



Fill Your Mind With the Latest Gearing Developments

Fall Technical Meeting * October 7-9, 2007 * Detroit, Michigan

Want to get the most for your travel dollar this October? AGMA will once again team our landmark Fall Technical Meeting with GEAR EXPO and provide the premier opportunity to learn about new design and manufacturing developments, all under one roof.

This year's FTM will be held **October 7-9 at Cobo Hall in Detroit, Michigan**. The program has been structured to allow ample time for you to visit the Expo.

The Technical Sessions will include 18 presentations divided into four sessions:

- **Technical Session I – Alternative Materials & Designs**
- **Technical Session II – Current Updates**
- **Technical Session III – Load Capacity & Micropitting**
- **Technical Session IV – Bevel Gear Design & Manufacture**

These are real world issues that many confront on an everyday basis. The FTM is the ONLY place to learn from the experts in the field.

2007 FALL TECHNICAL MEETING PRESENTATIONS

SESSION I

ALTERNATIVE MATERIALS AND DESIGNS

Estimation of Lifetime of Plastic Gears

Stefan Beermann, KISSsoft AG

This paper gives an overview on the state of art in plastic gear resistance calculation. The main problem with plastics is the depen-

dency of the stress cycle curve (Woehler line) with temperature. Today, more plastic gears (as in automobile headlights) are used in a high temperature range. Furthermore flank resistance depends strongly on lubrication (lifetime may vary by a factor of ten and more, if oil, grease lubricated or dry running).

As no secure data for plastic gears is available, how can nevertheless plastic gear design and life time prediction be improved? The best strategy is to use the feedback of existing reducers. Plastic gearboxes, before starting production in big series, are normally submitted to endurance tests. If these tests are used to check also the real lifetime limits – or by increasing test length, or by increasing applied torque – these results can be used to define the required safety factors for future gear design. This procedure has been very successful, and will be described with some examples.

Study of the Correlation Between Theoretical and Actual Gear Fatigue Test Data on a Polyamide

Steve Wasson, DSM Engineering Plastics

Fatigue tests have been run on actual molded gears in order to provide design data, using fully lubricated, plastic on plastic spur gears in a temperature controlled experiment. The purpose of the testing is to see if there is a good correlation between fatigue data, generated in a lab on test bars, versus the actual fatigue performance in a gear.

In order to do this, the theories of gear calculations to get root stresses also had to be examined. Advanced FEA showed that there are corrections needed to account for high loading or high temperatures in plastic gears.

The chemistry of various nylons used in gears is explained. A high crystalline nylon has been found which is an excellent material for gears in demanding applications and can withstand high torques and operating temperatures. The material has a crystallinity of 70%, which results in very good wear properties and excellent retention of mechanical properties (strength, stiffness, and fatigue) especially at elevated temperatures. Several commercial gear applications are currently utilizing these properties. These will be shown to demonstrate the benefits and manufacturability of this material.

Material Integrity in Molded Plastic Gears and Its Dependence on Molding Practices

Tim Vale, ABA-PGT Inc.

The quality of molded plastic gears is typically judged by dimensional feature measurements only. This practice overlooks potential deficiencies in the plastic injection molding process and its effect on the integrity of the plastic material. These deeper issues are often not given proper consideration until a related gear failure demands its study and evaluation. This paper identifies some of these oversights in the molding process, the resultant effect on the plastic

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material, and discusses their likely effect on short and long term gear performance.

Applying Elemental Gear Measurement to Processing of Molded Plastic Gears

Glenn Ellis, ABA-PGT Inc.

Although elemental gear inspection is rarely specified for molded plastic gears, the measurement equipment and practices can be valuable in advancing the molding processes and improving quality. After a brief description of plastic gear tooling and molding, this paper gives examples of specific elemental measurements and relates them to process changes and quality improvements. Such examples for spur and helical gears include: profile measurements, leading to gear mesh noise reduction; lead measurement, leading to increased face width load distribution and, continuing from that, even to the molding of crowned gears; and index measurement, leading to improved roundness of gears molded from fiber reinforced plastic materials.

