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2018 Fall Technical Meeting Papers

18FTM01. Filling Some Gaps in Spline Design Guidelines: Centering, Friction, and Misalignment
Author: **Stephen McKenny**

International spline standards and other widely used published documents have detailed definitions of two-dimensional spline geometry, and while they cover basic axial effects and stresses, more can be provided for design engineers. Results from an analytical study of misalignment factors and an experimental study of centering forces are discussed to provide information to help refine calculation methods. These include: how to calculate the effective pressure angle of straight-sided splines that must be used to accurately determine normal and radial loads; how to calculate the effective centering force of a spline pair; how to calculate the centering moment of a spline with ‘topping’; an update to current publications; and an update to the calculation of the maximum axial force that a spline can transmit via friction.

Pg. 1

18FTM02. Methods to Determine Form Diameter on Hobbed External Involute Gears
Author: **Shuo Zhang**

Two mathematical methods have been developed to be used for the calculation of true involute form diameter when specialized software or original gear designer information is not easily accessible. These methods are designed for external involute gears produced by the hobbing process, possibly followed by a finishing operation. Method A is a more precise match, but it requires special inputs that may be time consuming without special software. Method B, although not as accurate, still has relative error of TIF diameter below 0.1% over wide ranges of gear design parameters. Method B is also easy to apply and can be integrated into most existing gear design programs.

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18FTM03. Optimization of a Rack and Pinion Design for Offshore Jack-Up Applications
Author: **Adrian Nowoisky**

Lift boats or Jack up oil rigs are essential for the oil and gas industry. One offshore jacking system is pinion and rack to elevate legs and hull in operation. It is well known that rack and pinion of such applications exceed the permissible contact stress by the factor of 2 to 5. The design and evaluation of such systems is still a technical challenge. The pinion will be typically highly modified and analyzed based on the Hertzian contact stress theory of two cylinders in contact. This method will show how to start with a basic rack and pinion design. The true involute profile of the pinion will be replaced with a multi radii profile. In a second step, the pinion design will be analytical optimized to reduce the contact stress and improve the life expectation. The influence of major gear parameter such as module, profile shift coefficient as well as the pressure angle will be analyzed and explained. The results of the final pinion will be compared with an existing pinion design to evaluate and discuss a reuse of existing hardware. The results of the final designs will be verified by a numerical method. This paper demonstrates the impact of major gear parameters for a pinion design and their impact on the life expectation. The benefit of a custom pinion design and how much improvement can be achieved with emphasizing the design process properly will be shown. Furthermore it shall serve as a guideline for best practice to design a rack and pinion for offshore jacking applications.

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18FTM04. Gearbox Development for the Food and Beverage Processing Industry
Author: **Sandeep V. Thube**

Industry-specific power transmission needs can be efficiently served by a streamlined product development process. The ‘Food and Beverage’ industry has a variety of gearbox applications which are regulated by governmental industry standards, such as NSF and FDA. The scope of this paper is to design and construct a gearbox in compliance with these standards, which may be substantially different from typical industrial requirements.

The paper discusses details of a gearbox development for food and beverage applications. It mainly includes stainless steel housing and shaft designs, as well as oil seal, bearing and lubricant selections. The development process utilizes tools, viz. Quality Function Deployment (QFD), Failure Mode Evaluation Analysis (FMEA), computational ‘Finite Element Analysis’ (FEA), and 3D printing followed by prototype testing. QFD is used to prioritize features to be included in the product. Potential failures of the gearbox are identified with FMEA. The structural and thermal optimization of the newly designed housing is performed using FEA. 3D printing is utilized to find design defect at early stage, and validate the gearbox assembly procedure. Minimizing the number of physical prototype testing and iterations is the primary objective for the utilization of these tools.

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18FTM05. Increasing Static Friction with Laser
Author: **Gerhard Flores**

Flat and curved surfaces with the functionality of high static friction are increasingly needed for force-fitted nonslip power transmissions. This is especially true for con rod and cam structuring for high torque resistance or front face connections of sprockets, gears, or cam shaft adjustments. Expensive solutions such as diamond layers, diamond coatings, or form fitting design are increasingly being substituted. A modified laser process with defined exposed micro structures is the alternative for innovative manufacturing. Exposed micro melting burrs of smaller micrometer height with martensitic material structures are the precondition for the required high friction. So, such high static friction surfaces can be produced economically with repeatability of small tolerances in high-volume productions.

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18FTM06. Design and Optimization of a Hybrid Vehicle Transmission
Author: **Massimiliano Turci**

Hybrid vehicles seem to be the fastest solution for the containment of consumption and of pollution for personal transport. The designer of a hybrid transmission has to address additional issues with respect to the classical cases, in particular the high speed of the electric unit and the bidirectional motor/generator operation. In this case, a lot of attention should be paid to how to consider the four combinations of signs for torque and speed in the load spectrum. This paper discusses several approaches for the alternating bending factor, the effects of the asymmetric crowning (especially the helix modification tapered or parallel) and how to consider the housing stiffness in the TCA. Also included is an interesting solution from the kinematic point of view, the compound planetary, relatively well-known in the automotive, but much less so in industrial gearbox design.

