SESSION IV — Gear Design Issues

PRESENTATIONS

- **Calculation Method for Flank Breakage and Pitting of Bevel Gears for Truck and Bus Applications** - Authors: Dr. Christian Wirth and Dr. B.-R. Höhn, ZG – Zahnräder und Getriebebau and Dr. Ch. Braykoff, MAN Truck & Bus AG

- **Gear Design Optimization for Low Tooth Contact Temperature of a High-Speed and Non-lubricated Spur Gear Pair** - Authors: Dr. Carlos H. Wink and Nandkishor S. Mantri, Eaton Corporation

- **Dynamic Analysis of Cycloidal Gearbox Using Finite Element Method** - Authors: Sandeep Thube and Todd Bobak, Sumitomo Machinery Corporation of America

- **Analysis of Ripple on Noisy Gears** - Author: Dr. Günther Gravel, Hamburg University of Applied Sciences

- **Gear “Whining” Noise in Diesel Engines** - Author: Yefim Kotlyar, Navistar, Inc.

ABSTRACTS

**Calculation Method for Flank Breakage and Pitting of Bevel Gears for Truck and Bus Applications** - Authors: Dr. Christian Wirth and Dr. B.-R. Höhn, ZG – Zahnräder und Getriebebau and Dr. Ch. Braykoff, MAN Truck & Bus AG

A failure mode called “flank breakage” is increasingly observed in different applications of cylindrical and bevel gears. This mode typically starts from the active flank approximately in the middle of the active tooth height and propagate to the tooth root of the unloaded flank side. Crack initiation can be localized below the surface in the region between case and core of surface hardened gears. This failure mode can neither be explained by the known mechanism of tooth root breakage nor by the mechanism of pitting. The purpose of this paper is to describe a new material physically based calculation method to evaluate the risk of flank breakage versus the risk of pitting. The verification of this new method by experimental tests is shown.

The principle of the calculation model is the local comparison of the occurring stresses and the available strength values over the whole tooth volume. Therefore it is possible to evaluate the risk of initial cracks beyond the surface of the flank. Cracks close to the surface may grow and cause pitting - especially in the flank area with negative specific sliding. Cracks in the transient area between case and core lead to a high flank breakage risk.

First the local stresses and forces on the flank are determined by a loaded tooth contact analysis followed by the calculation of the maximum exposure (regarding yielding) and dynamic exposure (regarding fatigue) of the material inside the tooth. Stress components from the Hertzian contact, bending, thermal effects (flash temperature) and friction are considered. Furthermore the positive effect of residual compressive stresses and accordingly the disadvantageous effect of the residual tensile stresses are evaluated.

Recalculation of the test gears showed a good correlation between the occurred type of damage and the determined material exposure inside the tooth. The variants failed with flank breakage could be reliably distinguished from the variants failed by pitting by the new material-physical method. With this knowledge it is now possible to optimize the main geometry parameters of the gear set (e.g. number of teeth, spiral angle, pressure angle) as well as the micro geometry (Ease-Off) that influences the load distribution on the flank.

**Gear Design Optimization for Low Tooth Contact Temperature of a High-Speed and Non-lubricated Spur Gear Pair** - Authors: Dr. Carlos H. Wink and Nandkishor S. Mantri, Eaton Corporation

This paper presents a gear design optimization approach that was applied to reduce both tooth contact temperature and noise excitation of a high-speed spur gear pair running without lubricant. The optimum gear design search was conducted using the RMC (Run Many Cases) program from The Ohio State University. Over 480,000 possible gear designs were considered, which were narrowed down to the 31 best candidates based on low contact temperature and low transmission error. The best gear design was selected considering, also, its manufacturability. The selected optimum gear design was compared to an existing gear set using LDP (Load Distribution Program) from The Ohio State University. Tooth contact temperature was calculated for both designs using a dry steel-on-steel coefficient of friction. Predicted contact temperature correlated well with results observed on dynamometer tests with the existing gear set. Predictions with the optimized design showed a 48% contact temperature reduction and a 79% noise excitation reduction. The low contact temperature of the optimized design will significantly contribute to preventing tooth surface damage under no lubricant operating conditions.

**Dynamic Analysis of Cycloidal Gearbox Using Finite Element Method** - Authors: Sandeep Thube and Todd Bobak, Sumitomo Machinery Corporation of America

Speed reducers incorporating cycloidal technology as their primary reduction mechanism have always been active topics of research given their unique trochoidal tooth profile. A cycloidal reducer is recognized for its strength and mainly studied for rotational performance improvement. At this time, this study can be performed by digital prototyping, which has become a valuable tool for simulating exact scenarios without experimenting on an actual model.
This paper discusses the stress distribution, modeled in a dynamic simulation environment, on the rotating parts of a cycloidal reducer. A three dimensional finite element model was developed using Algor FEA commercial code to simulate the combined effect of external loading as well as dynamic inertial forces on a one-cycloid disc system. This model utilizes surface-to-surface contact to define interaction between rotating parts of the reducer assembly. The results were analyzed for the variation in stress and deformation with respect to time for a specified simulation period. This study gives an insight into internal load sharing of rotating parts and their capability of carrying shock loads.

**Analysis of Ripple on Noisy Gears** - Author: Dr. Günther Gravel, Hamburg University of Applied Sciences

A low noise level is an important quality feature in modern gearboxes for passenger cars. But a troublesome noise can have many causes. The noise origination and transmission is affected by the design layout, the actual deviations of the components, the assembly of the components, and also the mounting situation of the complete gearbox.

Damages, form errors and displacement errors, or ripples are often present on the flanks of a gear, and may be the cause of problems in a noise check. Ripples or ‘ghost frequencies’ of a gear are problematic, because up to now they rarely can be detected on a gear measuring device, but only in a relative complex single-flank roll checking procedure.

A new evaluation method now allows to identify and to describe ripples on the flanks of gears based on the results of a normal gear measurement. The deviation curves were approximated by sine functions, and the results are displayed graphically and by characteristic values. A combination of the deviation of each measured point with its rotation angle allows an evaluation equal to a rolling with the mating gear. The results show a very good correlation to a noise check and to a single-flank roll check.

The application of the software is demonstrated by practical examples of the manufacturing methods generating grinding, honing, broaching and shaving. Vibrations of machine tool and ripple generating influences in the manufacturing process can be verified down to a level of a few tenths of a micrometer. At the same time this method is well suited to describe long-wave form deviations like ovality or a 3- or 4-fold ripple caused by clamping or by a square blank.

With this new evaluation method gears can be tested in an early state of production for known, critical ripples, and conclusions can be drawn on the state of the machine tool, cutting tool and clamping device.

**Gear “Whining” Noise in Diesel Engines** - Author: Yefim Kotlyar, Navistar, Inc.

This paper is a field case study and development work performed to reduce diesel engine gear whining noise. It includes the problem definition, inspection of BOB & WOW engines, design of experiment, development and review of gear geometry modifications, inspection charts, sample size for a statistically significant analysis, and correlation of noise measurement results and tooth profiles.