Mechanism and Machine Theory 79 (2014) 46–63

Contents lists available at ScienceDirect

Mechanism and Machine Theory

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

Numerical and experimental investigation of drag torque in a two-speed dual clutch transmission☆

Xingxing Zhou [a,*], Paul Walker [a,**], Nong Zhang [a,b,1], Bo Zhu [a,c,2], Jiageng Ruan [a,3]

[a] School of Electrical, Mechanical and Mechatronic Systems, University of Technology, Sydney (UTS), Sydney, NSW 2007, Australia
[b] State Key Laboratory of Advanced Design and Manufacturing for Vehicle Design, Hunan University, Changsha 410082, China
[c] BAIC Motor Electric Vehicle Co. Ltd., Beijing 102606, China

ARTICLE INFO

Article history:
Received 7 November 2013
Received in revised form 15 April 2014
Accepted 15 April 2014
Available online 9 May 2014

Keywords:
Drag torque
Power loss
Mathematical model
Dual clutch transmission
Experimental investigation

ABSTRACT

The theoretical analysis of drag torques within a two-speed dual clutch transmission is presented in this article. The numerical models are developed to study the different sources of drag torques in dual clutch transmission. Simulations are performed in Matlab/Simulink platform to investigate the variation of drag torques under different operating conditions. Then an experimental investigation is conducted to evaluate the proposed model using an electric vehicle powertrain test rig. Outcomes of experimentation confirm that simulation results agree well with test data. Therefore the proposed model performs well in the prediction of drag torque for the transmission, and can be applied to assess the efficiency of the transmission. Results demonstrate that the entire drag torque is dominated by the viscous shear in the wet clutch pack and gear churning losses. This lays a theoretical foundation to future research on reducing drag torque and applications of drag torque in powertrain system efficiency optimization.

1. Introduction

In recent years there has been significant attention drawn towards reducing fossil fuel consumption and emissions in the automotive industry. Improvement of the overall energy efficiency of existing technologies is one of the most important subjects for developing new vehicle technologies. As a consequence of this, the development of commercially viable hybrid electric vehicles (HEVs), fuel cell vehicles (FCVs) for using in the short to mid term, and pure electric vehicles (EVs) in the long term is one of the major contributions in the automotive industry to solve related issues [1]. Pure EVs currently being used in the market are mainly equipped with single speed transmissions, with tradeoffs between dynamic (such as climbing ability, top speed, and acceleration) and economic performance (drive range). Nowadays, more and more EV researchers and designers are paying attention to application of multiple speed transmissions instead of traditional single speed transmissions, expecting to improve the EV performance. The usage of multispeed transmissions for electric vehicles is likely to improve average motor efficiency and

☆ This paper is submitted for possible publication in *Mechanism and Machine Theory*. It has not been previously published, is not currently submitted for review to any other journal, and will not be submitted elsewhere during the peer review.

* Corresponding author. Tel.: +61 2 9514 2517; fax: +61 2 9514 2655.
** Corresponding author. Tel.: +62 2 9514 2412; fax: +61 2 9514 2655.
E-mail addresses: Xingxing.Zhou@student.uts.edu.au (X. Zhou), Paul.Walker@uts.edu.au (P. Walker), Nong.Zhang@uts.edu.au (N. Zhang), zhubo@bjev.com.cn (B. Zhu), Jiageng.Ruan@student.uts.edu.au (J. Ruan).
[1] Tel.: +61 2 9514 2662; fax: +61 2 9514 2655.
[2] Tel.: +62 2 9514 2517; fax: +61 2 9514 2655.
[3] Tel.: +62 2 9514 2412; fax: +61 2 9514 2655.

http://dx.doi.org/10.1016/j.mechmachtheory.2014.04.007
0094-114X/

range capacity, or even can reduce the required motor size. The detail advantages of two-speed transmission over single speed are demonstrated in previously reported work [2].

