Mechanism and Machine Theory 92 (2015) 356–374

Contents lists available at ScienceDirect

Mechanism and Machine Theory

journal homepage: www.elsevier.com/locate/mechmt

Design and elastic contact analysis of a friction bearing with shape constraint for promoting the torque characteristics of a dual mass flywheel

Li Ping Zeng [a], Li Quan Song [a,*], Jian Dong Zhou [a,b]

[a] The State Key Laboratory of Mechanical Transmission, Chongqing University, Chongqing 400044, PR China
[b] Chongqing College of Electronic Engineering, Chongqing 401331, PR China

ARTICLE INFO

Article history:
Received 13 December 2014
Received in revised form 29 March 2015
Accepted 9 June 2015
Available online 24 June 2015

Keywords:
Dual mass flywheel
Friction bearing
Shape constraint
Displacement-based method
Elastic contact
Torque characteristics

ABSTRACT

A friction bearing with shape constraint is introduced into a dual mass flywheel (DMF) with single-stage stiffness to improve the counter torque of the DMF. In polar coordinates, a displacement-based method of elasticity, which is derived in this paper, is applied to establish the calculation model of the elastic contact between the secondary flywheel and the friction bearing block. With the known displacement boundary conditions, the distributions of strain and stress on the contact region and the torque characteristics generated by the contact effect are obtained. By theoretical calculation and experiments, the introduced friction bearing with shape constraint and design theory involved prove to be feasible for increasing the counter torque of the DMF, which makes the DMF well suited for more powerful engines. Meanwhile, the modified DMF with continuously variable stiffness characteristics still has low stiffness at small torsional angles, which ensures the DMF's performance of isolating the first-order resonance vibration so that the engine can operate at a low idle speed to reduce energy consumption.

1. Introduction

DMF, which was first introduced into vehicle power transmission system by German LuK Company to reduce torsional vibration [1,2], has been widely recognized by automobile manufacturers and users for its excellent damping characteristics. By changing the natural frequency of the power transmission of a vehicle, DMF makes the first-order resonant speed lower than the idle speed of the connected engine, and the second-order resonant speed higher than the maximum speed of the engine. Thus, resonant vibration is isolated outside the regular speed range of the engine, which makes the torsional vibration and noise of the power transmission system controlled effectively, relieves the impact of the transmission system, and makes the overload protection for the engine and the transmission system available. Applying DMF can improve the driving comfort, and make the engine work at a very low speed to reduce fuel consumption [3–5]. Many scholars have been devoted to the research on DMF in recent years. For example, Schaper et al. [6] presented a detailed ab-initio model of a DMF dynamics which mainly included a model for two arc springs in the DMF and their frictional behavior, and proposed a linear torque observer at low engine speeds by using the DMF equipped speed sensors. Kim et al. [7] applied a discrete method to study the performance of a DMF by establishing a discrete model of the elastic element, and presented a nonlinear friction model for simulating the Stribeck effect and viscous friction. By using a dynamically reconstructed continuous engine torque signal, Walter et al. [8] proposed a novel cylinder balancing method, and established the state space model of a

DOI of original article: http://dx.doi.org/10.1016/j.ebiom.2015.05.003.
* Corresponding author at: Room 235, College of Mechanical Engineering, Chongqing University, No. 174 Shazheng Street, Shapingba District, Chongqing 400044, PR China.
E-mail addresses: zengliping112@126.com (L.P. Zeng), slq@cme.cqu.edu.cn (L.Q. Song).

http://dx.doi.org/10.1016/j.mechmachtheory.2015.06.002
0094-114X/

DMF. It was proved that this method and model could accurately estimate the torque of an engine in real time. Lü et al. [9,10] carried out studies which mainly focused on the design of the elastic element of DMFs, and discussed the effects of its parameters on the torsional vibration reduction. Shi et al. [11] discussed the design principle of a multi-stage stiffness DMF with internal and external springs nested, and analyzed the natural characteristics of the transmission system at driving and idling conditions to evaluate the DMF's performance of controlling vibration. Li et al. [12] proposed a new type of DMF with radial spring, and obtained good nonlinear torsional stiffness characteristics for the DMF by allocating the rotational inertia of the torsional vibration damper reasonably and designing the torsional stiffness of the torsional vibration spring properly.

