ABSTRACTS

GEARS 2020 Abstracts.

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Helical gear efficiency testing of form ground and surface engineered gears

Authors: Jishan Zhang, Brian Shaw (Design Unit Newcastle University)

Summary:

Reducing mesh friction losses in gear is important to improve efficiency, minimise cooling requirements and reduce scuffing risk (and thus the need to environmentally unfriendly additive packages). Using a mechanical power recirculation 160mmm centres gear test rig at Design Unit of Newcastle University, gear efficiency tests have been conducted to:

1. evaluate the efficiency of a pair of external helical, case hardened, 6mm module cylindrical gears which are spray lubricated.
2. quantify the benefit from applying surface engineering techniques, including superfinishing and Tungsten carbide/carbon coating has on mesh friction efficiency

The presentation will describe the test rig, instrumentation used and the results from some of the tests. The presentation will also discuss how the choice of lubricant, gear module, tip relief and crowning strategy effects the overall efficiency of a gearing system.

Optimising efficiency of Gear Manufacture Using design of experiments (DOE/DOX)

Author: Denis Sexton (DGS)

Summary:

Introduction to DOE Fundamentals:

- Consideration of the experimental requirements:
    - Timing and sizing considerations for experimental gear trials
    - Understanding independent (predicator) and dependant (response) variables.
    - Numbers and levels of factors, runs and treatments
    - Fractional designs, screening, nesting and the optimal design matrix
    - Confounding, interaction, and post hoc considerations.

Planning considerations for an Experimental Trial:

- Determination of the required resources (typical examples):
    - Review historical data from production via Pareto Analysis
    - Brainstorming Activities to identify any likely key variables
    - Machine tool availability, time available and tooling selection
    - Availability of people, raw materials and consumables
    - Review and Validation of the measurement system (MSA for the CMM)
    - Replication, repetition, statistical stability and process capability.

Carrying out the experiment:

- Considerations during trials:
    - Ensuring that that the input parameters are recorded and monitored.
    - Numbering the blank parts and ensuring the order of manufacture
    - Observing the manufacturing process and recording anything unusual
    - Plotting the measurement results on a control chart in time series order

Review of Results, further Steps and recommendations:

- Understanding the Cause and Effect Relationship between variables:
    - Review of the data in time series (via control chart) for special cause within groups
    - Carry out numerical and statistical analysis of data via ANOVA
    - Identifying those input factors and interactions which have the most influence on the output characteristics under study, looking for trends such as comparing process capability with cycle time.
    - Planning any additional trials to confirm results (post hoc analysis).
    - Implement changes from experiment into production for process optimisation.

Fault Detection in a Fleet of Trains by Identifying Outlier Gearboxes using Smart Oil Plug.

Authors: N. Craig, S. Ellwood, S. Lowry, T. Rosinski, J. Rosinski and M. Nixon (Transmission Dynamics)

Summary:

The operation of modern railway infrastructure is dependent on reliable condition monitoring and maintenance. Advances in the Internet of Things (IoT) technology has made remote condition monitoring of a fleet of trains possible, partially due to the innovative development of sensor technology. One such example of this innovative sensor technology is the Smart Oil Plug (SOP), capable of remote monitoring of the final drive gearbox whilst in-service. Several sensors, incorporated into the design, are capable of measuring the temperature, oil debris and 3-axis acceleration of the gearbox. On-board software allows for the post-processing of the gearbox signals in real-time, using a range of data and frequency analysis techniques.

These SOPs have been deployed in a number of trains, all of the same class, and have been acquiring data over a period of several months. One of several approaches, currently being used to detect faults for this dataset, is the detection of outlier gearboxes by the comparison of well-known indicators of health. This approach takes advantage of the accumulated fleet worth of data, using fleet averages as a baseline to detect faults. Several cases are presented in which outlier gearboxes have been detected, for these cases further analysis provided insight into the possible causes.

Holistic evaluation of involute gears.

Authors: Martin Stein, Anita Przyklenk, (PTB- Physikalisch-Technische Bundesanstalt)

Summary:

The quality inspection of involute gears is still a vital step within contemporary manufacturing processes. High demands on the performance of gearboxes define the requirements that are placed on the applied measurement techniques. Current challenges in manufacturing metrology as derived from trends in production technology can be summarised in five keywords: fast, accurate, reliable, flexible and holistic.