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18FTM07. Influence of Thermal Distortion on Spur Gear Tooth Contact
Authors: **Jon Larrañaga, Ibai Ulacia, Aurea Iñurritegi, Aitor Arana, Jon German, and Julen Elizegi**

The reduction of component size and oil volume of current automotive and aeronautical transmissions, along with the increasing input speeds, are pushing gear teeth bulk temperatures to their scuffing limit. Even with development of new lubricant additives and coatings, high temperatures may produce other issues. This paper analyzes the effects of thermal distortion on the profile geometry and tooth contact parameters in the transverse plane of a spur gear by calculating the steady-state temperature distribution relevant to immersion depth, sump temperature, and lubrication regime in the contact area. Then, thermally distorted geometry and tooth contact analysis is computed by means of a 2D finite element model where load distribution, transmission error, backlash, and other parameters will be analyzed. The results of the study will allow one to set the limits of design backlash to avoid gear jamming and to size the initial profile shift or tooth modifications to reach the desired contact behavior.

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18FTM08. Oil-Off Characterization Method Using In-Situ Friction Measurement for Gears Operating Under Loss-of-Lubrication Conditions
Authors: **Aaron C. Isaacson and Matthew E. Wagner**

The oil-off performance evaluation of gears is of significant interest to the Department of Defense and various rotorcraft manufacturers, so that the aircraft can safely land in an accidental loss-of-lubricant situation. However, unlike typical gear failure modes, gear failure in an oil-off situation is very rapid and likely catastrophic. This paper describes the procedure and instrumentation utilized for an oil-off test to measure the frictional loss in the test gear mesh and the “air” temperature just out of mesh. Sound and vibration data was also recorded during testing. Data from typical failures showing the detection of scuffing onset and its progression to catastrophic failure for gears made from several aerospace alloy steels is presented.

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18FTM09. Application of Finite Element Analysis for the Strain Wave Gear Tooth Surfaces Design and Modifications
Authors: **Zhiyuan Yu and Kwun-Lon Ting**

This paper is on a rigorous definition and parametric study of tooth surface modification of the strain wave gear. You will see that optimal modification for a sample strain wave gear is found from FEA and tested by contact pattern, transmission error, and life cycling experiments. The resulting innovative design with modified fully conjugate tooth surface improves accuracy, backlash, and the life of the existing design.

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18FTM10. Experimental Study on the Pitting Detection Capabilities for Spur Gears Using Acoustic Emission and Vibration Analysis Methods
Authors: **Mateusz Grzeszkowski, C. Gühmann, P. Scholzen, Christoph Löpenhaus, S. Nowoisky, and G. Kappmeyer**

This paper discusses an experimental investigation on spur gears to characterize the pitting degradation process using monitoring features. Previous investigations have revealed that pitting has an impact on the gear vibration behavior. But is it possible to detect pitting at an early stage using acceleration sensors and acoustic emissions (AE) sensors to avoid consequential damages and subsequent correction activities? The paper will discuss this experimental investigation on spur gears to characterize the pitting degradation process using monitoring features. Also included is a discussion of the results of the investigation, including how the results show that a detection of pitting is possible several hours before complete gear failure, and more.

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18FTM11. Optimization of Power Density by Local Gear Failure Modeling

Authors: **Marco Kampka, Christian Brecher, Christoph Löpenhaus**

Power density is a key factor in gear design. Increasing the power density enables engineers to use smaller gears for their applications, which leads to smaller and lighter gear boxes. The most common way to design gears is using industry standards in which material strength can be obtained either from fatigue limit tables or by means of empirical formulae. Due to limited empirical data, a lot of averaging and approximations are used to make the available standards applicable to a wide range of applications. To design the gear closer to the power density limit, a high level of information is necessary. The paper shows how local FEA-based calculation approaches can be used to design gears closer to their power density limits for pitting, tooth root breakage, and flank fracture. The calculation results will be validated in running tests on different test rigs.

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18FTM12. Load Intensity Distribution Factor Evaluation from Strain Gauges at the Gear Root

Authors: **José Calvo Irisarri, Unai Gutierrez Santiago, Alfredo Fernández Sisón, and Pedro Olalde Arce**

Strain gauges are commonly used to obtain the load intensity distribution on the flank of a gear mesh. To get the load distribution on the flank, the strain data must be processed and changed into load intensity distribution on the tooth flank. Research has been conducted on the best methodology to place strain gauges when calculating load intensity distribution on the flanks of a gear. This paper discusses these research methods that use FEM models and his analysis of how to deal with the effect of strain gauge positioning errors, in order to find the optimal placement.

