26 kg*m^2
Torsional rigidity of left shaft	8095 Nm/rad
Torsional rigidity of right shaft	6825 Nm/rad
Torsional rigidity of tyre	395.3 Nm/rad
Tyre radius	0.342 m
Curb weight	1760 kg
Face area	2.6 m^2

Table 4: Parameters of other parts of the drive train.

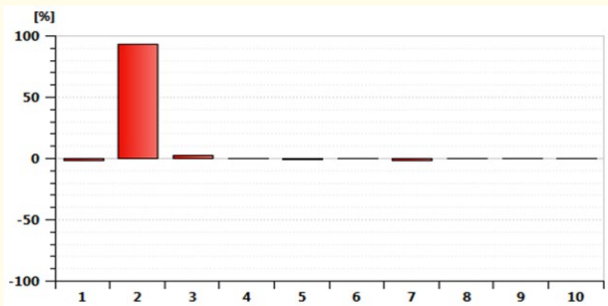
Parameters of other components of the vehicle hybrid power train are shown in Table 4:

Drive Train Modal Analysis

Build the physical model in the dynamics software, and set the parameters of each component according to Table 1-4. The modal analysis of the hybrid powertrain in direct drive mode is carried out. The modal modes related to the torsional vibration damper nodes in the drivetrain are shown in FIG. 8 and FIG. 9. According to the modal analysis results, there are one global mode and one local mode at the torsional vibration damper node in the low frequency range, and the local mode mode is that the internal spring adapter plate has the largest amplitude, and the corresponding reverse phase amplitude is also present at the drive motor position.



1Driving disc 2 Adapter panel 3 Driven disc 4 Clutch+Drive gear 5 Generator 6 Counter shaft 7 Drive motor 8 Differential 9 Left shaft 10 Right shaft.
Figure 8: First-order overall mode of torsional vibration damper (11.7Hz).

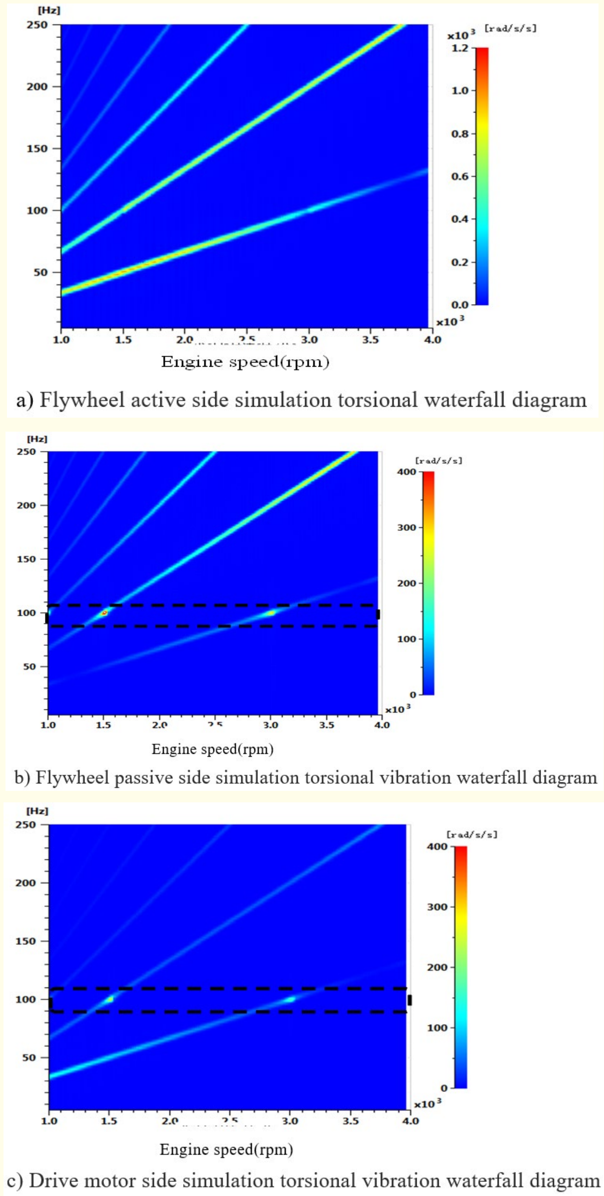


1Driving disc 2 Adapter panel 3 Driven disc 4 Clutch+Drive gear 5 Generator 6 Counter shaft 7 Drive motor 8 Differential 9 Left shaft 10 Right shaft.
Figure 9: First-order local mode of the torsional vibration damper (99.8Hz).