Vacuum Carburizing Technology for Powder Metal Gears and Parts

Janusz Kowalewski and Karol Kucharski, SECO/WARWICK Corporation

Carburizing is one of the leading surface hardening processes applied to the sintered, low-alloyed steel gears in the automotive industry. While diffusion of carbon in wrought steel is well documented, this is not the case for PM steel subject to carburizing in vacuum furnaces. This paper presents results that show that the density of the powder metal is the main factor for the final carbon content and distribution. Also important is the state of the surface of the part; either sintered with open porosity or machined with closed porosity. The way the carburizing gas moves through the furnace might be of some influence as well.

SESSION II

CURRENT UPDATES

Using Barkhausen Noise Analysis for Process and Quality Control in the Production of Gears

Stephen Kendrish, Theo Rickert and Robert Fix, American Stress Technologies, Inc.

The use of magnetic Barkhausen Noise Analysis (BNA) has been proven to be an effective tool for the non-destructive detection of microstructural anomalies in ferrous materials. Used as an in-process tool for the detection of grinding burn, heat treat defects and stresses, BNA is a quick comparative and quantitative alternative to traditional destructive methods.

This paper presents examples that demonstrate how BNA is used to evaluate changes in microstructural properties. Quantitative results correlate BNA test values to X-Ray diffraction values for the detection of changes in residual stress. Qualitative results correlate BNA test values to acid etch patterns/colors for the detection of grinding burn defects.

Grinding Induced Changes in Residual Stresses of Carburized Gears

Robert LeMaster, Bryan Boggs, Jeffrey Bunn, University of Tennessee at Martin; and Camden Hubbard, Thomas Watkins, Oak Ridge National Laboratory

This paper presents the results of a study performed to measure the change in residual stress that results from the finish grinding of carburized gears. Residual stresses were measured in five gears using the x-ray diffraction equipment in the Large Specimen Residual Stress Facility at Oak Ridge National Laboratory. Two of the gears were hobbled, carburized, quenched and tempered, but not finished. The remaining three gears were processed similarly, but were finish ground. The residual stresses were measured at 64

different locations on a tooth from each gear. Residual stresses were also measured at fewer points on other teeth to determine the tooth-to-tooth variation. Tooth profile measurements were made of the finished and unfinished gear samples.

The results show a fairly uniform and constant compressive residual field in the non-finished gears. There was a significant reduction in the average residual stress measured in the finished gears. Additionally, there was a significant increase in the variability of the residual stress that was introduced by the grinding process. Large variations were observed in both the lateral and longitudinal directions on a tooth surface. Analysis of the data suggests a linear relationship between the change in average residual stress and the amount of material removed by the grinding process.

Manufacturing Net Shaped Cold Formed Gears

Dennis Engelmann, Milwaukee Wire Products

An innovative metal forming process has been developed for manufacturing quality, durable and cost efficient gears for high volume production. In this paper, the development of net shaped Cold Formed Gears (CFG) is presented along with their suitable applications. The manufacturing technique and equipment is introduced, as well as the advantages and limitations. Applicable materials and heat treatment practices are also discussed. Gear tooth inspection charts are presented and compared to conventional manufacturing methodologies.

The Ikona Clutch & Differential

John Colbourne, Vladimir Scekcic, and Sasha Tesic, Ikona Industries Corp.

This paper describes two devices, a clutch and a differential, which are based on the Ikona CVT. This CVT is essentially an internal

gear pair, in which the pinion is mounted on an eccentric that can drive or be driven by an electric motor/generator, thus providing a variable ratio. Since this arrangement allows for "branching" of energy flow(s), it can be classified as summation-type CVT.

