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Design of nonlinear shaft torque observer for trucks with Automated Manual Transmission

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ABSTRACT

Knowledge of drive axle shaft torque improves the longitudinal dynamic performance of vehicles. An axle shaft torque observer is proposed for vehicles with stepped ratio transmissions, which is a class of switching systems. Model uncertainties, including the steady state error and the unmodeled dynamics, are considered as an additive disturbance input and the observer is designed such that the error dynamics is input-to-state stable for all gear positions. The lowest possible gain of the designed observer is achieved by solving a set of LMIs. In the designed reduced-order observer, the complex nonlinear characteristics of powertrain systems are included and appears as their usual form of MAPs. Finally, the proposed observer is tested on an AMESim powertrain simulation model of a medium-duty truck.

1. Introduction

Mechanical resonances of vehicle driveline may occur due to the elasticity of the driveline parts, such as clutch spring, propeller shaft and drive axle shaft. Driveline oscillations are a kind of disturbance to the driver. They also lead to overlarge mechanical stress and affect the dynamic performance of the driveline [1,2]. How to avoid or reduce the oscillations of driveline is an important problem, especially for heavy duty vehicles which have relatively large driveline torsion.

Some literatures on active damping of vehicle driveline have been published in recent years [3,4]. Engine torque is controlled actively to damp the driveline oscillations during transient maneuvers, such as tip-in and tip-out of accelerator pedal. Because drive axle shafts are the main compliance of the driveline, the driving performance can be improved by controlling the axle shaft torsion. In order to design the longitudinal speed controller handling of drive shaft torsion, it is often necessary to know the angle/torque of the axle shaft [5–7].

It is also well known that the gear shift quality can be improved if accurate measurement of axle shaft torque is available [8–10]. One example is Automated Manual Transmissions (AMTs) [11], which are widely adopted to offer easy drive and fuel efficiency for trucks. At the beginning of the gear shift of AMT, the torque transmitted by the transmission is decreased and then cut off by active engine control and clutch disengagement. If the timing of clutch disengagement is not well controlled, the potential energy of the driveline will lead to unwanted driveline and vehicle oscillations [9,12]. Knowing the axle shaft torque helps to determine the most optimal time point to disengage the clutch (or directly engage the neutral gear). On the other hand, at the end of the shift process, when the clutch is engaged and the engine torque level is recovered, closed-loop shift control algorithms could greatly benefit if a measurement of the axle shaft torque was available.

Although the knowledge of axle shaft torque is necessary for improving vehicle's longitudinal speed control performance, the shaft torque sensors [13] or high precision encoder [14] (the drive shaft torque could be calculated if the twist angle measurement is available) are seldom used in production vehicles because of the cost and durability. Hence, it is required to estimate the axle shaft torque. Luenberger observer [5,15] and Kalman Filter [2,9] have been used to estimate the drive axle shaft torque. Because automotive powertrain contains complex nonlinearities, these observers are designed based on the linearized models. The sliding mode observer [16] has also been designed to estimate the axle shaft torque in [8], and an adaptive sliding mode algorithm is proposed to estimate the turbine torque of a torque converter in [17]. Sliding mode observer offers a way to ensure robustness to modeling errors and parameter uncertainties if the uncertainties are limited in their assumed bounds [8]. Examples of applying sliding mode observers to the estimation of clutch torque and axle shaft torque can also be found in [10,18].

In [19], a nonlinear clutch pressure observer is proposed for automatic transmissions, where robustness is guaranteed in the

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