Tribological investigation of polymeric shift fork contact pad

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/ Department of Mathematics and Computer Science
/ PDEng Automotive Systems Design

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Design guidelines, performance validation and mechanism analysis of shift-fork pad wear in the gear actuation system of a dual-clutch transmission

Executive Summary

October 2019

Ayush Jain

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Eindhoven University of Technology
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Public Executive Summary

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The design that is described in this report has been carried out in accordance with the rules of the TU/e Code of Scientific Conduct.

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Abstract
This report presents a description of the investigations done to evaluate the tribological performance of shift-fork pad of a new hybrid dual-clutch transmission that is currently under development at Punch Powertrain. In the first part of the report, detailed problem analysis is done to understand the key objectives of the stakeholders. Following this, an improved system architecture for designing and testing of the shift-fork pad is described and tribological requirements are derived from the higher level requirements. Next, the test specifications and the testing process devised to validate the current shift-fork pad design are described and the results of the validation tests are presented. Finally, design guidelines are given and design tools are developed to enable a design engineer to meet the defined tribological design requirements.

Keywords
Shift-fork, dual-clutch transmission, tribology, thermal aging, automotive systems design, gear actuation system

Preface

This technical report is written as part of the graduation project, in pursuit of the Professional Doctorate in Engineering (PDEng) degree in Automotive Systems Design (ASD). The Professional Doctorate in Engineering program is a full-time, two-year technological designer program offered by one of the four universities of technology in the Netherlands. It falls within the 3rd cycle of higher education. This PDEng program in ASD is being pursued at Eindhoven University of Technology (TU/e). The graduation project is pursued in collaboration with Punch Powertrain Nederland B.V (PPE).

Punch Powertrain Nederland B.V. is an automotive company involved in the design and manufacturing of transmission systems. This graduation project was pursued in context of development of a new hybrid DCT (dual clutch transmission) at PPE and was focused on evaluating the tribological performance of shift-fork contact pads.

Ayush Jain
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Throughout the duration of the project, I was helped and supported by many people. I cannot image completing my project successfully without their support. Hereby, I would like to express my sincere gratitude to all these people who supported me in my journey of successful completion of the PDEng project. First of all, I want to thank Jacco and Jeroen for providing me this opportunity to pursue the PDEng project at Punch Powertrain. I owe special gratitude to my mentor, Xiao, and my team leader, Olcay, for their continuous support and valuable inputs throughout the duration of the project. They showed complete trust in me and my abilities which gave me the confidence to achieve great targets. I am really grateful to Joao who was always there with me to keep the test-rig up and running despite many difficulties that came on the way. I am thankful to all the colleagues at PPE and PPS who helped me and guided me in the project, especially, Pablo, Wim, Kees, Peter, Sava, Yongqing, Kyosuke, Thiago, Jan, Mark, Ruud, Toon, Rajesh, Pranav, Shiva, Sachin, Koray, Nikolaos, Imteyaz, Zhengyu, Pradeep, Rob, and many others.

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1. Executive Summary

This executive summary provides an overview of the activities and results achieved during the PDEng project.

1.1 Project Context

To keep pace with the growing demand for fuel-efficient vehicles and electric/hybrid vehicles, Punch Powertrain is developing new generation hybrid Dual Clutch Transmissions (DCT). One of the mechanical components of this hybrid DCT is a shift-fork. During the shifting of gears in a DCT, the shift-fork slides against the synchronizer sleeve at the contact pad locations. This contact between the shift-fork pad and the rotating synchronizer sleeve is tribologically critical due to the harsh sliding and lubrication conditions and also due to the high number of gear shift cycles during the lifetime of the vehicle. This shift-fork pad is the focus point of this project and main objectives of the project are:

- Framework/tools for designing of the shift-fork pad with wear within the specification;
- Evaluation of the tribological performance of the shift-fork pad.

1.2 Project approach and development cycle

For performing the problem analysis and to understand the requirements of the stakeholders, the CAFCR methodology is used. CAFCR (Customer-Application-Functional-Conceptual-Realization) is a system architecting method that helps to navigate from vague or ill-defined notions of problems towards a well-articulated and structured architecture description [1].

During the project, a new development V-cycle is proposed (Figure 1). In the proposed V-cycle, first, the part's tribological requirements are derived from the higher-level requirements, besides other structural and functional requirements. The part is then designed to fulfill these tribological requirements. After the design is completed, the design is validated on component-level and module-level tests before the complete system-level (transmission-level) tests. The component and module-level tests provide quick feedback about the design, hence reduces the countermeasure time in case a failure is detected during the validation tests.