When the CVT is used as a clutch, it would replace the friction-plate clutch in vehicles with standard transmissions, and the fluid torque converter in automatic transmissions. The new clutch will be referred to as the electric torque converter. Any excess energy is converted into electrical energy, and either stored in the battery, or reintroduced into the system through the motor/generator. Modulation of the clutch can be very smooth which is particularly advantageous when the vehicle starts from rest on uphill slopes. Since no friction element is involved, and only a fraction of torque is being manipulated, the modulation can be repeatable regardless of conditions. Finally, in a hybrid-vehicle arrangement, the clutch can be used to maintain the engine at its optimum speed (within limits), regardless of the road speed and the gearbox ratio.

Similar principals apply to the Ikona differential. Unlike today's limited slip differentials, the Ikona differential allows full torque to be transmitted through one drive wheel, even though the other drive wheel may have completely lost traction. Unlike traditional differentials that allow wheels to rotate at different speeds, the Ikona differential forces the wheels to do so. Accordingly when the vehicle is changing direction, the differential can be used to control the speed of each drive wheel, thus providing active torque steering.

The Gear Dynamic Factor, Historical and Modern Perspective

Donald Houser and David Talbot, *The Ohio State University*

The dynamic factor has been included in

gear design and rating formulas since the 1930's. Its original formulation was based on an assessment of entering tooth impacts, but in modern gear design procedures, where tip relief and lead modifications are common, these impacts may be virtually eliminated. With this elimination, one finds that gear dynamics are mainly excited by steady state phenomena such as transmission error, friction and axial shuttling of the mesh force. This paper will first provide a historical progression of the dynamic factor equations that are based on impact theory and will define when this methodology is appropriate. The paper will then discuss the various steady state modeling approaches and will use one of these approaches to demonstrate the effects of manufacturing deviations on predicted dynamic loads.

SESSION III

LOAD CAPACITY AND MICROPITTING

Helicopter Accessory Gear Failure Analysis Involving Wear and Bending Fatigue

Gregory Blake and Doug Schwerin, *Rolls-Royce Corporation*

Gear tooth wear is a very difficult phenomenon to predict analytically. The failure mode of wear is closely correlated to the lambda ratio, and can manifest into more severe failure modes, such as bending. Presented is a failure analysis in which this occurred.

A legacy aerospace gear mesh experienced nine failures within a two year time period. The failures occurred after more than eight years in service and within tight range of cycles to one another. Each failure resulted in the loss of all gear teeth with origins consistent with classic bending fatigue. None of the failures were detected prior to tooth loss.

Non-failed gears, with slightly lower time than the failed gears, were removed from service and inspected. Gear metrology mea-

surements quantified a significant amount of wear. The flank form of these worn gears was measured and the measured data used to analytically predict the new dynamic load distribution and bending stress. To predict if the failure mode of wear was expected for this gear mesh, an empirical relationship of wear to lambda ratio was created using field data from multiple gear meshes in multiple applications.

Presented are the metallurgical failure analysis findings, dynamic gear mesh analysis, the empirical wear rate curve developed, and design changes.

The Effect of Start-Up Load Conditions on Gearbox Performance and Life – Failure Analysis and Case Study

Raymond J. Drago, *Drive Systems Technology, Inc.*

When gearboxes are used in applications in which the connected load has high inertia, the starting torque transmitted by the gearbox can be much higher than the rated load of the prime mover. Power plants often require several evaporative cooling towers or large banks of air cooled condensers (ACC) to discharge waste heat. Because of the very large size of the fans used in these applications, they fall into this category of high inertia starting load devices. When started from zero speed, a very high torque is required to accelerate the fan to normal operating speed. If the fan is started infrequently and run continuously for long periods of time, this high starting torque is of minimal significance. However, when the fan is started and stopped frequently, the number of cycles at the high starting torque can accumulate to a point where they can cause extensive fatigue damage, even if the gear system is adequately rated.

Where the gear unit is marginally rated, very early, catastrophic gear failure is often

the result. As part of the overall investigation of several failures in such gearboxes, we measured starting torque on a typical installation, examined many failed gears, and calculated the load capacity ratings for the gearboxes under actual operating conditions. This paper describes the failures observed, the testing conducted, the data analyses and the effect of the high measured starting torque on the life and performance of the gear systems. The test results revealed surprising results, especially during starts where the fan was already wind-milling due to natural air flow in the ACC bank.