With breakthroughs of the critical technologies represented by turbocharging and in-cylinder direct injection, engines with large power have gained a great development [13,14]. However, the development of DMF faces increasing challenges, especially in improving counter torque. In order to enable DMF to get good flexibility at low speeds and small torsional angles, and high counter torque at high speeds and large torsional angles, LuK Company developed a piecewise step stiffness DMF, each stage stiffness of which is constant [15]. Although the torque characteristics of this type of DMF are continuously variable, abrupt changes in the torsional stiffness of this DMF may cause impact loads and noise upon the gear engagement of the gearbox [6,16]. To make the piecewise step stiffness DMF have a multistage and continuously variable stiffness without step change, Song et al. [15] added a torque compensation device into the DMF, and proposed a balance mechanism to eliminate the inertia force produced by the compensation device. DMF with single-stage stiffness is also widely used for its advantages of simple structure, high reliability and large continuous counter torque. For the single-stage stiffness DMF, the stiffness of this DMF at low speeds and small torsional angles should be low to ensure the first-order resonant speed of the driveline system lower than the idle speed of the engine. As mentioned by Rahnejat [14], decreasing spring rate decreases DMF's resonance frequency accordingly. And when lowering the arc spring rate, one must consider the maximum torque which the DMF should be able to transmit. Thus, increasing the stiffness of the damping spring is obviously not a superior way to increase the counter torque of the DMF at large torsional angles. GAT Company made use of the mutual wedging between the spring seats at large torsional angles to generate frictional force to increase the counter torque of single-stage DMF. In addition, the mutual wedging between the spring seats can also prevent springs from being overloaded. Song et al. [17] changed the inside profile line of the primary flywheel to make the formed shape constraint between the primary flywheel, the secondary flywheel and the spring seats increase the counter torque of a DMF at large torsional angles without changing the small flexibility of the DMF at small torsional angles.

By introducing a friction bearing with shape constraint, this paper aims at further improving the counter torque of a DMF with single-stage stiffness at large torsional angles. In plane polar coordinates, the elastic mechanics model of the elastic contact effect between the friction bearing block and the secondary flywheel is established, and the elastic mechanics problem is solved by taking the derived displacement-based method which takes displacement components as basic variables and introduces an intermediate variable function in this paper. Furthermore, the torque characteristics produced by the contact effect are presented and verified through experiments.

2. Structure of DMF and design philosophy

The structure of the studied DMF is illustrated in Fig. 1. As is shown, the DMF is mainly made up of spring damper (including springs and spring seats), secondary flywheel, friction bearing block, friction bearing inner ring and primary flywheel. The spring 2 is connected with two spring seats (1 and 3), and they (1, 2 and 3) are arranged in the intracavity of the primary flywheel 7. The friction bearing block 5 is installed between the friction bearing inner ring 6 and the secondary flywheel 4 (can be seen as a friction bearing outer ring). And the friction bearing inner ring 6 is jointed with the primary flywheel 7 by bolts.

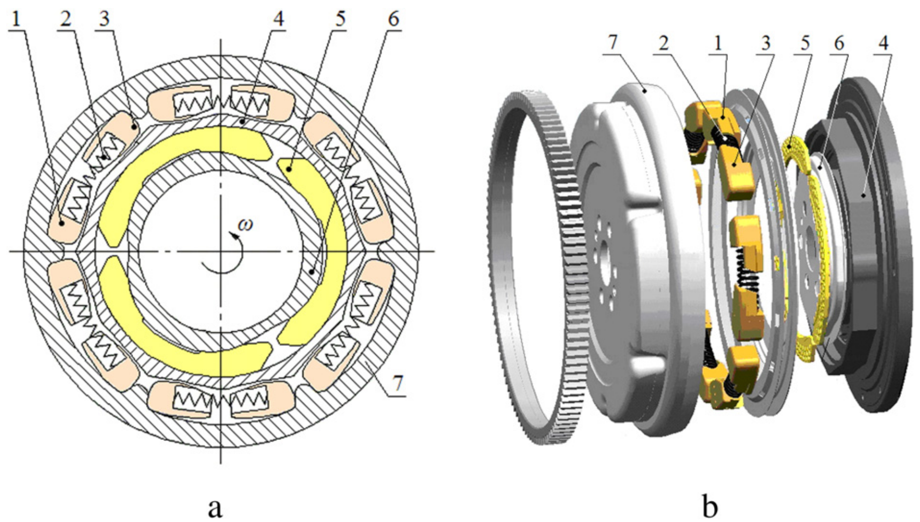

Fig. 1. A schematic plot of a DMF with single-stage stiffness: (a) planar structure; (b) three dimensional structure. 1, 3-spring seat; 2-spring; 4-secondary flywheel (friction bearing outer ring); 5-friction bearing block; 6-friction bearing inner ring; 7-primary flywheel.