Modern coordinate metrology systems can gather holistic information about the dimensions and surface of complex-shaped workpieces with high point density in short time scales and on a decent accuracy level. However, standardised evaluation procedures still refer to single lines representing the gear geometry in the most relevant 2D-sections. This has been state of the art for many decades and may be sufficient for quality control as long as the production method follows the kinematic principle of mating gears and manufacturing tolerances aren't too tight. However, holistic evaluation procedures considering the complete gear surface in one common model have several advantages. Besides obvious benefits, that deviations along the whole flanks can be determined and geometrical fitting parameters are more stable and sounder, holistic treatment allows to find correlations between different gear measurands and to properly understand possible manufacturing errors. Moreover, modern production methods that do not follow the generative principle like five-axis milling need holistic gear inspection for reliable quality assurance.

This contribution proposes a novel 3D evaluation strategy for cylindrical involute gears that builds on a recently developed algorithm used for holistic thread metrology at Physikalisch-Technische Bundeanstalt (PTB) in Germany. We will introduce the topic with a historical overview of previous works (Lotze, Sourlier, Pfeifer, Goch) and work out the main aspects considered in our own approach. The focus will be on describing the benefit of holistic evaluation against the established method and on "cleaning up" the prejudices on the meaningfulness of best-fit geometries. We will hence point out the "correspondence principle" between areal and line-based strategies by showing that the latter is just a special case of the 3D method. Eventually, we will give an outlook on how we plan to continue the work in a joint research project together with University of Newcastle and other partners into the direction of harmonic content analysis.

Power skiving - a step changing manufacturing process applicable to multifunctional 5-axis machine tools.

Authors: Bethany Cousins, Chao Sun, Ben Cook. AMRC (Advanced Manufacturing Research Centre - University of Sheffield)

Summary:

AMRC are specialising in developing gear machining methods using multifunctional 5-axis machine tools. One machining method applicable to multifunctional machine tools is power skiving. This modern gear cutting process is gradually being adopted by industry but its application is considered a secretive black art. AMRC's focus is to develop and quantify the capabilities and publicise this for the benefit of industry. The outstanding capability of power skiving has previously been showcased by AMRC on Newcastle Design Unit's 'Pulsator' geometry: a spur gear of 120 mm diameter and module 4, which has had teeth roughed and finished in 6 minutes 20 seconds achieving a quality of ISO1328 class 5 (AGMA 2000-A88 class Q12).

Further test geometries have been since been trialled, including helical gears and internal splines to ascertain how the process performance transfers to alternate geometries and what are the key process variables affecting productivity and gear quality. Software models have been developed to predict cutting forces and establish cutting parameters for new geometries in order to expedite the process development. A range of cutting parameter strategies have been employed to establish an optimal approach for enhanced quality and reduced vibration. Cutting tool life has also been established for a range of geometries and parameter sets with a view to quantifying the commercial viability of the process.

Power skiving offers great opportunities for production with step-changing productivity, particularly for internal gears, whilst offering high quality finishing capabilities and being applicable on a 5-axis machine tool with its inherent flexibility and multi-functionality.

GMaRC - Industrialists’ Roadmap Update.

Authors: Ben Cook, Michael Farmery. AMRC (Advanced Manufacturing Research Centre - University of Sheffield).

Summary:

As electrification and lightweighting are introduces to numerous industries, the architecture and specification of transmissions will change. With this change, what are the opportunities for the UK to be at the forefront of manufacturing technology for novel transmissions?”

This was the opening gambit for our TAD roadmapping event in February. The world has changed markedly since then, but the opportunities for the UK remain and are ever increasingly important to realise and exploit.

We will revisit the themes discussed in this session, including lightweighting, electrification, smart manufacture, transmission efficiency and remanufacture, and disseminate the ideas generated and the resulting roadmap. This will lead us toward considering the potential opportunities for research to advance the UK’s competitiveness in the new world we face.

Filtering effects on measured gear profile and helix errors.

Authors: Tom Reavie, Rob Frazer (Design Unit Newcastle University)

Summary:

The trend towards greater gear power density and lower noise requires more stringent tolerances and better measurement strategies to ensure the gears are fit for purpose. It is common that helix, profile and pitch deviation are measured and evaluated using the ISO 1328-1:2013 'Cylindrical gears — ISO system of flank tolerance classification Part 1: Definitions and allowable values of deviations relevant to flanks of gear teeth'.

The 2013 version of this ISO standard specified, for the first time in a gear tolerance standard, a mandatory Gaussian type filter. Older gear tolerance standards did not specify a filter, but instead relied on gear measuring machine manufacturers to define their own filters. These were usually selected to remove 'noise' from the measurement result, some of which would be generated from the measuring machine itself.