Influence of Grinding Burn on the Load Carrying Capacity of Parts under Rolling Stress

Fritz Klocke, Tobias Schröder, Christof Gorgels, RWTH Aachen University of Technology

The demand for continuous improvement concerning economic efficiency of products and processes leads to an increasing cost pressure in manufacturing and design of power transmissions. Also, the power density of gears has been increased which leads to a demand for higher gear quality. In more and more cases this can only be achieved using hard finishing processes.

The demand for higher gear qualities leads to an increased use of gear grinding, which incurs the risk of thermal damage, such as grinding burn on the gear flank. The influence of thermal damage on the set in operation is nevertheless hard to judge so that damaged gears are often scrapped. This leads to increasing failure costs.

The lack of knowledge of the effect of grinding burn on the load carrying capacity of gears leads to the point that the same degree of damage is judged differently by different companies. Therefore it is necessary to do trials with thermally damaged parts in order to know how much a certain degree of thermal damage

influences the load carrying capacity.

The investigations described in this report are aimed at determining the load carrying capacity of parts under rolling stress. Thermally damaged rollers are employed on a roller test rig, since with this analogy process the part geometry is easier to describe and easier to damage reproducibly.

Roughness and Lubricant Chemistry Effects in Micropitting

A. Oliver, D. Dini and E. Lainé, Imperial College; and, D. Hua, T. Beveridge, Caterpillar, Inc.

Micropitting has been studied using a disc machine in which a central carburized steel test roller contacts three, harder, counter-rollers with closely controlled surface roughness. Roughness was varied using different finishing techniques, and the effects of different oil base-stocks and additives were investigated.

Damage on the test rollers included dense micropitting and "micropitting erosion" in which tens of microns of the test surface were completely removed. This phenomenon is particularly damaging in gear teeth where it has the potential to destroy profile accuracy. It was found that anti-wear additives led to a high rate of micropitting erosion, and the effect correlated more or less inversely with simple sliding wear results. There were also appreciable effects from base-stock chemistry.

The key parameter affecting the severity of damage seemed to be the near-surface shear stress amplitude arising from the evolved roughness; different chemistries led to the evolution of different roughness during initial running and to different contact stresses and levels of damage.

Experience with a Disc Rig Micropitting Test

M. Talks and W. Bennett, QinetiQ Fuels and Lubricants Centre

The experimental work carried out was aimed at developing a test method that was able to consistently produce micropitting damage and could discriminate between a good oil (i.e., one that rarely produces micropitting in service) and a poor oil (i.e., one that does produce micropitting in service).

The disc rig control system allows test parameters such as entrainment velocity, contact stress and slide/roll ratio at the disc/roller contacts to be accurately and independently controlled. This enables the effect of key parameters to be studied in isolation, which is something that cannot be easily achieved using conventional gear test rigs.

A test procedure has been developed which provides a good level of repeatability and discrimination between oils. In addition, a study of the effect of slide/roll ratio (SRR) has shown that the severity of micropitting damage increases as SRR increased, whereas at 0% SRR no micropitting occurred, and, at negative SRRs, microcracking occurred, but not micropitting. This is the way that SRR seems to affect micropitting in gears.

SESSION IV BEVEL GEAR DESIGN AND MANUFACTURE

Straight Bevel Gear Cutting and Grinding on CNC Free Form Machines

Hermann Stadtfeld, The Gleason Works

Manufacturing of straight bevel gears was in the past only possible on specially dedicated machines. One type of straight bevel gears are those cut with a circular cutter with a circumferential blade arrangement. The machines and the gears they manufacture have the Gleason trade name Coniflex®. The cutters are arranged in the machine under an angle in an interlocking arrangement which allows a completing cutting process. The two interlocking cutters have to be adjusted independently during setup, which is complicated and time consuming.

