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A Mild Hybrid Vehicle Control Unit Capable of Torque Hole Elimination in Manual Transmissions

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CERTIFICATE

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.

Signature of Student:

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ
فَإِنَّ مَعَ الْعُسْرِ يُسْرًا (٥) إِنَّ مَعَ الْعُسْرِ يُسْرًا (٦) (سورة الشرح)
For indeed, with hardship {will be} ease (5). Indeed, with hardship {will be} ease (6).
{Quran, The Soothing/ash-Sharh 94}

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Abstract

This thesis describes a new technique for eliminating the "torque hole" in conventional manual transmission-equipped vehicles (CV). This technique involves designing a hybrid control system for a hybridized powertrain, which was used in the development of the new control techniques. To develop a mild hybrid electric vehicle (MHEV) that is both relatively cheap to manufacture, and offers smooth torque transfer during a gear change, as well as a degree of damping against torque oscillation. It needs a small electric motor (EM) at the transmission output, in addition, clutch position measurement, and optionally, automatic actuation. The function of the motor is to eliminate or reduce the torque hole during gear changes by providing a tractive force when the clutch is disengaged, and also provide damping, particularly during gear changes and take-off. In another instance, the electric motor may act as a motor or generator in certain driving situations. The MHEV requires only a single EM in its powertrain to function as an electric motor or generator in different time intervals controlled by an energy management strategy (EMS). In other words, the motor of the vehicle act as an accelerator during acceleration to assist Internal combustion engine (ICE) and act as a generator during deceleration. This powertrain uses electric energy sources in the form of battery or ultracapacitors pack.

In this work, through a power flow analysis of the powertrain, the main vehicle components were sized according to the vehicle parameters, specifications and performance requirements to meet the expected power requirements for the steady-state velocity of an average typical small 5-passenger light vehicle. After the sizing process, the components were selected based on the simulation, which was based on a 1990 Mazda MX-5 (Miata). Then, the model of individual components that make up the overall structure of the MHEV powertrain, are

developed in Simscape/Simulink environment and the Simscape and SimDriveline tool boxes environment to study their operational performance in various drive cycles measured under real-life conditions. The accuracy of the model is verified and validated by a comparison between the simulation results from the CV and the Advanced Vehicle Simulator (ADVISOR) codes during a number of standard drive cycles.

This project aims to develop a low-cost electric hybrid drive system for small vehicles as a proof of concept. The hybrid drive system being developed is such that in a mass-manufacturing situation the total extra cost of the system should not exceed 5% over the expense of the base vehicle as manufacture cost for hybridization to include motor, inverter, and battery. Such a system would be suitable for low-end cars typically sold in developing nations and would serve both to reduce fossil-fuel dependency in these regions as well as improve air pollution characteristics, which are typically poor owing to urban particulate matter. Extensive analysis has been conducted on the fuel economy, greenhouse gas (GHG) emissions, electrical consumption, operation cost and total lifetime cost computed for different standard drive cycles.

Dynamic investigations of the system with numerous degrees of freedom are conducted in this thesis, and the resulting sets of equations of motion are written in an indexed form that can easily be integrated into a vehicle model. Lumped stiffness-inertia torsional models of the powertrain will be developed for different powertrain states to investigate transient vibration. The mathematical models of each configuration, using eight degrees of freedom (DOF) for the MHEV, compared to seven degrees of freedom for a CV. Free vibration analysis is undertaken to compare the two powertrain models and demonstrate the similarities in natural frequencies and mode shapes.

The impact of motor power on the degree of torque hole compensation is also investigated, keeping in mind the practical limits to motor specification. This investigation uses both the

output torque, vehicle speed as well as vibration dose value (VDV) to evaluate the quality of gearshifts at different motor sizes.

A credible conclusion is gained, through different simulation phases in the form of Software-in-the-loop (SIL), Rapid prototyping, and hardware-in-the-loop (HIL) to support the MHEV scenario in the development. The strategies proposed in this thesis are shown to not only achieve shifting performance, driving comfort and energy recovery rate during all conditions but also to significantly reduce cost in both the short and long terms.

Keywords — Automotive; Battery; BLDC; Constraint modeling; Driveability; Driving cycle; Dynamic programming; Dynamics; Emissions; Fuel economy; Gearshift strategy; Hardware-in-the-loop (HIL); Hybrid powertrain architectures; Life cycle assessment; Manual transmission; Mild Hybrid Electric Vehicle (MHEV); Model-Based Design; Operation cost; Optimal control; Passenger vehicles; Rapid Prototyping; Simulation; Torque-fill; Torque-hole; Whole-life costing;

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Acronyms and abbreviations

ACG	Auto code generation
ADC	Analog to digital converter
ADVISOR	Advanced vehicle simulator
AGO	Australian greenhouse office
AMT	Automated manual transmission
AT-PZEV	Advanced technology partial zero-emissions vehicle
AWD	All-Wheel Drive
B-DAQ	Bluetooth data acquisition
BLDC	Brushless dc electric motor
BSA	Belt starter alternator
BSG	Belt starter generator
CAFE	Corporate average fuel economy
CAGR	Compound annual growth rate
CAN	Control area network protocol
CO	Carbon monoxide
CO^2	Carbon dioxide
CSHVR	City-suburban heavy vehicle route
CV	Conventional vehicle
CVT	Continuously variable transmission
DAC	Digital to analog converter
DAI	Data acquisition interface
DCT	Dual-clutch transmissions
DOF	Degree-of-freedom
ECU	Engine control unit
EM	Electric machine
EMC	Energy management controller
EMF	Electromotive force
EMS	Energy management strategy
EPA	Environmental Protection Agency
EPS	Electric-propulsion system
ESC	Electronic speed control
EV	Electric vehicles
FEAD	Front-end accessory drive
FOC	Field Oriented Control
GHG	Greenhouse gas emissions
HC	Hydrocarbons
HEV	Hybrid electric vehicles
HIL	Hardware-in-the-loop
I/O	Digital inputs and outputs
ICE	Internal combustion engine
IM	Induction motor
ISG	Integrate Starter-Generator
Li-ion	Lithium-ion
MBD	Model-based design
MHEV	Mild hybrid electric vehicle
MT	Manual transmission
NEDC	New European drive cycle
NiMH	Nickel metal hydride
NOx	Oxides of nitrogen
NVH	Noise, vibration, and harshness
NYC	New York cycle
NYCDDS	New York city dynamometer drive schedule
OECD	Organization for economic co-operation and development

OEM	Original equipment manufacturer
PC	Personal computer
PID	Proportional–integral–derivative
PM	Permanent magnet motor
PMSM	Permanent magnet synchronous motor
PWM	Pulse width modulation
PZEV	Partial zero-emissions vehicle
RBM	Rigid body mode
RCO	Relative cost of ownership
RCP	Rapid control prototyping
RDC	Rural driving cycle
RPM/rpm	Revolutions per minute
RTI	The real-time interface
RTP	Real-time processor unit
SIL	Software-in-the-loop
SOC	The state of charge
SPF	Sale price factor
SRM	Switched reluctance motor
SULEV	Super ultra-low emissions vehicle
TCO	Total cost of ownership
TCU	Transmission control unit
UDDS	Dynamometer drive schedule
ULEV	Ultra-low emissions vehicle
VDV	Vibration dose value
ZEV	Zero-emissions vehicle