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# Design and analysis of a dual mass flywheel with continuously variable stiffness based on compensation principle

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ABSTRACT

A new structure of dual mass flywheel (DMF) with continuously variable stiffness is proposed based on compensation principle in order to release the impact produced by the step changes of stiffness. By theoretical calculation and experiments, the proposed structure and design theory involved are proved to be feasible for reducing the torsional vibration of the power transmission system for automobiles with large-power and high-torque engines. The natural characteristics of the vehicle power transmission system carrying the DMF are analyzed to investigate the influence of torsional stiffness on the first-order and the second-order resonance speeds. The results show that this new DMF can lower the idle speed of the engine, realize high counter torque at a large torsional angle, and avoid the impact due to the abrupt changes of stiffness. An inertia balance mechanism is proposed to eliminate the inertia forces produced by moving parts of the compensation device, which can successfully put the torque compensation theory into engineering practice.



## 1. Introduction

It is hard for vehicles with a conventional clutch torsional vibration damper (CTD) to meet the increasing demand for good comfort, reductions in the torsional vibration and noise of a vehicle power transmission system. In the early 1990s, to overcome the problem of torsional vibration in the transmission system, a method of adding mass and elastic elements into the system was proposed by companies represented by LuK, with which the conventional CTD was replaced by DMF torsion damper [1–4]. Through constantly being improved, DMF has been put into batch production and widely adopted in automotive powertrains to date [5]. DMF can realize the first-order resonance speed of the vehicle power transmission system lower than the idle speed of the engine, and the second-order resonance speed higher than the maximum speed of the engine, in which case the resonance of the vehicle is absolutely isolated from the normal speed of the engine. DMF has been playing a significant role in reducing the torsional vibration and noise, relieving the impact, realizing the protection of the engine and gearbox against overload, and enabling the engine to operate at lower speeds to reduce fuel consumption [6–9]. Owing to the excellent properties of DMF, many studies have been carried out. Schaper et al. [10] introduced the structure and working principle of a circumferential spring DMF, and analyzed the different torsional characteristics of the DMF from both experimental and theoretical aspects. By analyzing the damping characteristics of the circumferential arc spring DMF, Zhao et al. [11] obtained an ideal torsion damping characteristic for this kind of DMF. Lü et al. [12–15] mainly focused on the design of the elastic elements of DMF and its torsional vibration reduction properties. Shi et al. [16] proposed an innovative arrangement of elastic structure applied in DMF to make this vibration damper have multi-piece step stiffness. And analysis of the natural characteristics of the transmission system at driving and idling

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conditions was conducted to evaluate the effect of vibration control of the multi-stage nonlinear DMF. By allocating the rotational inertia of a DMF-radial spring torsional vibration damper reasonably and designing the torsional stiffness of the torsional vibration spring correctly, Li et al. [17] obtained good non-linear torsional stiffness characteristics for the radial spring DMF. Kim et al. [18] introduced a discrete analysis approach to investigate the performance of a DMF, and proposed the nonlinear friction model to describe Stribeck effect and viscous friction depending on the relative sliding velocity. It was found that the discrete DMF model could describe the automotive driveline behavior closely and the friction characteristics of the arcspring depended on the relative sliding velocity between the friction surfaces. Walker et al. [19] analyzed the influence of DMF on the transient response of a vehicle powertrain equipped with a dual clutch transmission under two models. L.Q. Song et al. [20] proposed the design theory of a friction double-stage piecewise variable stiffness DMF, which could realize the flexibility with small stiffness at small torsional angles, and achieve large stiffness and high counter torque at large torsional angles. Test systems of torsional vibration for DMF were established by Kang et al. [6,7,21,22], which provided the basis for the performance test and parameter optimization of DMF. Walter et al. [23] introduced an optimized solution for idle speed control regarding conventional combustion engines equipped with DMF, which was based on conventional PID-control strategies with improved fuel injection scheduling. All these achievements are significant to explore the inherent nature, characteristics and engineering application of DMF.

