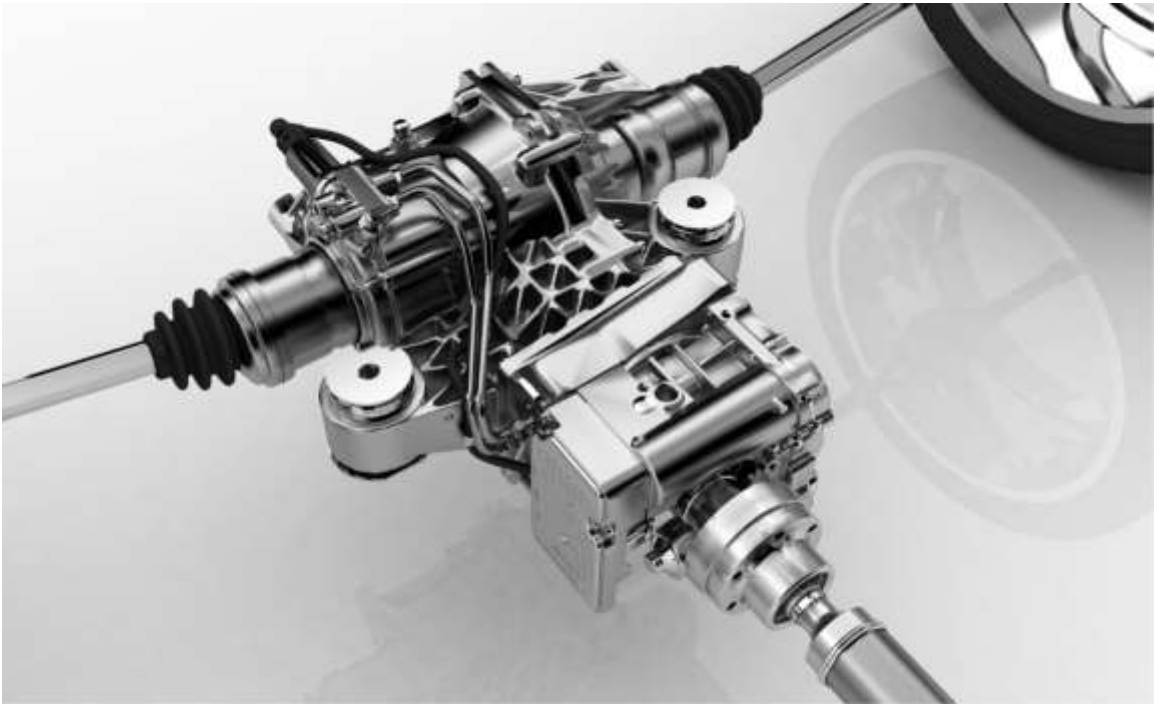


FFI

FORDONSSTRATEGISK
FORSKNING OCH INNOVATION

Ageing wet clutches



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Program: Fordonsutveckling

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FFI in short

FFI is a partnership between the Swedish government and automotive industry for joint funding of research, innovation and development concentrating on Climate & Environment and Safety. FFI has R&D activities worth approx. €100 million per year, of which half is governmental funding. The background to the investment is that development within road transportation and Swedish automotive industry has big impact for growth. FFI will contribute to the following main goals: Reducing the environmental impact of transport, reducing the number killed and injured in traffic and Strengthening international competitiveness. Currently there are five collaboration programs: Vehicle Development, Transport Efficiency, Vehicle and Traffic Safety, Energy & Environment and Sustainable Production Technology.

For more information: www.vinnova.se/ffi

Ageing wet clutches I & II

The project Ageing wet clutches has been carried out as a five-year project, 2009-01-01 to 2013-12-31. Funding for the project has been divided into two sub-projects, both granted and financed by VINNOVA/FFI, of which the first project, "Ageing wet clutches", was carried out in the first four years (2009-2012), and the second subproject, "Ageing wet clutches II", was carried out during 2013. The entire project has been carried out in cooperation between the same project partners, i.e. BorgWarner Transfer Systems (formerly Haldex Traction), Statoil Fuel & Retail (former Statoil Lubricants) and Luleå University of Technology.

The reason for this division into two subprojects was because it only was possible to seek funding from VINNOVA/FFI for a 4-year project when the project began. This reporting is based, therefore, on the whole the five-year project implementation because the research work carried out in the two subprojects have gone into each other and depend on each other, and are thus difficult to separate on ...

