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Vibration isolation analysis of clutches based on trouble shooting of vehicle accelerating noise

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ABSTRACT

Vehicle accelerating noise is a troublesome issue commonly existing in automobiles, leading to negative passenger experience. Considering real experimental results and practical issues, a nonlinear 3-degree of freedom (DOF) torsional model of the clutch system is developed for reducing abnormal noise during vehicle accelerating. In this model, the nonlinear characteristics of the multi-staged clutch damper and the gear backlash are carefully studied. This greatly facilitates the analysis of the vibration transmission characteristics of the clutch and helps understanding of the influence of each critical physical parameter on noise generation. To reduce the accelerating noise, an optimization method for the clutch dynamics is proposed, based on the parameter analysis results, and the effectiveness is validated both in simulations and experiments.

1. Introduction

Noise, vibration and harshness (NVH) are important factors in overall customer satisfaction [1,2]. Vehicle accelerating noise, as a powertrain NVH which can appear in the idle condition [3], is a commonly encountered issue in automobiles leading to negative influence on passenger comfort. Gear meshing vibration [4–6] and noise on bearings of the transmission path [7] are potential sources which can cause the abnormal noise during vehicle accelerating. Sliding and rolling motions exist during synchro-mesh transmission, which inevitably produce clashing or grinding behaviors and thus result in various noises. To reduce the noises, manufacturing precision of gears could be improved, and the assembly error and gear assembly clearance should be reduced [6]. However, these will increase the manufacturing cost of the transmission system. Effective sound suppression and absorption products can also be applied in the front fire-wall of the engine cabin to decrease the noise level transmitted to passengers [8]. Importantly, optimal design of the torsional stiffness and damping of the clutch could be an alternative approach for isolating the engine output rotational fluctuation (torsional vibration) to the transmission input shaft, and thus to significantly reduce the gear meshing noise [9]. This method is simple but could be more effective and cost-saving, especially for suppression of vibration and noise at vehicle development stage when the vehicle is already prototyped.

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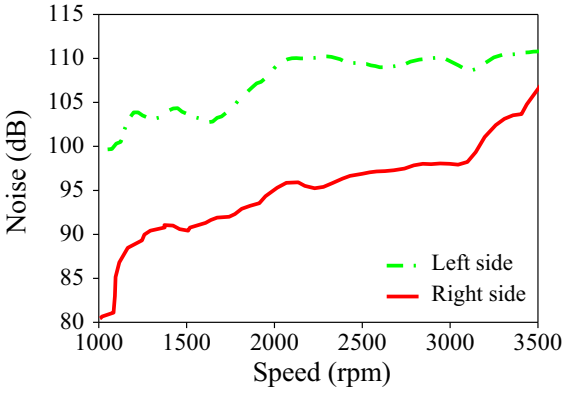

Fig. 1. Measured noise in engine compartment during 3rd accelerating.

For the analysis and design of the clutch to achieve vibration reduction in the transmission system, Crowther and Zhang et al. [10] and Cai [11] proposed a nonlinear dynamic model for the gear transmission, and the backlash of gears [10] and the time-varying mesh stiffness [11] were also considered. Almahdi, Michael, Yoon et al. [12–14] studied the multi-staged stiffness and hysteresis elements as well as spline nonlinearities in the nonlinear dynamics of the clutch, and the effect of the clutch dynamic characteristics on transmission gear rattling under different engine conditions were analyzed [14]. For solving the problem of auto transmission gear rattling, a 3-degree-of-freedom torsional vibration model was established in [15,16], which discussed the influence of the stiffness and damping parameters of the clutch and the moment of inertia of the flywheel on reducing gear rattling.

Steinel et al. [17] studied parameter optimization for the clutch with a commercial vehicle and proposed a vehicle vibration noise evaluation method corresponding to the subjective evaluation via passengers. Regarding the vehicle idle noise problem, Steinel et al. [18] utilized the commercial software, ITI-SIM, for severity analysis and modelling considering nonlinearities of transmission gears and spline gap. The simulation results showed that a pre-damper in the clutch can effectively reduce the idle noise. The authors in Ref. [19] analyzed the abnormal noise generated by transmission gears from the perspective of nonlinear dynamics, and studied the nonlinear vibration problem of a single pair of gear backlash. The stability condition of the system in terms of some critical parameters such as excitation frequency, load ratio and damping ratio that can affect gear dynamic response, is provided.

In this study, a nonlinear torsional model with 3 degree-of-freedoms (DOF) is proposed and used for reducing abnormal noise during vehicle accelerating. By considering the torsional stiffness and dry friction damping of the clutch disc, and the gear meshing stiffness characteristics of the transmission, the proposed model provides a useful way to analyze the influence of each critical parameters on noise and vibration suppression of the clutch, and consequently improvement methods for structural designs of the clutch are proposed and further validated in a real car. The proposed model and analytical results are all validated with experimental results. In our experiments, an improved clutch is installed in the car, and the measured noise at the engine compartment and the cabin, and the measured vibration at the bracket of transmission mount, are then compared with the baseline. It is shown that the noise and vibration are reduced obviously with the proposed method.

It should be noted that, although the modeling and simulation methods in the paper partly exist in the available literature, few results actually addressed the dynamic model which includes the nonlinear characteristics of the clutch. Moreover, most researches concentrate only on the characteristics of gear and gearbox when encountering the vehicle acceleration noise, without considering the clutch dynamics (as what we are doing in this paper). The other point is that, the simulation results in the literature are almost all verified only by a benchmark testing but lacking of real vehicle experiments. In this paper, an optimization method is proposed to solve the vehicle acceleration noise by investigating the vibration isolation performance of the clutch. The influence of critical physical parameters of the dynamic model on vibration suppression is analyzed such as the first and second hysteresis, and the first transition angle etc. These are also not well investigated in the literature. Importantly, instead of benchmark testing, real vehicle experiments are conducted for validation of theoretical results.

2. Noise and vibration problems of a real car

A passenger car (1.8 L engine displacement, 5 speed manual gearbox) has the problem of abnormal noise during vehicle accelerating. Sound pressure data measured at the right and left side of the engine compartment are shown in Fig. 1. Sound pressure data measured at the driver's right ear and acceleration on the transmission mount bracket are shown in Fig. 2, respectively. In Fig. 1, the sound pressure at the right side of the engine compartment (near the engine) increases with the speed gradually, with a normal trend. However, the noise level at the left side of the engine compartment (near