Torsional Vibration Analysis Under Direct Drive Acceleration Condition

Since the local mode of the series spring torsional vibration damper is within the usual speed excitation frequency range of the 4-cylinder engine, it is necessary to further confirm the influence of this local mode on the torsional vibration of the drive train during the acceleration of the vehicle and whether it will cause the corresponding gear rattle problem.

Torque fluctuation excitation of 4-cylinder engine was applied to the simulation model for torsional vibration analysis. From the torsional vibration waterfall of the active end, the passive end of the torsional vibration damper and the drive motor shaft, it can be seen in Figure 10 that the input shaft and the drive motor shaft have a resonance frequency of 99.8 Hz in the engine speed range of 1000 rpm -4000 rpm under the direct drive acceleration condition. The corresponding engine speed is 2994 rpm, and the engine speed is 1497 rpm. The torsional vibration of the input shaft and the drive motor shaft in the resonant speed section is large, and there is a risk of the drive train gear rattle.



a) Flywheel active side simulation torsional waterfall diagram

b) Flywheel passive side simulation torsional vibration waterfall diagram

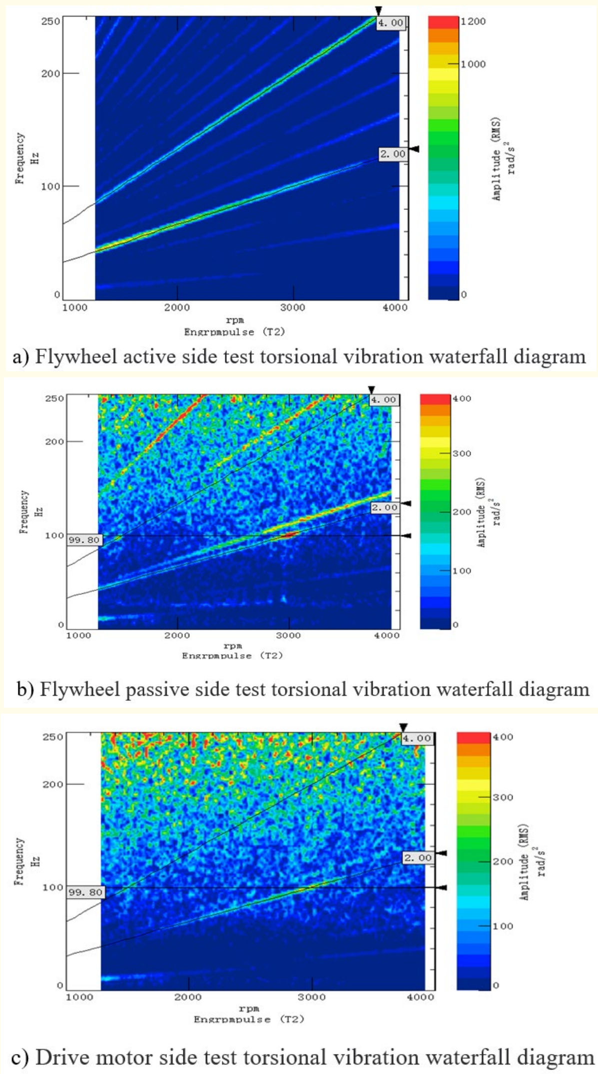
c) Drive motor side simulation torsional vibration waterfall diagram

Figure 10: Simulated waterfall diagram of torsional vibration of the drive train (torsional stiffness 6.9Nm/°).

Torsional Vibration Test in Direct Drive Acceleration Mode

After the simulation analysis, it is necessary to verify the transmission system of the real car equipped with this series spring shock absorber, and confirm the corresponding relationship between the real car and the simulation analysis by collecting torsional vibration signals under the direct drive acceleration condition, and determine the real car gear rattle risk.