The outdated mechanical machines have never been replaced by full CNC machines, but there is still a considerable demand in a high variety of low quantities of straight bevel gears. Just recently it was discovered that it is possible to connect one of the interlocking straight bevel gear cutter disks to a free form bevel gear generator and cut straight bevel gears of identical geometry compared to the dedicated mechanical straight bevel gear generator. A conversion based on a vector approach delivers basic settings as they are used in modern free form machines. The advantages are quick setup, high accuracy, easy corrections and high repeatability.

Simulation Model for the Emulation of the Dynamic Behavior of Bevel Gears

Christian Brecher, Tobias Schröder and Adam Gacka, RWTH Aachen University of Technology

The impact of bevel gear deviations on the noise excitation behavior can only be examined under varying working conditions such as different rotational speed and torque. The vibration excitation of bevel gears resulting from the tooth contact is primarily determined by the contact conditions and the stiffness properties of the gears. By the use of a detailed tooth contact analysis, the geometry based gear properties can be developed and provided for a dynamical analysis of the tooth mesh.

A model has been developed for the simulation of the dynamic behavior of bevel gears. With the aid of a load-free tooth contact analysis, the geometry-based part of the path excitation is determined. With a tooth contact analysis under load, the path excitation caused by deflections can be calculated. The geometry based part of the path excitation and a characteristic surface of the excitation values is created and provided for dynamic simulation.

This dynamic model is able to consider

every deviation of the micro- and macrogeometry from the ideal flank topography, i.e., waves and/or grooves in the surface structure, in combination with two and three dimensional flank deviations like profile deviations, helix deviations and twists. It is also possible to consider the influence of friction and the contact impact caused by load and/or manufacturing errors with a test rig to verify the calculations.

Bevel Gear Model

Ted Krenzer, Consultant

The paper presents a method for developing an accurate generic bevel gear model including both the face milling and face hobbing processes. Starting with gear blank geometry, gear and pinion basic generator machine settings are calculated. The contact pattern and rolling quality are specified and held to the second order in terms of pattern length, contact bias and motion error. Based on the setup, a grid of tooth points are found including the tooth flank, fillet and, if it exists, the undercut area. It is proposed as the model for the next generation of bevel gear strength calculations in that the procedure produces true bevel gear geometry, uses blank design parameters as input and is vendor independent except for cutter diameter.

How to Determine the MTBF of Gearboxes

Gerhard Antony, Neugart USA LP

Mean Time Between Failures (MTBF) became a frequently used value describing reliability of components, assemblies, and systems. While MTBF was originally introduced and used mainly in conjunction with electronic components and systems, the definition and application for mechanical components, such as gearboxes, is not broadly available, used, or recognized. In the field of gears it is difficult to obtain an MTBF from the manufacturer due to the lack

of applicable, generally recognized definitions and standards. The paper will evaluate, compare and suggest ways in determining a gearbox MTBF based on the already established, proven, design calculation standards and test methods used in the gear design.

REGISTRATION DETAILS

Fees

AGMA Member: \$575.00

AGMA Member Spouse/Guest:
\$75.00

AGMA Non-Member: \$865.00

AGMA Non-Member Spouse/Guest:
\$125.00

Students (with Technical papers):
\$95.00

Students (admission only): \$25.00

To register, visit www.agma.org or call AGMA at 703-684-0211.

Hotel Information

Detroit Marriott Renaissance Center
Renaissance Center
Detroit, MI 48243 USA
Phone: 313-568-8000
Fax: 313-568-8146
Rate: \$164.00 (Single/Double)
Cut-Off Date: September 10, 2007

To obtain the preferred rate, be sure to mention AGMA when making your reservations. FTM attendees are responsible for making their own hotel and travel reservations.

About the hotel: *The hotel is considered the FTM & GEAR EXPO 2007 Headquarters Hotel and is located in the center of the General Motors Global Headquarters complex. It is three blocks from Cobo Center and has indoor access to the People Mover. It has undergone a complete renovation since becoming a Marriott. The extensive renovation project was completed in 2004. There is high-speed Internet access available in all guest rooms.*