Smooth running

As researchers continue to seek ways to improve energy efficiency, Professor Andreas Almqvist has undertaken a study to investigate how energy loss can be reduced by predicting tribological performance.

Firstly, what is the overall aim of your research?

The aim is to develop sophisticated mathematical models and methods that help improve our understanding about mechanisms connected with the lubrication process of various tribological applications: bearings, gears, cam-mechanisms, etc. The vision is to deliver computational tools that enable the prediction of tribological performance, in terms of friction and film formation, which helps improve energy efficiency and reduce environmental impact.

Could you provide an insight into what inspired you to pursue this line of study?

By following individual surface asperities passing through the lubricated conjunction in a rolling element bearing, we found some fascinating events contributing to film breakdown and extreme stresses which are factors intimately coupled to the life of the components. This was the spark that ignited my interest in Tribology, especially the lubrication process. Making possible investigations of the effect of surface microstructure on film formation and friction in tribological contacts has been what I’ve devoted most of my time to during my graduate studies and thereafter.

Does energy loss through high levels of friction represent a significant issue? Would a reduction in energy loss provide substantial environmental and economic benefits?

In machines, wherever contacting surfaces move relative to each other, friction is a determining factor for energy loss. For example, in an internal combustion engine, reducing friction in the lubricated contact between the piston ring and the cylinder liner by 10 per cent can reduce energy loss by 0.25 per cent. This may sound like a small figure, but it will save millions of litres of fuel per year, counting passenger cars only, in a country with a small population like Sweden. In turn, millions of litres of unburned fuel saves the environment from unnecessary CO₂ and NOx emissions.

Can you describe the mathematical theories and the numerical methods that you are employing to gain a better understanding of tribological performance?

The surface microstructure, or more precisely, the surface roughness, is one of the features with the greatest influence on tribological performance. Due to its rapidly oscillating nature, the surface roughness requires special consideration while developing the mathematical model and numerical methods. The solution is either to build a mathematical model that considers the effects induced by the roughness, or construct a numerical solution technique that has built-in acceleration to address the problem. In some cases, a combination of these may be the only feasible alternative. Together with Professor Peter Wall at Luleå University of Technology, whose special interest is in homogenisation, we have been able to shape and create novel applied mathematics tailored to suit the abovementioned requirements. The theorems have then been utilised to derive equations governing the tribological performance in lubricated devices such as hydrodynamic bearings and cylinder liner-piston ring contacts.

Could you describe the types of tools that you wish to develop to enable the prediction of tribological performance? What applications might these tools bear?

Over the course of the research we have created a very versatile theoretical foundation from which we can draw conclusions directly and which could possibly be used in the analysis of related problems. The development of the models and methods is advanced work, requiring very specific knowledge and experience. The models and methods can be used by specialists and graduate students to gain fundamental understanding about mechanisms connected to tribological performance. Unfortunately, this means that during the development phase of the computational tools, they cannot be easily used directly by the engineer. We aim to make this possible. Operated by a specialist, the advanced models and methods can be used for extensive parameters studies. From these parameter studies, useful easy-to-use formulae that estimate the tribological performance of various applications can then be obtained.

How soon do you expect these mathematical models to be made available?

Before easy-to-use tools that incorporate the effects we’re focusing on become available, there is still quite a lot to do. On the other hand, during the course of development of these tools, more advanced models and methods become available to the specialists who can utilise them to help problems within industry. This is in fact a very successful way of working, since the industrial needs can be considered directly and new ideas can be implemented as the research progresses.
Fact and friction

Since the term ‘tribology’ was coined 40 years ago, the area of research it covers has become a very important focus for long-term development.

THE EARLY 1960s saw a steep increase in the reported failures of plant machinery due to wear, some causing heavy financial losses. This trend was recognised by specialists involved in the subjects of friction, wear and lubrication, and numerous papers on various facets of these subjects were presented until, in October 1964, a conference on iron and steelworks lubrication revealed the magnitude of the problem and its occurrence on an international scale.

In December of the same year, a working group was formed to “investigate on an informal basis the current state of lubrication education and research, and to give an opinion on the needs of industry in respect thereof”. From this meeting came the Jost Report which concluded that in a typical industrialised country, approximately 10 per cent of GDP is spent on overcoming friction and wear, and the widespread use of optimum lubricants alone could lead to savings of 1 per cent of GDP. The report also recognised such savings help improve energy efficiency, and any energy efficiency savings result in lower CO₂ emissions.

To address this issue today, Professor Andreas Almqvist, a researcher at the division of Machine Elements at Luleå University of Technology, Sweden, with expertise in computational tribology, has recently completed the first year of a postdoctoral commission looking at methods of predicting tribological performance with a view to reducing energy loss.

OBJECTIVES

Defined as ‘the science and technology of interacting surfaces in relative motion’, tribology encompasses the study of friction, wear and lubrication. The mode of lubrication, or lubrication regime, particularly influences performance, i.e. efficiency, film formation, friction and wear, environmental impact and other measurable quantities of special importance for the application. While the Strieber curve has been frequently used to distinguish between the different hydrodynamic lubrication regimes (i.e. full film, mixed and boundary), it is not a universal tool; and, as the demand for attaining high levels of performance while demonstrating concern for environmental issues is becoming tougher to meet, the need for fundamental understanding of tribological mechanisms is greater than ever. The main task in the study is therefore to perform research with focus on the lubrication process and how lubricant composition and surface roughness affect film formation and friction.