1. Executive summary

In the automotive industry, there is always a need for components to be smaller, lighter, more efficient, have a higher power density, cost less and have a longer life. Components should at the same time become "smarter" i.e. be able to adjust themselves to its operating conditions and provide information on the existence of any emergency service needs. This of course also applies for wet clutches that transmit torque through a friction interface to various parts of the vehicle's transmission. One area of application is in all wheel drive systems for cars, where a wet clutch is used to control the torque to the rear wheels. Friction behavior in the clutch is changing with time as the friction disc surfaces wear and lubricant's additives are consumed/transformed. Research conducted in this research project has aimed to investigate how a clutch system is aging, how the ageing can be delayed, corrected and/or predicted. The research has been carried out in cooperation between Borgwarner TorqTransfer Systems, Statoil fuel and retail and Luleå University of Technology.

Borg Warner manufactures wet clutches to four-wheel drive system and Statoil supplies lubricants to the vehicle industry. The goal of the research project was to understand how life is consumed and that, by extension, using this knowledge to predict the service life of the clutch. The work has been multidisciplinary, i.e., to have been able to pick up knowledge from different areas, such as:

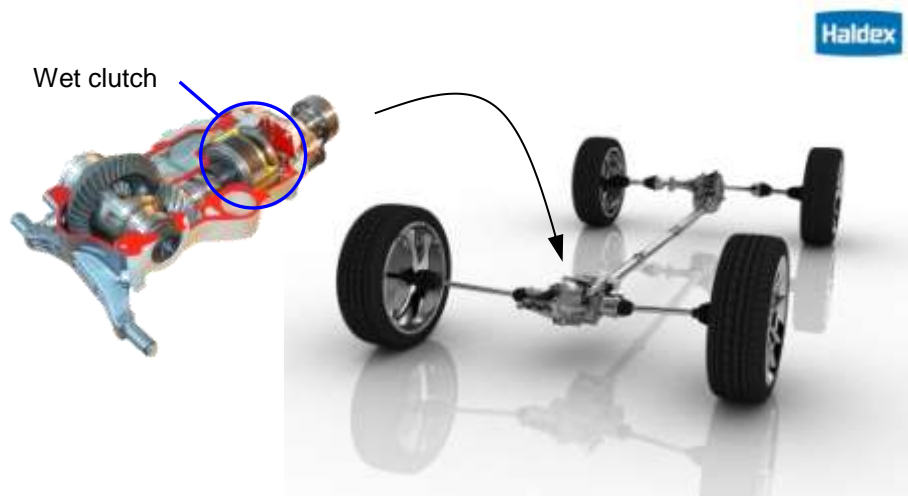
- Mechanical engineering, in order to understand the application
- Physics and mechanics of materials, in order to understand the interaction between the surfaces
- Chemistry to, for example, understand the interaction between oil and surfaces as well as for the ageing of the oil

- Material knowledge, to understand how the surfaces are influenced by the ageing
- Maintenance technology, for building models to predict the length of the clutch's service life
- Thermodynamics, for understanding heat transfer

When wet clutches age, the frictional behavior is changing, which can lead to failure of other mechanical components in the powertrain or vibrations and noises from the drivetrain. In this research project a test rig has been designed for aging of wet clutches. The test rig is equipped with different types of sensors to measure the system's state, for example, temperature, torque, force, pressure, oil parameters such as viscosity and density. Furthermore, also parameters which affect the ageing and/or are indicators of the ageing has been identified. With the help of an ageing model developed in this project can now compensate for the control electronics for changes in friction and thus avoid costly breakdowns or unwanted behavior of the drivetrain. The ageing model can also be used in the development process by modeling the dynamics of the car's powertrain for different ageing of the wet clutch. In this way you can predict what kinds of operating conditions which can lead to problems with vibrations and noise.

2. Background

In the automotive industry, there is always a need for components to be smaller, lighter, more efficient, have a higher power density, cost less and have a longer life. Components at the same time become "smarter", i.e. are able to adjust themselves to the surrounding operating conditions and provide information on the existence of any emergency service needs. This of course also applies for wet clutches often used in vehicles to transmit torque in transmissions. A wet clutch transmits torque through a friction interface between the friction discs which are mounted in the clutch. The Haldex Limited Slip Coupling, see Figure 1, which is a part of an all-wheel drive system to cars uses a wet clutch to control the torque to the rear wheels. This coupling is produced by BorgWarner TorqTransfer Systems (formerly Haldex Traction), Landskrona Sweden.



Figur 1: Haldex Limited Slip Coupling and driveline to passenger car.

