UNIVERSITY OF TECHNOLOGY SYDNEY

Research on Intelligent Suppression for Torsional Vibration of Electric Vehicle Drivetrain

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CERTIFICATE OF ORIGINAL AUTHORSHIP

This research is supported by the Australian Government Research Training Program.

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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GLOSSARY OF TERMS

ABBREVIATIONS USED IN THESIS

Chapter 1

AMT- Automated Manual Transmission

ASTW-Adaptive Super Twisting

AT- Automatic Transmission

CVT-Continuously Variable Transmission

DCT-Discrete Cosine Transform

EKF- Extended Kalman Filter

GA-Genetic Algorithm

HIL- Hardware in Loop

KF- Kalman Filter

LQG- Linear Quadratic Gaussian

LQR- Linear Quadratic Regulator

MIMO- Multi-input Multi-output

MPC- Model predictive control

NVH- Noise, vibration, and harshness

PD-Proportional Derivative

PID- Proportional-Integral-Derivative

PMSM- Permanent Magnet Synchronous Motor

QGA- Quantum Genetic Algorithm

RCP- Rapid Control Prototype

RLS- Recursive Least Squares

RMS- Root Mean Square

SISO- Single-Input-Single-Output

SM-Sliding Mode

SMC-Sliding Mode Control

SMO-Sliding Mode Observer

STW-Super Twisting Sliding Mode Observer

SVPWM- Space Vector Pulse Width Modulation

UKF- Unscented Kalman Filter

UT- Unscented Transformation

Chapter 3

PF- Particle Filter

SIS- Sequential Importance Sampling

Chapter 4

AASTW- Accelerated Adaptive Super-Twisting Sliding Mode Observer

AcSTW-Accelerated Super-Twisting Sliding Mode Observer

AdSTW-Adaptive Super-Twisting Sliding Mode Observer

CAN- Controller Area Network

MCU- Motor Control Unit

VCU- Vehicle Control Unit

Chapter 5

QGA- Quantum Genetic Algorithm

ABSTRACT

Compared with the conventional fuel-consumption vehicle, electric vehicle does much better in controllability, regarding more accurate controlling of torque or rotation speed and more rapid response. The characteristic of rapid torque response will bring step motor torque output approximately when the drive tip in/out, because there exist torsional elastic damping parts such as tires and drive shaft in the drivetrain, moreover, there exists no flywheel to save the energy and buffer jerking, and then longitudinal vibration of vehicle that more sensitive to human will be introduced. In this thesis, by taking advantage of the excellent controllability of electric vehicle, active damping control of torsional vibration in vehicle drivetrain is researched, motor torque control in active damping for drivetrain torsional vibration is realized based on parameters intelligent estimation and motion state observation for the drivetrain. Improvement of electric vehicle drivability is realized focusing on driver's tipping in/out and unloading motor torque before shifting. The main content of the thesis is as follows.

Based on the drivetrain of electric drive logistics vehicle with two speeds automated manual transmission, multibody dynamic model of electric drivetrain is established, by Fourier transforming the multi-body dynamic model, frequency response function matrix of the system is obtained and frequency response analysis of the electric driving system can be carried on, and then natural frequencies, mode shapes and resonance characteristics of the drivetrain system can be revealed.

In order to solve this problem nonlinear particle filter-based intelligent parameter estimation method is proposed in this thesis. As a critical parameter in dynamic control of powertrain, vehicle mass varies continuously in a wide range and large magnitude during operation, it is one of the most significant variables in control law constituting, but vehicle mass is difficult to be measured automatically in real-time. The particle filter is recursive filter based on Monte Carlo algorithm, using the processes of importance sampling and resampling and according to motor torque output and motion states of drivetrain, parameter estimation of vehicle mass can be realized. Besides, this vehicle

mass intelligent estimation method is robust and statistical characteristics of disturbances and uncertainties in the powertrain system is unnecessary to be known.

In this thesis accelerated adaptive second order super-twisting sliding mode observer (SMO) is proposed, it can remarkably attenuate “chattering”, the inherent drawback of sliding mode (SM) variable structure algorithm, and estimation error convergence is accelerated to a large extent by introducing of the “system damping”. Motion states are also necessary in the control law designing for the drivetrain system, aiming to get the state variables of the drivetrain that are not measured directly, Based on the proposed novel sliding mode observer, torque accumulated in the drive shaft is observed to provide information for selection of appropriate shifting time, so that torsional vibration and jerking in drivetrain caused by sudden releasing of torque accumulated in the drive shaft after shifting is avoided, meanwhile, it also provides state information for the active control algorithm in the following content.

Based on the parameter estimation and state observation of the drivetrain, quantum genetics optimization and Linear Quadratic Gaussian joint algorithm is proposed to design the optimal control law to actively damp torsional vibration in drivetrain. According to the multi-feedbacks of the current motion states of drivetrain, optimal motor torque output command is calculated to compensate motion oscillations of drivetrain. The quantum genetic optimization unit utilizes qubits to replace binary encoding and quantum transformation is realized from quantum rotating gates so that the parameter in Linear Quadratic Gaussian to be optimized is searched faster to minimize the fitness function. By optimization of the parameter in Linear Quadratic Gaussian controller, more authentic and objective optimization of the controller performance is realized than the controller with subjective parameter selection from designer. Meanwhile, it will not increase the complexity and computational power consumption of the control law.

Rapid prototyping experiment, test rig experiment and real vehicle experiment are carried on focusing on parameter estimation, state observation and torsional vibration damping control to test the performances of the proposed algorithms in this thesis.