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EXPERIENCES OF STUDYING GEAR TRIBOLOGY IN A FZG TEST SET-UP

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ABSTRACT:

The main objective of this study is to review the last decade of experimental work in the field of gear pitting life and efficiency of an FZG gear test rig. Located at KTH Machine Design, the FZG rig has led to critical findings with an impact on gear transmissions, such as high efficiency and long fatigue life. The different FZG test set-ups, the sampling methods and the results (and their limitations) are discussed, and measures are proposed to reduce the limitations. The findings of this study are used as input to an impact case on how research at a university can provide the major transport industry in Sweden with the knowledge and the methods to evaluate gear performance.

Keywords: FZG; Gear rig; Efficiency; Pitting life; Impact.

INTRODUCTION

Modern society is critically dependent on transport and there is a constant endeavour to reduce frictional losses along the powerline, in turn potentially reducing costs significantly [1]. Sweden has a strong automotive industry, in particular in the heavy vehicles area; it has been estimated that about 10% of all transmissions for such vehicles in the world are manufactured in Sweden, with contributors such as Volvo Trucks, Volvo Construction Equipment, Scania CV, GKN, Volvo Cars, Leax and, Swepart. Furthermore, in the automation sector, a company like ABB successfully manufactures many transmission parts.

There have been several national research initiatives linked to gear manufacturing and gear design over the last three decades. One of the largest, KUGG, was started in 2005 with five PhD students from two universities, and almost a dozen companies. This was later re-named FFI Sustainable Gear Transmission Realization.

When the FZG gear test rig, funded by Vinnova, arrived at KTH in 2011 more research activities were initiated. In 2014 the research network Transmission Cluster (in Swedish: Energieffektiva transmissioner) was started. Seven PhD students (at Chalmers and KTH) were and are still linked to this project. Generally the projects cover: distribution of lubricant in gearboxes and the effect of running-in; surface stress in gears; gear shifting and synchronisation strategies; research on powder metallurgy gears; and the dynamic behaviour of gearboxes. Additionally, in 2016 funding was received from SSF for a project named Nanotechnology Enhanced Sintered Steel Processing targetting application gears, which also makes use of the FZG rig. This project involves 5 PhD students from Chalmers, Uppsala University, Lund University, and KTH.

MATERIALS AND METHODS

The FZG back-to-back gear test rig is situated at KTH Machine Design department. Most of the testing is performed with a pitting test setup, Figure 1. The pitting test was originally designed to determine the pitting load capacity of gear transmission lubricants but we use the FZG gear test rig to study gear wear and efficiency.

To load the test gear placed in the test gearbox (1), dead-weights are hung on the load clutch (2). The slave gearbox and test gearbox are connected to a loop by shafts that enable power to circulate between them. The power needed to drive the loop is equal to the energy losses that occur in the loop due to friction. A torque and speed sensor (4) is connected to the slave gearbox. An electrical motor is used to apply the loss power of both gear boxes (5).

Another FZG test set-up is to measure efficiency. Then the gearboxes (1) and (4) are identical, and a total of 4 test gears are needed (pitting tests has one test gearbox, the slave consists of a helical gear pair which seldom wears out). The power needed to drive the loop is equal to the energy losses that occur in the loop due to friction in the gears, bearings, seals and churning of the lubricant. Testing requires a number of steps including disassembly and assembly. A thorough investigation on the effect of assembly errors was done to highlight the importance of the handling of the rig [2].

Gear materials tested so far at KTH are standard gear steel, isotropic steel and powder metallurgic steel.

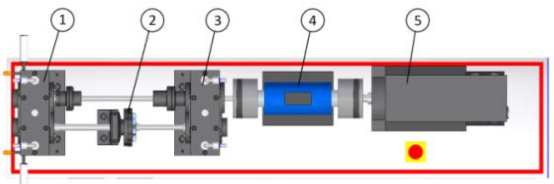
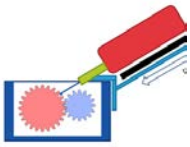
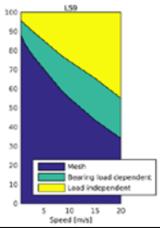


Figure 1. Schematic of the FZG back-to-back gear test rig with the main part marked. 1-test gearbox, 2- load clutch, 3- slave gearbox, 4- torque and speed sensor, 5- motor.

RESULTS AND DISCUSSION

Since the FZG rig was installed in 2011, several methods and models have been developed/implemented (Table 1) to study wear and develop accurate efficiency measurements.

Table 1. Developed/implemented methods and models to the FZG rig.

Method	Illustration	Read more
Gear wheel temperature		[3]
Spray lubrication (inlet and outlet)		[3]
In situ surface measurements		[4]
Bearing losses model		[5]

For gears spray lubricated at the mesh inlet, tested at a maximum contact pressure of 0.96 GPa and at a pitch velocity of 20 m/s, the gear mesh efficiency can be significantly increased and hence gear wheel temperature reduced by running superfinished gears rather than ground gears by up to 0.2 % and 4 °C respectively.

Initial wear can be measured in situ with a profilometer since form, waviness and roughness can be extracted. This is a minimal system change and is not considered to affect the measurement. Evaluated ground and honed gears show a change in surface topography and efficiency depending on the running-in load. Their largest topography and efficiency/frictional changes occur in the first cycles. Tested superfinished gears show no measurable change in surface topography or in efficiency when changing running-in load.

Figure 2 (based on data from [6]) shows how superfinished gears provide significantly lower torque losses at high speeds compared to ground and shoot peened gears.

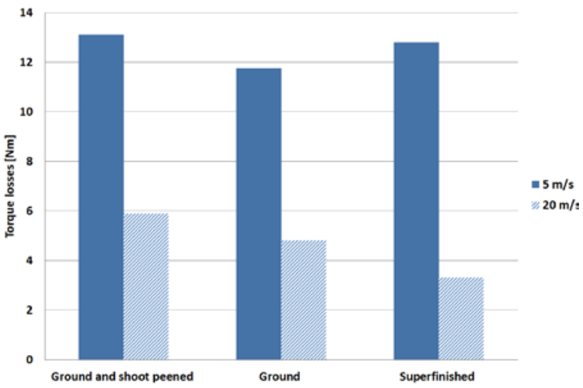


Figure 2. Influence on gear finishing and speed on torque losses.

When modeling the total gearbox losses, the contribution from each component and how they interact has to be investigated and modeled, as well as load-independent and load-dependent losses. One important finding was that changing the bearing model has a larger effect than changing the running-in method or a change of surface topography.

Looking forward

We look forward to many new applications and future projects using the FZG rig. In the near future we plan to add online particle counting of the gear oil to indicate when pitting or severe wear occurs. This will also improve test efficiency, i.e. the time it takes to finish a pitting life test. At the time of writing, a model to predict form changes during the running-in is being developed. In-situ form measurements techniques are also developed to provide input to pitting life estimation models.

The implementation of temperature models are of great importance. For example, in what way does asperity flash temperature affect wear? Such models will further help to explain the effects that we have been able to measure so far.

CONCLUSIONS

- Four doctoral and two licentiate theses have made use of the FZG rig measurements as input to be able to answer industrial relevant research questions. All have adequate work in industry today.
- The FZG rig has been (and remains) a great infrastructure investment. It was motivated by research performed before its arrival, which is one reason behind the fast research implementation.

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