The frictional behavior of the clutch is a complex function of many parameters, eg. friction material of the friction discs, friction disc surface structure and composition of the lubricant. In addition, the frictional behavior may change during operation depending on the temperature and other external factors such as vibration and pollution in the lubricant. Clutch friction behavior is also changing with time as the friction disc surfaces wear and the lubricant's additives are consumed/transformed. Previously, there was not enough understanding of how the coupling system was aging, which meant that time was wasted and costly service life tests was needed in the industry before the product could be used in the powertrain.

Knowledge about how the aging process, which are developed in this project, has yielded a number of new possibilities in the design process of a new wet clutch system:

- The system can be optimized so that the ageing of the system becomes as small as possible.
- The ability to compensate for the ageing of the system so that the function and driver's comfort is not affected.
- A detailed knowledge of how the aging process provides the ability to control the clutch so that the ageing can be minimized
- Systematic methods to examine how different lubricants and friction material age provides enhanced opportunities to use new materials and lubricants in the design of a new application.
- Knowledge of how the clutch age provides an opportunity to minimize the service life tests of new clutch systems in test rig and full scale test.

3. Objective

The project aimed to gain more knowledge about how the system's aging takes place, if it can be delayed, corrected and/or predicted. The knowledge that has developed in the project is very important when new clutch systems will be designed. The project sought to achieve new knowledge in an area which until now had not been examined in sufficient detail, namely the ageing of wet clutch systems. The objectives and research questions which formed the basis for the work that has been done is:

- To understand how and why the function of a wet clutch change over time.
- Defining life – i.e. specify how it is possible to determine the tribological service life and what that is determining when the life is completely consumed.
- To develop methods for measuring the residual service life – passive and/or active.
- To develop methods to actively extend the service life and clutch function.
- To develop an understanding of how three types of test relate to one another. That is, how can the model- or component test results be correlated into field test results?
- To develop methods for the study of wear in normal pace under normal operating conditions.

One purpose of the project was that the results would be directly applicable in the industry and that the results would lead to wet clutches being optimized in terms of performance, weight and size. Direct result of this is that it can minimize the negative effects on the environment by consuming less lubricant in the clutch at the same time as the reduction in weight will contribute to lower emissions compared to the existing structures, all this despite the obvious security advantage that a vehicle with all-wheel drive by "Haldex-type" in comparison with a standard 2WD drivetrain of a vehicle.

4. Project realization

The project was conducted in cooperation between Luleå University of Technology and the industrial partners BorgWarner TorqTransfer Systems and Statoil Fuel and Retail. Most of the work in the project has consisted of experimental activities, mainly in laboratory environment, but also in the full-scale vehicle test at Borg Warner. In a laboratory environment at Luleå University of technology has a number of different test rigs been used. Most of the tests were performed in the rig which was built within the project to simulate the actual application, i.e. the Haldex coupling, and enable ageing under well controlled ageing sequences, even based on measurements from the vehicle test. In addition to the work in this rig has other model test been used, a Pin-on-disc-test, as well aging test in an oven and rheology measurements in the viscometer. At Statoil fuel & retail was several different ageing tests performed, for example in a so-called Dry TOST (Turbine Oxidation Stability Test). Measurements of other lubricant parameters have also been implemented in Statoil's testing laboratory.

In order to ensure that the project has been implemented in a way that has led to meet the project objectives physical projects meetings have been conducted with all project partners with approximately 6 months intervals. This has given all the partners a good understanding of the work carried out and have given all partners the ability to influence the direction of the project for further work. These physical project meetings have been carried out on both at Luleå University of technology, BorgWarners and Statoil's premises, which has also led to a dissemination of knowledge between industry and University.

5. Results and deliverables

The project's main objective was to study the aging process of wet clutch systems. In order to achieve this objective, several aging methods of lubricants and friction behavior of investigated the aged lubricants have been tested. These include ageing tests carried out in test rigs at BorgWarner and in oxidation rigs at Statoil Lubricants, as well as test of aging simulated by new lubricants with lower additive content. A large part of the project was focused on how to make a wet clutch system age in the test rig without accelerate the test so much that other ageing mechanisms than those which arise in the application became prevalent. To get better control on ageing tests has a clutch rig built at Luleå University of Technology been used to age the clutch system. The test rig's properties have aimed to better mimic the working conditions in the real applications than what have been possible with earlier designs.