Filtering is an important part of the metrology process, but it is equally important that designers, manufacturers and inspectors understand the characteristics of the filter so they can properly interpret the results.

As the functional performance requirements of gears increase it is required that we understand more about the gear flank surface. While most of us are using the ISO 1328-1:2013 tolerances only, some are using the measured gear surface data in CAD packages to predict the performance of gears in terms of stress, friction losses and transmission error. This approach is needed in Industry 4.0 manufacturing environments where Geometrical Product Specification (GPS) compliant functional measurement strategies are part of the process is to create 'digital twins' a virtual model of a physical workpiece.

The presentation will provide examples that show the effects of the filter for evaluation of the ISO 1328-1:2013 profile and helix evaluation parameters but will also quality the potential errors they cause to data near the ends of facewidth or the tips of teeth. This may be important for CAD package modelling. Methods of minimising these effects will be illustrated with the application of the ISO 16610 'end effect filter methods' in some examples.

Modelling Gear Production by Skiving.

Authors: M Fish (Dontyne Systems), K Uriu (Kashifuji Works)

Summary:

The move to electric vehicles has required, and will continue to require, substantial changes in production within the automotive industry and many new approaches will be required. Some will present opportunities for new technologies and some will require significant improvements on current processes.

Power skiving of internal gears has emerged as a solution for providing internals in sufficient numbers required for the planetary systems preferred in EV gearboxes. Though the process is well established, it has not been driven to such speed and accuracy needed for high volume automotive production. It has been necessary to look in more detail at the process.

Dontyne Systems produces software for the design and analysis of geared systems as a program called The Gear Production Suite. A specialty of the software is to link design data to production equipment to design tools, simulate machining, and inspect the gear components. Following the successful introduction to the market of software to model many other gear production methods, Dontyne has now developed a skiving model. The model allows calculation of the gear profile resulting from a given tool and nominal alignments of a suitable machine. The presentation will show that default design and settings in the process will result in an asymmetric gear profiles with errors significant enough to cause NVH problems.

The new software can be used to change tool profile and machine settings to control these effects prior to manufacture. Experimental data has been used to validate the calculations. The presentation will consider tool design and the consequence of tool sharpening, variations for pre-finishing or finishing, as well as production on either dedicated skiving machines or multi-axis platforms. The presentation will also highlight points that will have to be addressed using R&D programs for more productivity using this process in future production.

Why we need to measure gears differently- an introduction to the Met4Wind project

Authors: Rob Frazer (Design Unit Newcastle University) and Martin Stein (PTB)

Summary:

Traditional gear measurement methods usually involve measuring profile, helix and pitch deviations and then comparing the results to tolerances which are specified on the gear drawings or in accordance with tolerance standards such as DIN 3962, ISO 1328 or AGMA 2015. Over the years measuring machines have become more accurate, and we specify design deviations such as tip relief and helix crowning to improve performance, but in principle the strategy of simply comparing measurement results to an allowable deviation, remained the same.

However, some things are changing:

- digitisation of manufacturing is becoming more widespread with Industry 4.0 type developments.
- alternative measurement strategies embodied in standards such as the Geometrical Product Specification (GPS) series, potentially better linking geometry specifications to functional performance related characteristics such as stress, scuffing risk and noise is being considered.
- predicting the performance of gears using the actual measured gear pair geometry and the use of 'digital twins' to provide better life prediction and maintenance strategies, are becoming practical.

This presentation will discuss the background and potential benefits from these developments. Specific reference is made to a new EURAMET EU project, for wind turbine transmissions (Met4Wind). This will focus on the gear-specific work in this wide-ranging project and include:

- the application of precision optical measurement sensors to gear measurement. What are the potential benefits from the additional data they provide?
- an investigation into the capability of using portable optical scanning measurement systems for evaluating gear damage and wear. This may be important for predicting life and maintenance strategies for gears where removal, repair and potential downtime are costly. It also supports digital twin development and refinement.
- the potential benefits from harmonic analysis of full gear tooth surfaces to characterise gear performance and characterise manufacturing processes. Some harmonics may excite noise and affect performance. The increasing use of multi-axis general purpose machine tools to make gears may mean we need to reconsider how we perform gear product and machine tool validation.
- using gear measurement data linked with Tooth Contact Analysis (TCA) to provide data for a Wind Energy System Digital Twin.
- developing and evaluating a self-calibration strategy for gear manufacturing machine rotary tables, using an example generic CNC machine tool.
- investigating the performance and calibration of a gear machine tool on-board measurement systems to reduce manufacturing times and improve machining performance.