The data collected by the real vehicle include: engine flywheel speed signal (crankshaft speed signal plate 60 missing 2 teeth pulse signal), torsional vibration damper passive end speed signal, drive motor shaft speed signal, and transmission housing vibration. The vibration noise data acquisition system is used to collect the above signals, and the corresponding signal processing is carried out. The corresponding relationship between the torsional vibration signal of shafting and the vibration of the shell is obtained, as shown in Figure 11 and Figure 12.



a) Flywheel active side test torsional vibration waterfall diagram

b) Flywheel passive side test torsional vibration waterfall diagram

c) Drive motor side test torsional vibration waterfall diagram

Figure 11: Waterfall diagram of torsional vibration test of the drive train (torsional stiffness 6.9Nm/°).

From the torsional vibration waterfall diagram of the passive end and the drive motor end, it can be seen that there is a torsional vibration resonance response at 99.8 Hz, corresponding to the engine's second-order excitation speed of 2994 rpm and the fourth-order excitation speed of 1497 rpm. Through the vibration of the gearbox housing, it can also be found that there are gear tapping signals near the 1497rpm speed segment and 2994rpm speed segment, which is consistent with the subjective evaluation in the car. The red line in Figure 12 is the shell vibration signal, and the green line is the engine speed signal. The larger vibration signal of the shell indicates that there is a gear rattle phenomenon.

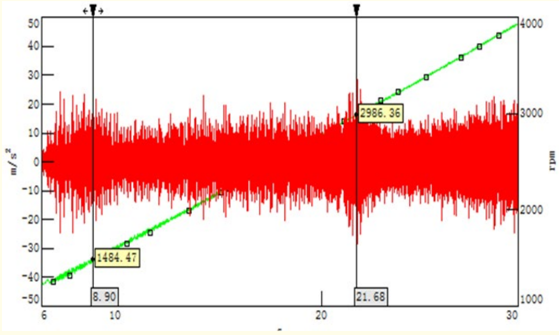


Figure 12: Vibration signal of gearbox housing.

Local Modal Sensitivity Analysis

For the local mode of the torsional vibration damper, it is found through sensitivity analysis that the spring stiffness and inertia related to the spring adapter disc have the most obvious influence on the local mode of this order. Under the condition that the inertia of the adapter disc remains unchanged and there is no damping between the adapter disc and the driving disc, the influence of the torsional vibration damper stiffness on the local mode is shown in Table 5. The spring stiffness of the torsional vibration damper is affected by the torque load and vibration isolation level, with a minimum of 257 N*m/rad and a maximum of 790 N*m/rad. Corresponding resonance frequency 80.8 Hz~124 Hz, still in the four-cylinder engine commonly used speed excitation frequency range.

Items	***Modes***
Torsional rigidity 257 N*m/rad	80.8 Hz
Torsional rigidity 619 N*m/rad	99.8 Hz
Torsional rigidity 790 N*m/rad	124.4 Hz

Table 5: Influence of damper stiffness on modes.

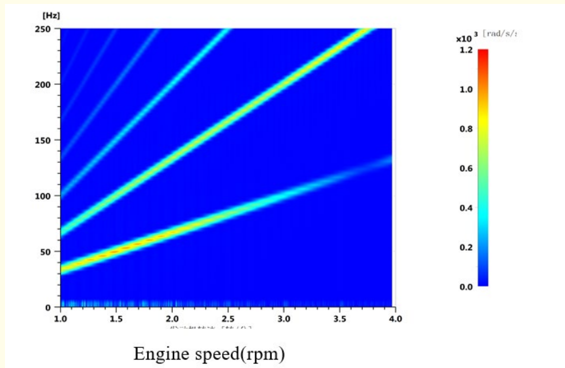
Under the condition that the spring stiffness of the torsional vibration damper is 619 N*m/rad, the effect of changing the inertia of the transfer disk on the local mode is shown in Table 6.