5.1 Delivery to FFI-goals

The project has contributed to the following FFI-targets associated with the program “Vehicle development” in the following ways:

- *How well the project fills the objectives defined in the transport, energy and environmental policy:*
The project aims, among other things, to reduce consumption of lubricants and reduce raw material consumption by increasing the service life of the investigated vehicle components.
- *Industry's ability to in a competitively way keep knowledge based production in Sweden.*
Partners of the project are besides Luleå University of two industrial companies in Sweden. To these companies continued to operate within Sweden and internationally required a constant development of their products which these projects have helped to achieve.
- *Contribute to a continued competitive automotive industry in Sweden*
The project has contributed to the development of the products of partner companies (lubricant and all-wheel-drive operating system) that is necessary if these products shall continue to keep a high level of competitiveness.
- *Lead to industrial technology and skills development through the work of the project*
The participating industry gained a better understanding of the technology behind their products. This up-skilling business is of utmost importance because they continue to manufacture competitive products.
- *Contributing to security of employment, growth and strengthening of R&D activities*
The professional development that has taken place in the companies will be of the utmost importance for to continue to keep the high standards required to continue to exist in the international competition in the automotive industry.
- *Contribute to concrete improvements of production*
The developed artificial ageing model that has been implemented in some of BorgWarner Transfer Systems customers' AWD system was considered to be one of the reasons why these companies chose BorgWarner as future supplier of the coupling in their AWD system.
- *Supporting research and innovation environments*
The university which participated in the project, Luleå University of technology, is one of Europe's most experienced research group working with wet clutches. A reason for this is the research projects that have been carried out with funds from the FFI (former PFF) in collaboration with Haldex Traction (Currently Borg Warner) and Statoil. These project has strengthen Luleå's leading position in research on wet clutches.
- *To ensure that new knowledge is developed and implemented, and that existing knowledge is implemented in industrial applications*
The ageing model developed within the project has, as mentioned earlier, already been implemented in some of Borg Warner Transfer Systems customers' AWD system and will therefore soon to be out in the market.

- *Strengthen cooperation between the automotive industry and universities*
This project has further strengthened the collaboration between the two industrial partners in the project and Luleå University of Technology. Discussions have already begun about starting up a future research project which will then become the fourth 5-year research project in order with the same industrial/university partners.

6. Dissemination and publications

6.1 Knowledge and results dissemination

Project results has partly been shared between different wet clutch-research projects at the university and have also been used in the education of future engineers in mechanical engineering, i.e. in the course "Advanced machine elements"

6.2 Publications

Berglund, K, 'Predicting wet clutch service life performance, Doktorsavhandling Luleå tekniska universitet, 2013

Berglund, K, Marklund, P, Larsson, R & Lundh, H 'Predicting driveline vibrations caused by ageing limited slip differentials', To be submitted for publication, Part of PhD thesis.

Berglund, K, Marklund, P, Larsson, R & Olsson, R , 'Predicting boundary friction of ageing limited slip differentials', Submitted for publication 2013-11-08, Journal of Engineering Tribology, Part of PhD thesis.

Berglund, K, Marklund, P, Larsson, R & Olsson, R 'Evaluating lifetime performance of limited slip differentials', Lubrication Science, 2013, Article in press. Part of PhD thesis.

Berglund, K 'Sustainable performance of wet clutch systems' Licentiatavhandling Luleå tekniska universitet, 2010

Berglund, K, Marklund, P & Larsson, R 2010, 'Lubricant ageing effects on the friction characteristics of wet clutches', Institution of Mechanical Engineers. Proceedings. Part J: Journal of Engineering Tribology, vol 224, nr 7, s. 639-647. Part of PhD thesis.

Berglund, K, Marklund, P, Larsson, R, Pach, M & Olsson, R 2010, 'Wet clutch degradation monitored by lubricant analysis', S A E Technical Papers, nr 2010-01-2232. Part of PhD thesis.



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Marklund, P. 2010 'Permeability measurements of sintered and paper based friction materials for wet clutches and brakes.' S A E Technical Papers no: 2010-01-2229. 8 s.

7. Conclusions and future research

The project has led to a great increase in understanding of how wet clutch system age in real applications. Work of the project has consisted partly of measurements in laboratory as well as in vehicle tests and modeling work, which means that it is now possible to simulate the ageing of a wet clutch system for a proposed driving cycle. The results have been so good that the aging model already has been implemented in parts of BorgWarner Transfer Systems customers' AWD systems.

This project is the third 5-year-old major research project (this third project is divided into aged wet clutches I and II) of the arrangement of cooperation between Luleå University of Technology, BorgWarner (former Haldex Traction) and Statoil. The research within the research area wet clutches is an important field for Luleå University of Technology (LTU) which continuously have several projects in this research field running in collaboration with various vehicle companies in Sweden. LTU plans to continue to work in this research area and will start discussions with the partner companies in this project to launch a fourth large research project within the research area of wet clutches.

8. Participating parties and contact persons

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