Study on Vibration Damping Characteristics of Centrifugal Pendulum Double Mass Flywheel

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Keywords: Centrifugal pendulum absorber, Torsional vibration, Path optimization.

Abstract. Based on a certain type of vehicle carrying double mass flywheel (DMF), the torsional vibration model of the whole vehicle transmission system under the 3rd gear driving conditions is established by AMESim software. Compare and analyze the vibration damping performance of DMF with or without centrifugal pendulum absorber (CPA) and verify the validity by the tests of real vehicle. Finally, simulate and analyze the influence of CPA swing path on the damping performance of DMF-CPA. The simulation results show that DMF-CPA can effectively avoid resonance in the frequency range, and the vibration isolation effect is better than the ordinary DMF. The bifilar type CPA with epicycloidal path has order independence and it owns the optimal isolation effect.

Introduction

Nowadays, the engine uses miniaturization and high torque output to reduce fuel consumption, which causes the torsional vibration of the drive train to increase. Due to the limitations of the applied speed, the widely used dual mass flywheel has poor damping effect. The centrifugal pendulum damper is proposed as a new damping technology.

The bifilar-type centrifugal pendulum absorber (CPA) was introduced as a concept in conjunction with the dual mass flywheel (DMF) as early as 2002[1]. The idea successfully went into series production a few years later. The simple physical principle, modular design and extremely good isolation have led to increasing acceptance and proliferation not only in the DMF, but also in other damping concepts such as torque converters and clutch discs. However, the research on centrifugal pendulum-type dual-mass flywheel vibration absorber in China is still at its preliminary stage[2]. The relative technology is backward and immature. It is necessary to develop the technology of centrifugal pendulum absorber, and development foreground is very optimistic and impressive.

The Principle of Centrifugal Pendulum Absorber

The motion diagram of the centrifugal pendulum is shown in Figure 1. The secondary flywheel rotates around the O-point of the shaft center. The centrifugal pendulum is connected to the flange through a massless rod and operates in accordance with the swing path of the CPA. According to the geometric relationship in Fig. 2 and references [3-4], the natural frequency of a centrifugal pendulum can be obtained by assuming that the pendulum angle is small. Natural frequency is \( \omega \), tuning order is \( n \), \( \Omega \) is the engine speed; \( R \) is the distance between the axis and the connection point on the flange; \( L \) is the radius of curvature. \( R_g \) is the distance between the center of the pendulum and the axis.

\[
\omega = \Omega \sqrt{\frac{R}{L}}
\]

(1)

\[
n = \sqrt{\frac{R}{L}} = \sqrt{\frac{R_g}{L-1}}
\]

(2)

From Eq.1, the natural frequency of the centrifugal pendulum is proportional to the engine speed, and the engine torque excitation frequency is also proportional to the engine speed. Therefore, we can adjust the CPA structure parameters to maintain a constant order(natural frequency to speed
frequency ratio) independently of the magnitude of the angle. This approach is the only way to achieve optimum isolation over the whole engine speed for partial throttle as well as for wide-open throttle. From Eq.2, if the pendulum path is designed to be circular, the tuning order of the pendulum will be keep the same as the main order of the engine for small stroke. But at large strokes, the tuning order of the circular path is reduced because of the decreased $R_g$, showing a strong nonlinearity. In order to keep the tuning order constant, the radius of curvature $L$ is reduced to compensate for the decrease of $R_g$. Therefore, the cycloid and epicycloid become the new directions of CPA path design.

Simulation and Verification of Automobile Transmission System

The research object is a automobile equipped with a 1.0T engine, a 6-speed manual transmission and a dual mass flywheel. For the 3rd driving condition, establish the simulation model of automobile transmission system with ordinary dual mass flywheel based on the concentrated mass modeling method, as shown in Figure 2.

![Figure 2. Simulation model of vehicle transmission system.](image)

The dynamic cylinder pressure curve of the quasi-transient engine model is used as the power input of the transmission system. In the 3rd driving condition, the engine cylinder pressure corresponding to each speed is different. For a three-cylinder engine, the engine runs two cycles in one cycle and ignites according to the ignition sequence of cylinder 1-cylinder 3-cylinder 2. The ignition timing of each cylinder differs by 240°CA.