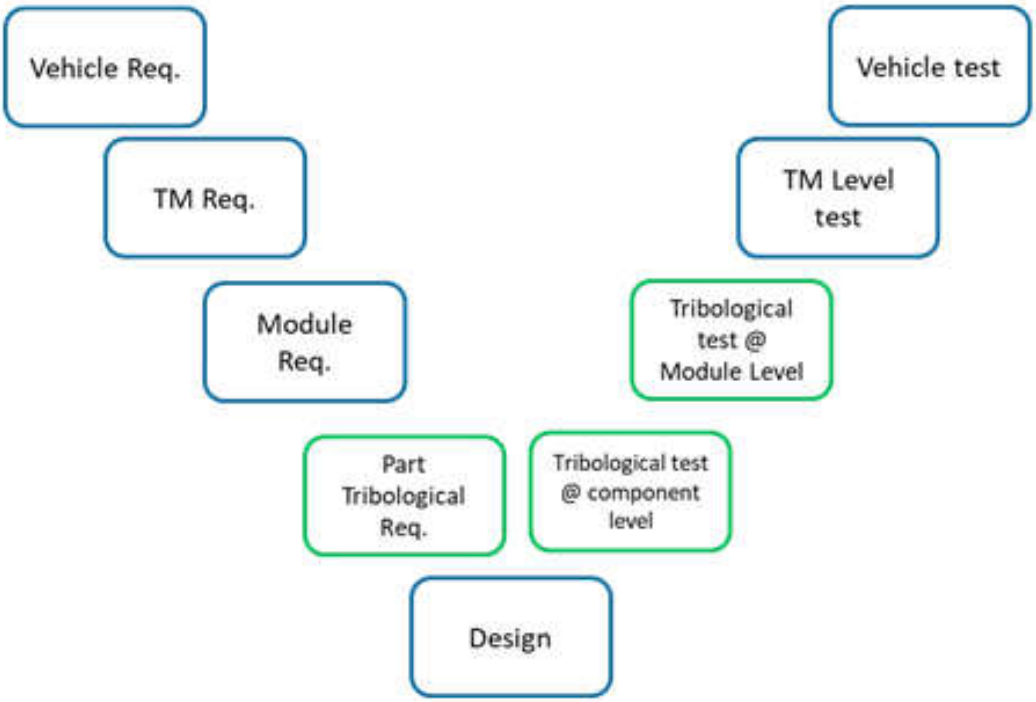

Figure 1: Proposed V-model

1.3 Design requirements and design tools

In this project, tribological design requirements for the shift-fork pad are defined. Design guidelines and design tools are developed to enable designing of the shift-fork pad against these tribological requirements. Mainly, three different design tools are developed to facilitate a robust and optimized shift-fork pad design.

The first design tool developed, calculates the steady-state and transient surface temperature rise of the shift-fork pad surface due to frictional heating, hence enables the designer to choose the correct pad material. The second design tool calculates the oil film thickness in the contact zone and facilitates to achieve the correct lubrication regime and avoid excessive wear. The third design tool theoretically evaluates the deterioration in the mechanical strength of the polymer part due to thermal aging.

1.4 Design validation tests and wear mechanism analysis

For validating the tribological performance of the shift-fork pad, tribological test requirements are defined and the test specifications are derived from them. The validation tests are carried out on the module-level and the total wear on the shift-fork pad surface is measured. This objective is achieved by devising a new test setup.

The measured wear on the tested shift-fork pads is found to be within the specified limit. For the tested parts, a detailed wear mechanism study is done using SEM-EDX analysis and optical interferometry

techniques. This understanding of the involved wear mechanism is critical in order to understand the failure mode and hence identify the critical operating parameters.

Finally, material characterization tests are done to understand the deterioration in the mechanical properties of the shift-fork pad due to the thermo-chemical aging. To accelerate the material aging i.e., to achieve material damage equivalent to the complete lifetime in a short duration, a technique is devised to calculate the accelerated aging parameters.

1.5 Conclusion

In this project, a detail investigation of the tribological behavior of the shift-fork contact pad is done. Tribological design and test requirements are defined for the part. Design guidelines and design tools are developed to enable a designer to develop a robust shift-fork pad design. Tribological validation tests are done at module-level to have a proof of concept of the design. Finally, a detailed wear mechanism analysis is done for the tested parts.

Glossary

ASD	Automotive Systems Design
CVT	Continuous Variable Transmission
CAFCR	Customer-Application-Functional-Conceptual-Realization
DCT	Dual Clutch Transmission
EDX	Energy Dispersive X-Ray Analysis
EV	Electric Vehicle
i.e.	exempli gratia (that is)
PD	Professional Development
PDEng	Professional Doctorate in Engineering
PPE	Punch Powertrain Eindhoven
SEM	Scanning Electron Microscopy
TEC	Thesis Evaluation Committee
TU/e	Eindhoven University of Technology

Bibliography

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About the Author

Ayush Jain was born in Kanpur, India on 15th July 1990. He completed his Bachelor of Technology degree in Mechanical Engineering from the Indian School of Mines (IIT-ISM), Dhanbad. After completing his bachelor's degree in 2012, he worked for Maruti Suzuki India Limited, India's largest passenger car OEM, as Transmission Design and Development Engineer.

In September 2015, he started pursuing Masters in Science degree in Tribology. After completing his master's studies, he joined the Eindhoven University of Technology to pursue Professional Doctorate in Engineering (PDEng) in Automotive System Design (ASD). In January 2019 he started his final project at Punch Powertrain Nederland B.V. as a PDEng Trainee.

Outside of work, Ayush enjoys hiking, playing chess and reading books on human psychology.