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Experimental validation of advanced gear contact models applied to a planetary stage

Type: Internship for Master students
Duration: 6 months
Starting date: Flexible
Supervisor: Ali Rezayat, ali.rezayat@siemens.com

Keywords: Gear contact, order tracking, modal analysis, multibody system, finite element analysis, manufacturing variability, statistical analysis, planet mesh phasing.

Planetary gears are commonly used in power transmission systems and drivetrains such as wind turbines, automobiles, helicopters. The particular design of planetary gear stages allows to transmit high torque ratios while being relatively compact. However, with these proven advantages in place, planetary gear sets are also known to exhibit several unique behaviors, which cannot be found in other fixed-center gear trains [1]. This is mainly because understanding of complex dynamic behaviors of a planetary gear is lacking, such as multiple gear contacts, non-stationary axis of rotation [2].

The analysis of the interaction of gear meshing phenomenon with other interfacing components (such as bearing, shaft and housing) in a gearbox constitutes a crucial point during the NVH process. In order to design quieter gearboxes, the tooth contact mechanism under load needs to be understood. Time varying tooth mesh stiffness is the key parameter to excite tooth vibration, and various methodologies to compute this mesh stiffness can be found in literature [3-5].

Figure 1: Examples of industrial gearboxes involving planetary gear sets (image credits: [6-7]).

The RTD team of Siemens Industry Software (SISW) in Leuven has implemented a state of the art numerical tool that allows to accurately model gear contacts within the Simcenter 3D platform [8-9]. Simcenter 3D uniquely combines system simulation, 3D CAE and testing capabilities to model, evaluate and predict the performance indicators of different types of systems. In particular, various gear contact methodologies are implemented within the Motion multibody package. Several levels of accuracy and computational complexity are available ranging from simple ISO norms to advanced FE-based gear contact.

The objectives of this internship are the following:

- Modeling different gears of a planetary stage using Simcenter 3D;

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- Application of available processing techniques on the raw data obtained from numerical and experimental analysis;
- Validation of advanced numerical techniques with experimental data;
- Statistical analysis of the influence of manufacturing variability on transmission error;
- Performing (numerical) modal analysis using the CAD data.
- Identification and classification of system harmonics in the spectrum;
- Iterating to improve the validation quality by increasing model complexity.

The following figures illustrate some examples of data processing analysis (see Figure 2).

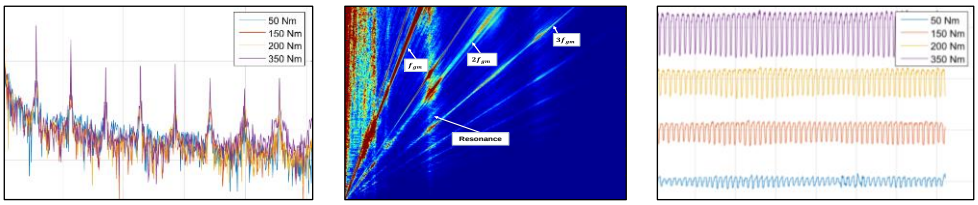

Figure 2: Some examples of the obtained results, both in static and dynamic conditions.

A summary of the tasks is available below:

Literature review

- Understanding the fundamentals of the each gear contact computation method used in SISW tools;
- Review of fundamental signal processing techniques (sampling, windowing, frequency/order analysis, etc.);
- Understanding the dynamic behavior of planetary gears and the corresponding spectral content;

Getting familiar with various software and tools

- Simcenter 3D Motion: General purpose multibody simulation software;
- Transmission Builder (TB): Preprocessing software to automatically build complex gear transmissions;
- Matlab: Programming language used for implementing processing techniques;

Performing signal processing

- Post-process the simulated transmission error signals and comparison with acquired test rig data;
- Identification and classification of frequency/order harmonics: gear mesh, resonances, modulation, etc.;
- Create various types of plots, such as waterfall, spectrogram, etc. in different operating condition (speed and load);

Validation (Simcenter models vs. experiments)

- Compare the static or dynamic TE for each loading conditions;
- Iterate the validation process by:
  - applying misalignments and component deformations in the system;
  - gradually increasing the model complexity;
- Validate the modulation sidebands of the gear systems;

What do we look for in students?