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18FTM13. Impact of Root Geometry Manufacturing Deviations from a Theoretical Hob Rack on Gear Bending Stress

Authors: **Rahul V. Nigade and Carlos H. Wink**

Gear reliability is a key requirement of any automotive transmission. Two common failure modes of gears are pitting and bending fatigue. So, the total gearing reliability depends upon the bending and pitting reliability. This paper discusses a comparison of a theoretical root fillet geometry generated by the hob racks of gear drawings to an actual measured tooth fillet geometry of manufactured gears, which determines the impact of the different root fillet geometries on tooth bending stresses. An emphasis is placed on the importance of using a root fillet geometry truly representative of the actual gears in production for the bending stress calculation so that the required bending reliability can be achieved in the field.

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18FTM14. Fatigue Life Predictions of Spherical Gear Couplings

Authors: **Ibai Ulacia, Jon Larrañaga, Aitor Arana, Aurea Iñurritegi, and Julen Elizegi**

Spherical gear couplings are mechanical components that allow transmitting torque by means of equally spaced teeth. Modern roll-leveling machines are characterized to level high-strength steels by using small rolls under high torque requirements. The small size of the rolls decreases the space between the spline couplings, causing misalignments up to 7 degrees. This paper discusses a geometry-generating procedure that has been developed for both the hub with internal teeth and the crowned teeth shaft in spherical gear couplings. A finite element model has been developed to study the effect of backlash and misalignment on the number of teeth in contact and root stresses. Finally, fatigue tests are performed, and numerical predictions are correlated with experimental results.

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18FTM15. Potentials of Free Root Fillets in Planetary Gearbox Applications

Authors: **Jonas Pollaschek, Christian Brecher, Christoph Löpenhaus**

Planetary gear stages are commonly used in many different fields of application, including wind turbine and automotive gearboxes. This paper discusses the potential for increased root load carrying capacity at the planet gear of a planetary gear application. The approach considers local material characteristics such as hardness, fatigue strength, and mean stress sensitivity, as well as residual stresses and different stress rations that result from the mesh with the sun and ring gear. It offers a detailed tooth contact analysis based on the Finite Element Method. The result of this work allows for the possibility of changes in the gear design.

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18FTM22. Integrated Approach for Gear Testing of High-Performance Clean Steels
Authors: **Dieter Mevissen, Christoph Löpenhaus, Lily Kamjou, and Elias Löthman**

The power density of gearboxes is continuously increased by different research activities. Besides new material developments, the cleanliness of steels comes to the forefront in order to meet future requirements regarding load carrying capacity of gears. This paper discusses an integrated approach for gear testing of steels. In order to determine the differences between steels of different cleanliness levels, the testing approach has to be improved as a whole.

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18FTM23. Lean Heat Treatment for Distortion Control
Authors: **Volker Heuer and David Bolton**

Controlling distortion is of key importance during the case hardening process in the production of gear components. By effective control of distortion and the variation of distortion, significant costs in post-heat treatment machining processes can be avoided. This paper focuses on new vacuum furnace designs that allow the treatment of small batches in a single layer of parts (2D treatment), which allows for easy automated loading and unloading of the fixture-trays. When performing case hardening, the components are Low Pressure Carburized (LPC) at high temperatures, followed by gas quenching. The treatment in single layers offers an optimum quality with temperature homogeneity; quench homogeneity; and distortion control.

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18FTM24. Residual Stress Measurement of Case Hardened Steel Gears
Author: **David Easton**

Aerospace gear components are required to demonstrate excellent load carrying and endurance characteristics. Case hardened steels are often utilized for these parts, but often residual stresses are developed. These residual stresses are known to have a significant effect on distortion during the heat treatment and machining processes. This paper presents research conducted on gears manufactured from two different starting points: as-received bar material and hot-forged billet. This paper will also discuss the results of the work and compare the two sets of spur gears.

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18FTM25. Combining Ultra-High-Strength and Toughness for Affordable Power Densification in Steel Gears Components
Author: **E. Buddy Damm**

In the last few years, improvements in clean steel technology have been coupled with development of new ultra-high-strength, high-toughness steels. These technologies provide affordable solutions for critical, power-dense components. This paper reviews and compares steel cleanness metrics between re-melted steels and steels that meet AGMA grade 3 cleanness. The new steels provide yield strengths ranging from 175-210 KSI, ultimate tensile strengths ranging from 230-250 KSI, and Charpy impact energies ranging from 35 to 50 ft.-lbs., allowing these grades to provide longer life, more power, and/or lighter weight. The higher fatigue strength of these steels is compared to more commonly used gear steels, and an analysis is presented that illustrates a potential for either a 30% reduction in gear set mass or a 45% increase in gear set torque capacity.

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18FTM26. Reliability of Gears – Determination of Statistically Validated Material Strength Numbers
Authors: **Michael Hein, Michael Geitner, Thomas Tobie, Karsten Stahl, and Burkhard Pinnekamp**

This paper is intended to provide a review on the statistical reliability behavior of cylindrical gears with regard to pitting and tooth root breakage failures. A mathematical reliability approach was developed and drafted to expand standardized load capacity calculation methods. The deduced models and procedures allow the consideration and conversion of different reliability levels in the design process of cylindrical gears. Practical examples of the research are provided.

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