The curve of the speed fluctuation amplitude in the primary and secondary flywheels with the change of engine speed, as shown in Figure 3. According to the formula[^6], at the frequency of 37.5 Hz, the fluctuation of engine speed reaches the peak value, and resonance is easy to occur. The peak value of speed fluctuation is reduced by about 142r/min at this frequency.
In order to verify the correctness of the torsional vibration simulation model of the vehicle transmission system, the vehicle was tested on the whole lane road. According to the structural space of the vehicle, a measuring gear ring is installed on the main shaft side of the transmission. The two magnetic speed sensors are installed in the engine starting gear side and gearbox input shaft side. The test adopts wide open throttle (WOT) acceleration condition in the 3rd gear and the speed ranges of 1000rpm to 4000rpm. This paper mainly uses the MATLAB software platform to program, using a more concise basic frequency signal extraction method, through the torsional vibration signal per revolution data points to the average method to extract the base frequency [5]. The speed fluctuation curves of primary and secondary flywheels are collected and compared with the simulation data. The results are shown in Figures 4.

It can be seen that the peak value of speed fluctuations by the simulation is steeper than the test value in the low speed section. This may be due to the non-test real-time measurement of the cylinder pressure curve in the model and the simulation of the WOT acceleration condition. However, the speed fluctuation trend of the primary and secondary flywheel is consistent in the range of running speed, and the error between the simulation value and the test value is less than 10%. The results show that the torsional vibration model and boundary conditions are correct. It can be used in the simulation analysis of CPA.

Analysis of CPA Damping Characteristics

Based on the model in Figure 2, the inertia element of the secondary flywheel is replaced by TRCPA02 sub-model, which represents a bifilar type centrifugal pendulum with a general path connected to the inertia of the secondary flywheel. The path of the CPA is adjustable, considering the movement of the roller and the frictions between the components. The simulation model of automobile transmission system with CPA is established, as shown in Figure 5. For a three-cylinder engine, the main harmonic order of the vibration torque is 1.5. The path uses an epicycloid type, whose tuning order is also set to 1.5. The centrifugal pendulum mass is equal to 1.0 kg, a reasonable value for a DMF in a car powertrain. Comparison diagram of vibration isolation effect is shown in Figure 6.
When the DMF has CPA, the amplitude of the angular acceleration fluctuation at the end of the secondary flywheel decreases. There is no peak value of the angular acceleration fluctuation within 1.5 times of engine speed frequency, so resonance can be avoided in this frequency range. Besides, the vibration isolation rate increased significantly in the working speed. Maximum vibration isolation rate is changed from 17.4dB up to 27.8dB. The ratio of vibration isolation is up by nearly one half. Therefore, centrifugal pendulum reduces angular velocity fluctuation by centrifugal force, which is more effective than damping by friction heating.

To study the effect of the swing path on the damping performance, this paper analyzed the vibration isolation rate by introducing the parameter in the simulation. For three different paths, the results are shown in Figure 7. When the middle and high speed, the motion of CPA reaches a steady state. At this time, the difference in the radius of curvature between the circular and cycloidal paths is small, so the vibration isolation effect is basically the same. In the low speed, the CPA types with regular circular paths either do not affect vibration levels, or amplify them, which is highly undesirable. However, the epicycloidal pendulum path has order independence and the vibration excited by the main order of the engine can be reduced to the greatest extent. In general, the ultimate damping performance of the CPA
type with epicycloidal path can be achieved and have a more substantial upgrade than other two kinds, which is the best of three. It should be noted that the parameters of the pendulum path need to be properly designed, different engine characteristics, the optimal parameter values for each pendulum path will be some differences.

Summary

Through the above simulation study, the following conclusions can be drawn:

1) The centrifugal pendulum absorber is installed on the flange of dual mass flywheel. Analyze the working principle of DMF-CPA. The theory shows that it can achieve the better vibration isolation in all speed ranges with the proper structural parameters and correct tuning.

2) For the 3rd driving condition, establish the simulation model of automobile transmission system with the ordinary dual mass flywheel and carry out the vehicle road test. There is the high consistency of simulation results to the test. It indicates that the simulation model can describe the actual working condition of the automobile transmission system. Besides, the resonance phenomenon of the transmission system with ordinary DMF will be unavoidable in the specific low frequency region.

3) Based on the above model, add a centrifugal pendulum absorber to the DMF. Compare the results with that of ordinary double mass flywheel. The simulation indicates that the vibration isolation effect of DMF-CPA is obviously better than that of ordinary DMF. Meanwhile, eliminate the resonance phenomenon at specific frequency successfully.

4) Optimize and analyze the swing path of CPA. The results show that epicycloidal path allows for a pendulum that behaves entirely linear, i.e. has the same frequency regardless of amplitude. It owns optimal isolation effect and provides an effective reference for path design.

References