This internship seeks a motivated student willing to dive into the various technologies present in the proposal. The requirements are listed here below:

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Essentials

English language: Effective communication and collaboration, both written and oral;
Independence: Drive your own competence development and networking/teaming efforts;
Dedication and motivation: Expand your skills and competences across the scientific and the non-technical dimensions;
Key assets towards industry: Structured research approach, abstraction, develop an application view;
Programming: Knowledge of Matlab is required;

Desirable

Programming: Knowledge of Python or any other programming language is a plus;

SISW carefully evaluates each fellowship application before making a decision. After the revision of the CV and motivation letter, an interview with the candidate will be organized (either face-to-face or online). The final decision will be made after the interview. The student will be informed about the decision via email.

Student benefits

During this internship**,** SISW provides the student with:

- an apartment during the stay;
- a computer to be used for research during the stay;
- guidance and coaching for the research/work.

Academic supervision

The student has to propose an academic supervisor in the university in which he/she is conducting the research (usually a professor). The academic supervisor should be a member of the partner university. The second supervisor (technical) will be automatically assigned by SISW.

Holidays

In addition to the official (Belgian) holidays, the student is entitled to 10 holidays for an internship of 6 months.

Company profile

Siemens Industry Software (SISW) is a software and engineering company based in Leuven, Belgium, which is part of the Siemens PLM (Product Lifecycle Management) Software division. Originating as LMS International, one of the oldest and the largest spin-offs of the KU Leuven University, it was acquired in 2013 by Siemens to enable the development of a truly end-to-end closed loop.

The PLM solution portfolio helps industry in their objective to build the right product, and build it the right way. This quest is complicated by a number of factors, including increasing product complexity, regulatory requirements, and global development with local requirements. To enable industry to turn complexity into a competitive advantage, the driving mission of SISW is to collaborate with companies to deliver open solutions that help them turn more ideas into successful products. As such, we help thousands of companies to make great products by optimizing their lifecycle processes, from planning and development through manufacturing and support.

References:

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[1] Inalpolat, M., & Kahraman, A. (2009). A theoretical and experimental investigation of modulation sidebands of planetary gear sets. Journal of Sound and Vibration, 323(3–5), 677–696.
[2] Park, J., Ha, J. M., Youn, B. D., Leem, S. H., Choi, J.-H., & Kim, N. H. (2014). Model-Based Fault Diagnosis of a Planetary Gear Using Transmission Error. Annual Conference of the Prognostics and Health Management Society.
[3] Drew, S. J., Stone, B., & Leishmann, B. (2000). Measured torsional damping levels for two spur gearbox rigs. Multi, body Dynamics: Monitoring and Simulation Techniques II, 245.
[4] ISO 6336:1: Calculation of load capacity of spur and helical gears part 1.
[5] Cai, Y., and Hayashi, T., 1994, "The Linear Approximated Equation of Vibration of a Pair of Spur Gears (Theory and Experiment)," ASME Journal of mechanical design, June, Vol. 116, pp. 558-564.
[6] http://www.moog.com/content/dam/moog/literature/ICD/Moog-Wind-DesignNews-May2011-Article-en.pdf.
[7] http://www.herediaymulero.com/85754/t7-heavy-duty/.
[8] Simcenter 3D Motion: Siemens PLM Software, webpage accessed on 26/04/2018, https://www.plm.automation.siemens.com/global/en/products/simcenter/simcenter-3d.html
[9] Siemens PLM Software: Boosting Productivity in Gearbox design: Efficiently build and effectively simulate multibody simulation models, white paper, 26/04/2018, https://community.plm.automation.siemens.com/siemensplm/attachments/siemensplm/Simcenter_event_tkb/117/2/Siemens-PLM-Boosting-Productivity-in-Gearbox-Engineering.pdf