Items	***Modes***
0.004 kg*m^2	99.8 Hz
0.002 kg*m^2	144.6 Hz
0.001 kg*m^2	199.8 Hz

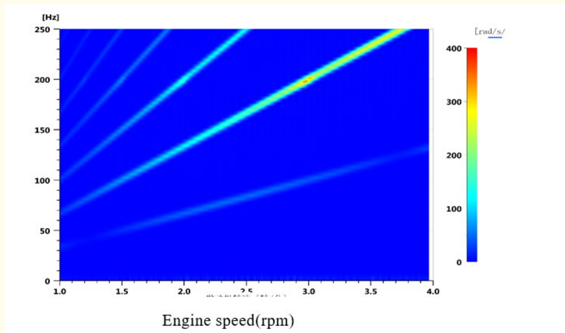
Table 6: Influence of inertia of adapter disc on mode.

Optimization Effect Verification

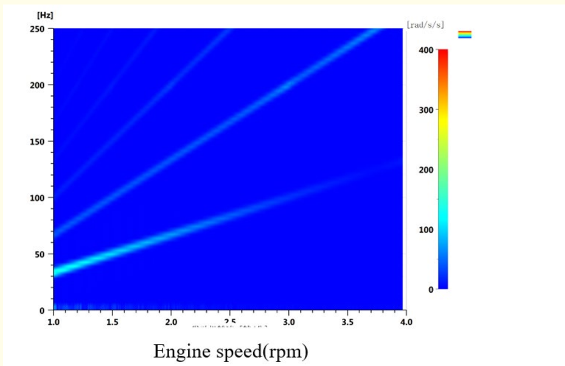
According to the above sensitivity analysis, it can be seen that this local mode needs to be increased to more than 200Hz to avoid the excitation frequency segment of the common engine speed. Therefore, the spring adapter disc of the series spring damper needs to be redesigned to reduce its moment of inertia. The driveline simulation analysis was carried out on the redesigned series spring shock absorber (transfer disc inertia 0.001 kg*m^2). From the torsional vibration waterfall Figure 13, it can be seen that this local mode will not affect the torsional vibration of the driveline and will not cause related gear rattle problems within the common speed range of the engine.



a) Flywheel active side simulation torsional waterfall diagram



b) Flywheel passive side simulation torsional waterfall diagram



c) Drive motor side simulation torsional vibration waterfall diagram

Figure 13: Torsional vibration simulation waterfall diagram of the drive train (adapter panel inertia 0.001kg*m^2).

Conclusion

This paper systematically introduces the torsional vibration characteristics of series spring damper for hybrid vehicles. The conclusion shows that the inertia is introduced into the series spring damper adapter plate, which causes local modes, affects the whole vehicle drive train and causes the gear rattle problem. It is necessary to optimize the matching between the spring stiffness of the torsional damper and the inertia of the adapter plate.

1. The simulation model of the vehicle hybrid power transmission system matching the series spring torsional shock absorber was established by using the dynamics software. The local modes related to the torsional shock absorber were obtained through modal analysis. The simulation analysis and test confirmed that the local modes could cause the torsional vibration of the drive train, and the gearbox tooth knocking was caused by the real vehicle test.
2. The influence factors of the local modes were parameterized, and the correlation between the local modes of the series spring torsional shock absorber and the torsional stiffness of the torsional shock absorber and the inertia of the transfer plate was determined. The local mode is improved by optimizing the inertia of the transfer plate.
3. The simulation and verification of the series spring damper with optimized rotary plate inertia show that this mode has avoided the common speed range of the engine speed.

The research in this paper has a good reference significance for the torsional vibration optimization of series spring damper. Then, the influence of local modes is further studied from the Angle of the transfer plate and the master-slave moving plate damping.

References

1. Li Wei and Shi Wenku. “Research review of Dual-mass flywheel (DMF)”. Noise and Vibration Control (2008).
2. Zink M and Hausner Welter R. “The Clutch and the Release System”. Anengaging topic 8. LuK (2006).
3. Editorial Board of the Journal of Automotive Engineering. “Automotive Engineering Manual Design”. Beijing: People’s Communications Press (2011).
4. Li Zhi., et al. “Research and test on torsional characteristics of hybrid power transmission system”. SAECCE2020-EV092 m590 (2020): 596.
5. Yan Minggang., et al. “Optimization of Torsional Shock absorber Parameters for a Hybrid Powertrain”. Automotive Technology, 8 (2015): 34-42.
6. Zou Liang., et al. “Torsional Vibration and Noise Analysis of Hybrid Car Drivetrain”. Automotive Engineering 36.6 (2014): 709-714.

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