With breakthroughs of the critical technologies represented by turbocharging and in-cylinder direct injection, large-power engines have gained a great development. To adapt to large-power and high torque engines, LuK Company and Sachs Company et al. have studied and developed the DMF with piecewise step stiffness.

The DMF with piecewise step stiffness is more flexible at small torsional angles, has greater counter torque at large torsional angles, and features of continuous torsional characteristics. However, abrupt changes in the torsional stiffness of this DMF may cause impact load and noise upon the gear engagement of the gearbox [10,24]. To solve these problems, a new structure of DMF with continuously variable stiffness is presented based on compensation principle, and the design theory involved is verified through torsional experiments.

## 2. Structure of the DMF based on compensation principle

Fig. 1 shows the structure of DMF based on the compensation principle, which is mainly made up of primary flywheel, shock absorber, drive plate, secondary flywheel, compensation device, inertia balance mechanism, bearing inner ring, pressure plate and end cover. The shock absorber (including springs and spring seats) is arranged in the intracavity of the primary flywheel, and the drive plate is fixed on the secondary flywheel by bolts. The compensation device and inertia balance mechanism are mounted on the secondary flywheel, and the bearing inner ring and three bearing block are put into the intracavity of the secondary flywheel and sealed by the pressure plate. In addition, the connection of bearing inner ring and end cover by bolts forms a journal bearing, which is finally fixed with the primary flywheel.

Fig. 2 presents the change in stiffness of DMF. Fig. 2a is the initial state. In the DMF's operation, the secondary flywheel is assumed to rotate relative to the primary flywheel. Spring seat 1 rotates due to the action of the drive plate fixed on the secondary flywheel. While there are no contacts among all the spring seats shown in Fig. 2b, in which case springs 1, 2 and 3 installed between these spring seats are connected in series, and thus the first-stage stiffness of the DMF is formed. On the other hand, after turning a certain angle, spring seat 3 makes contact with spring seat 4, in which case, spring 3 is no longer pressed while springs 1 and 2 are in series and continue to be compressed. Thus the second-stage stiffness is generated, as shown in Fig. 2c. Besides, when spring seat 2 is in connection with spring seat 3 (already contact with spring seat 4), only spring 1 with the largest stiffness can continue to be pressed until spring seat 1 contacts with spring seat 2 (i.e., the torsional angle reaches the maximum value), and thus, the third-stage stiffness comes into being, as shown in Fig. 2d.

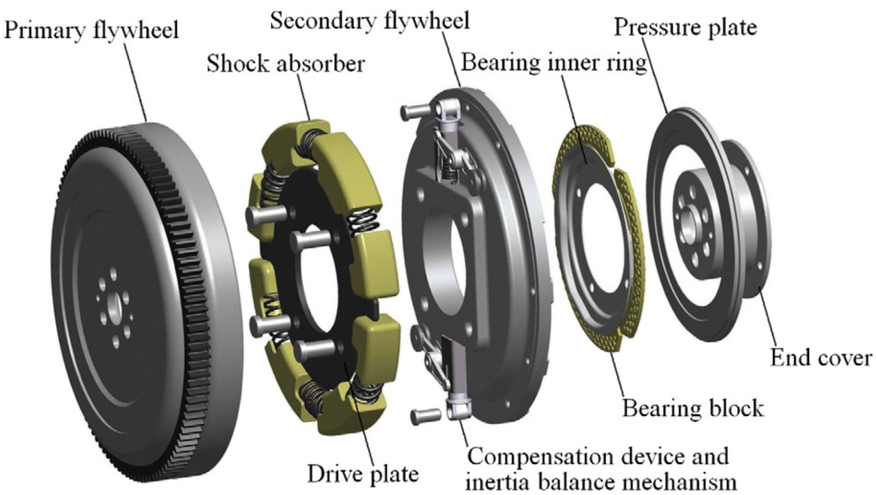


**Fig. 1.** Structure of DMF based on compensation principle.