As an important part of electric vehicle powertrain system design and optimization, it is of great importance to predict the transmission efficiency early in the design process, leading to improved powertrain efficiency as the system is refined. In addition to the design characteristics of the transmission, drag torque, acting as the sources of power losses within transmission, is affected by operating conditions, including variations in both speed and load. The total drag torque within a gear-train for any transmission is generally made up of several parts, including gear friction [3–6], windage [7–9] and oil churning [10,11]. Other important drag torque sources have to be considered as well, comprising bearings and seal [11–13], synchronizer and free-pinion losses [14,15]. If the clutch is immersed in oil, torsional resistance and its influences caused by the viscous shear between wet clutch plates should be considered as well [16,17]. Several researchers have done some specific studies regarding the drag torque within disengaged wet clutches [18–21], which will be analysed in the 2nd section.

However, in order to comprehensively improve the whole automotive powertrain system efficiency, it is necessary to consider all aspects of the transmission power losses [22]. There are only a few reported works on the entire transmission power losses [23–27], which are mostly focused on a manual transmission (MT) gear-train. There is limited, if any, published work to combine the gearbox components and wet clutch losses together to study. Especially, there is no published report on a study of an entire drag torque within wet dual clutch transmissions (DCT).

In this paper, drag torque within a two-speed dual clutch transmission is discussed. A general two-speed wet DCT is suggested to be equipped into a pure electric vehicle (EV), as shown in Fig. 1. The system under consideration is modified from a 6-speed DCT (DQ250) into a two-speed DCT. The two-speed DCT housing is made from an aluminium alloy. And the DCT is made up of two clutches, the inner clutch (C1) and the outer clutch (C2). The two clutches have a common drum attached to the same input shaft from the electric motor, and the friction plates are independently connected to the 1st or second gear. C1, shown in green, hereby connects the outer input shaft engaged with the 1st gear, and C2, shown in red, connects the inner input shaft engaged with the 2nd gear. In order to make the transmission control system simpler and save manufacture fees, there are no synchronisers in this new type of two-speed DCT. Thus, the transmission can be looked at as two clutched gear pairs, and, in this sense, shifting is realised through the simultaneous shifting between these two halves of the transmission. For this special layout, a vehicle equipped with a DCT can not only change speed smoothly with nearly no power hole, identified by Goetz [28], but also improve the EV efficiency as well.

This paper is organised as follows. In the 2nd section, the different sources of drag torque in the DCT is theoretically analysed and modelled including torsional resistance caused by viscous shear caused between wet clutch plates and concentrically aligned shafts, gear mesh friction and windage, oil churning, and bearing losses. Then experimental aspects comprising the description of the UTS test rig, and the drag torque test procedures are presented and discussed in the 3rd section. In the 4th section, simulation and experimental results are compared and analysed to validate the effectiveness of the numerical model. Finally, some significant conclusions drawn from the study are summarized in the 5th section.

2. Theoretical analysis of drag torque in wet dual clutch transmissions

The sources of power loss in a two-speed DCT, or drag torque, can be divided into five major origins: gear related meshing, windage and churning losses, bearings and oil seal related losses, concentric shaft related viscous shear losses, and disengaged

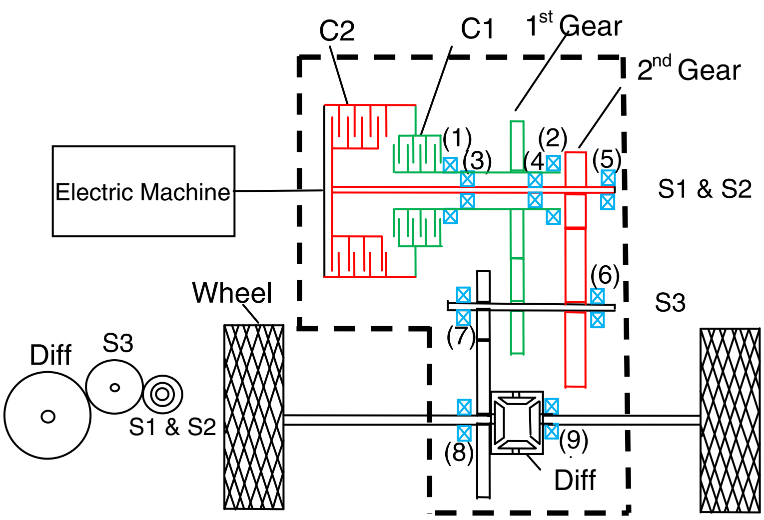

Fig. 1. Schematic of a two-speed DCT powertrain system.