Another important objective within the project is to preserve as much generality of the models and methods as possible, to cover a broad spectrum of applications. This will increase both versatility and the likelihood for applying the models and methods in other fields of research. This will be realised through the application of rigorous mathematical techniques to the equations that govern the lubrication process, thus enabling efficient treatment of the surface topography, the rheology of the involved fluid, and the material characteristics. Almqvist explains: “This directs us in the development of the theoretical foundation and the more advanced models and it also facilitates the creation of useful engineering tools”. He adds: “Helping training graduate students in connected areas by acting as co-supervisors for each other’s students is also a means of providing a high level of generality”.

In parallel to the more fundamental type of research, the project also runs applied projects to encourage a high degree of interaction with industry.

IMPORTANCE OF COLLABORATION

In order to gain fundamental understanding of the complex tribological processes taking place in, for example, the interfaces inside machine elements, between a tyre and a wet road, or even inside human joints, it is vital to develop and utilise advanced theoretical modelling and analysis. As a consequence, tribology is an interdisciplinary field encompassing sciences such as fluid mechanics, structural mechanics, thermodynamics and chemistry. This means predicting tribological performance involves highly complex theoretical models, which in general are described by non-linear, integro-differential systems of equations that require sophisticated mathematical techniques to be solved. Tackling such problems calls for state-of-the-art knowledge in all the connected fields. Almqvist’s project is therefore highly dependent on useful connections and cooperation with other researchers within the relevant areas. Moreover, unique laboratory resources are also provided through the consortium. The required mathematical foundation has only been developed very recently and is still considered to be a work in progress, but Almqvist nevertheless recognises the success of the chosen interdisciplinary structure: “We have
In order to gain fundamental understanding of the complex tribological processes taking place, it is vital to develop and utilise advanced theoretical modelling and analysis. This involves understanding the effects induced by surface roughness. Moreover, the results produced will be of a rigorous mathematical nature that will form a solid basis for future research and development.

**FIGURE 1 (a & b).** Two ‘in-situ snapshots’ of a deformed surface and the pressure distribution causing the deformation.

**ACHIEVEMENTS**

The project has produced a number of promising results. Theoretical work based on the hypothesis that the lubricant has the ability to form layers suggests there is a possibility to minimise friction between the piston ring and cylinder liner, providing a lubricant with this assumed ability to form layers could be attained in practice. Due to the composition of the research group and interacting business partners, the team has been able to use the computational tools they have today, directly in the development process of a number of tribological devices. For example, it has been possible to reduce the power loss in a hydraulic motor by up to 80 per cent. The same tools have been used towards the development of a retarder to assist braking trucks and construction equipment. The inclusion of specialists in mathematics has also increased the project achievements as the researchers have proved that it is possible to gain fundamental understanding and facilitate results by introducing modern applied mathematics in hydrodynamic lubrication.

**FUTURE INFLUENCE**

Research and advances in tribology enable progress in the development of most machinery, including wind power plants, high-speed trains, aircraft, space stations, computer hard drives and even hip and knee implants. The current aim is to be able to address the multi-physics couplings linking material composition, structural mechanics, fluid dynamics, rheology and chemistry better than we do today. One problem to overcome here is how to best model the highly non-linear integro-differential problems, which arise due to these couplings. Another goal is to develop or adapt feasible numerical solution methods. Almqvist believes that the project will build further on previous work: "It will enable simulation of tribological applications where the effects of realistic surface topographies, lubricant properties, etc. are being considered". The results may be used directly in the design process, or as a basis to increase the fundamental understanding of the effects induced by surface roughness. Moreover, the results produced will be of a rigorous mathematical nature that will form a solid basis for future research and development.

**INTELLIGENCE**

**REDUCING ENERGY LOSS THROUGH PREDICTING TRIBOLOGICAL PERFORMANCE**

**OBJECTIVES**

This project aims at developing sophisticated mathematical models and methods that may be used to facilitate fundamental understanding about mechanisms connected to the lubrication process of various applications such as bearings, gears, cam-mechanisms, etc. The vision is to deliver computational tools that enable prediction of tribological performance, in terms of friction and film formation, which also improve energy efficiency and decrease the environmental impact.

**PARTNERS**

Hägglunds Drives · Scania · Volvo CE · Haldex
Traction · Statoil Lubricants · SKF · SAAB
Powertrain · Shell Global Solutions, UK

**KEY COLLABORATORS**

Professor Erik Höglund, Division of Machine Elements; Professor Roland Larsson, Division of Machine Elements; Professor Lars-Erik Persson, Professor, Department of Mathematics; Professor Peter Wall, Department of Mathematics, Luleå University of Technology, Sweden

Dr Robert Ian Taylor, Shell Global Solutions, UK

Dr Bo Persson, IFF, Forschungszentrum Jülich, Germany

**CONTACT**

Professor Andreas Almqvist
Project Coordinator
Department of Engineering Sciences and Mathematics
Luleå University of Technology
University campus, Porsön
Sweden

T +46 (0)920 492407
E andreas.almqvist@ltu.se
http://vrproj.vr.se/detail.asp?arendeid=61722

**PROFESSOR ANDREAS ALMQVIST** completed his PhD in Machine Elements at Luleå University of Technology in 2006. He received a Marie Curie Fellowship and pursued postdoctoral studies in the field of lubrication between 2007-09, and was awarded the SAGE Best Paper Award 2010 for a paper published in Proceedings of the Institution of Mechanical Engineers. Part J: Journal of Engineering Tribology.