AGMA
Catalog of Technical Publications
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American Gear Manufacturers Association

AGMA is a voluntary association of companies, consultants and academicians with a direct interest in the design, manufacture, and application of gears and flexible couplings. AGMA was founded in 1916 by nine companies in response to the market demand for standardized gear products; it remains a member– and market–driven organization to this day. AGMA provides a wide variety of services to the gear industry and its customers and conducts numerous programs which support these services. Some of these services and programs are:

- **STANDARDS:** AGMA develops all U.S. gear related standards through an open process under the authorization of the American National Standards Institute (ANSI).
- **ISO PARTICIPATION:** AGMA is Secretariat to TC60, the committee responsible for developing all international gear standards. TC60 is an ISO (International Organization of Standardization) committee.
- **MARKET REPORTS AND STATISTICS:** AGMA's Operating Ratio Report, Wage & Benefit Survey, and Monthly Market Trend Reports help you stay competitive by giving you up–to–date information on the gear industry.
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- **GEAR EXPO:** This is the only trade show dedicated solely to the gear industry.
- **TECHNICAL COMMITTEE MEETINGS** are the core of the open AGMA standard writing process keeping members abreast of new developments while ensuring that AGMA standards are kept current.
- **THE AGMA TRAINING SCHOOL FOR GEAR MANUFACTURING** uses current technology to offer hands–on training in hobbing, shaping, and inspection. At the "Gear School", operators learn how to maximize their productivity. Enrollment is open to all.
- **NEWS DIGEST,** AGMA's quarterly newsletter, offers you timely, useful information you can use immediately.

If you would like additional information about our programs, or on how to become a member of AGMA, please contact AGMA Headquarters.

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AGMA 217.01 (R1999) ***Information Sheet - Gear Scoring Design Guide for Aerospace Spur and Helical Power Gears***

Covers all aerospace spur and helical power gears lubricated with MIL–L–7808 and MIL–0–50–81, Grade 1005 oils and presents an improved flash temperature index formula and a recommended operating index range. Guides designers in determining the scoring resistance of spur and helical gear sets intended for use in aerospace applications.

ISBN: 1–55589–020–2 Pages: 22

AGMA 299.01 (R1999) ***Gear Sound Manual: Section I, Fundamentals of Sound as Related to Gears; Section II, Sources, Specifications, and Levels of Gear Sound; Section III, Gear-Noise Control***

Discusses how noise measurement and control depend upon the individual characteristics of the prime mover, gear unit, and driven machine –– as well as their combined effects in a particular acoustical environment. Indicates certain areas that might require special consideration.

ISBN: 1–55589–528–4 Pages: 56

AGMA 900-G00 ***Style Manual for the Preparation of Standards, Information Sheets and Editorial Manuals***

Presents the requirements for preparing AGMA standards, editorial manuals, and other technical literature. A new annex "ISO symbols used in metric documents", has been added, which includes a comprehensive listing of the symbols used in ISO gear rating standards. **Revision of AGMA 900-F96.**

ISBN: 1–55589–775–4 Pages: 38

AGMA 901-A92 (R1997) ***A Rational Procedure for the Preliminary Design of Minimum Volume Gears***

Presents a simple, closed–form procedure as a first step in the minimum volume spur and helical gearset design. Includes methods for selecting geometry and dimensions, considering maximum pitting resistance, bending strength, and scuffing resistance, and methods for selecting profile shift.

ISBN: 1–55589–579–4 Pages: 37

AGMA 904-C96 ***Metric Usage***

Serves as a guide in preparing AGMA metric standards.

ISBN: 1–55589–681–2 Pages: 20

AGMA 908-B89 (R1999) ***Information Sheet - Geometry Factors for Determining the Pitting Resistance and Bending Strength of Spur, Helical and Herringbone Gear Teeth***

Gives the equations for calculating the pitting resistance geometry factor, I, for external and internal spur and helical gears, and the bending strength geometry factor, J, for external spur and helical gears that are generated by rack–type tools (hobs, rack cutters or generating grinding wheels) or pinion–type tools (shaper cutters). Includes charts which provide geometry factors, I and J, for a range of typical gear sets and tooth forms.

ISBN: 1–55589–525–5 Pages: 78

AGMA 910-C90 (R2003) ***Formats for Fine-Pitch Gear Specification Data***

Consists of a series of printed forms for gear drawings that contain the appropriate data the gear designer must tabulate for the gear manufacturer. Includes a series of definitions of the various tabulated items. Appendix contains blank, pre–printed forms that can easily be copied for the user's drawings.

ISBN: 1–55589–571–9 Pages: 29

AGMA 911-A94 (R2000) ***Guidelines for Aerospace Gearing***

Covers current gear design practices as they are applied to air vehicles and spacecraft. Goes beyond the design of gear meshes. Presents the broad spectrum of factors which combine to produce a working gear system, whether it be a power transmission or special purpose mechanism. Covers only spur, helical and bevel gears. (Does not cover wormgears, face gears, and various proprietary tooth forms). **Replaces AGMA 411.02.**

ISBN: 1–55589–629–4 Pages: 97

AGMA 913-A98 ***Method for Specifying the Geometry of Spur and Helical Gears***

Provides information to translate tooth thickness specifications which are expressed in terms of tooth thickness, center distance or diameter into profile shift coefficients. It describes the effect that profile shift has on the geometry and performance of gears. Annexes are provided which contain practical examples on the calculation of tool proportions and profile shift.

ISBN: 1–55589–714–2 Pages: 25

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!! NEW !!

AGMA 914‑B04, *Gear Sound Manual - Part I: Fundamentals of Sound as Related to Gears; Part II: Sources, Specifications and Levels of Gear Sound; Part III: Gear Noise Control*

This information sheet discusses how noise measurement and control depend upon the individual characteristics of the prime mover, gear unit, and driven machine, as well as their combined effects in a particular acoustical environment. It indicates certain areas that might require special attention. This document is a revision of AGMA 299.01 to include updated references and a discussion of Fast Fourier Transform analysis.

ISBN: 1‑55589‑820‑3 Pages: 37

AGMA 915‑1‑A02 *Inspection Practices - Part 1: Cylindrical Gears - Tangential Measurements*

Provides a code of practice dealing with inspection relevant to tangential element and composite deviations of cylindrical involute gears (measurements referred to single flank contact). **Supplement to ANSI/AGMA 2015‑1‑A01.**

ISBN: 1‑55589‑798‑3 Pages: 39

AGMA 915‑3‑A99 *Inspection Practices - Gear Blanks, Shaft Center Distance and Parallelism*

Provides recommended numerical values relating to the inspection of gear blanks, shaft center distance and parallelism of shaft axes. Discussions include such topics as methods for defining datum axes on components; the use of center holes and mounting surfaces during manufacturing and inspection; and, recommended values of in‑plane and out‑of‑plane deviations of shaft parallelism. **Modified adoption of ISO/TR 10064‑3:1996.**

ISBN: 1‑55589‑738‑X Pages: 9

AGMA 917‑B97 (R2003) *Design Manual for Parallel Shaft Fine‑Pitch Gearing*

Provides guidance for the design of spur and helical gearing of 20 through 120 diametral pitch including internal and rack forms. Manual contains such specialized subjects as inspection, lubrication, gear load calculation methods, materials, including a wide variety of plastics. **Replaces AGMA 370.01.**

ISBN: 1‑55589‑694‑4 Pages: 84

AGMA 918‑A93 (R1998) *A Summary of Numerical Examples Demonstrating the Procedures for Calculating Geometry Factors for Spur and Helical Gears*

Provides numerical examples for calculating the pitting resistance geometry factor, I, and bending strength geometry factor, J, for typical gearsets that are generated by rack‑ type tools (hobs, rack cutters or generating grinding wheels) or pinion‑type tools (disk‑type shaper cutters).

ISBN: 1‑55589‑617‑0 Pages: 42

AGMA 920‑A01 *Materials for Plastic Gears*

This document serves to aid the gear designer in understanding the unique physical, mechanical and thermal behavior of plastic materials. Topics covered include general plastic material behavior, gear operating conditions, plastic gear manufacturing, tests for gear related material properties, and typical plastic gear materials.

ISBN: 1‑55589‑778‑9 Pages: 40

AGMA 922‑A96 *Load Classification and Service Factors for Flexible Couplings*

This Information Sheet provides load classifications and related service factors that are frequently used for various flexible coupling applications. Typical applications using smooth prime movers and special considerations involving unusual or more severe loading are discussed. **Update of AGMA 514.02.**

ISBN: 1‑55589‑680‑4 Pages: 6

AGMA 923‑A00 *Metallurgical Specifications of Steel Gearing*

This document identifies gear material characteristics which are important to performance. AGMA standards for gear load capacity calculations require allowable stress numbers related to material grade, which are based on type and heat treatment. For each heat treatment method and AGMA grade number, acceptance criteria are given for various material characteristics identified in this document.

ISBN: 1‑55589‑777‑0 Pages: 31

!! NEW !!

AGMA 925‑A03 *Effect of Lubrication on Gear Surface Distress*

This document provides currently available information pertaining to oil lubrication of industrial gears for power transmission applications. It is intended to serve as a general guideline and source of information about gear oils, their properties, and their tribological behavior in gear contacts. Equations provided allow the calculation of specific film thickness and instantaneous contact (flash) temperature for gears in service, and to help assess the potential risk of surface distress (scuffing, micropitting and macropitting, and scoring) involved with a given lubricant choice.

ISBN: 1‑55589‑815‑7 Pages: 51

AGMA 926‑C99 *Recommended Practice for Carburized Aerospace Gearing*

Establishes recommended practices for material case and core properties, microstructure and processing procedures for carburized AISI 9310 aerospace gears. This document is not intended to be a practice for any gears other than those applied to aerospace. **Replaces AGMA 246.02a.**

ISBN: 1‑55589‑758‑4 Pages: 9

To search this document, CTRL "F"

AGMA 927-A01 ***Load Distribution Factors - Analytical Methods for Cylindrical Gears***

Describes an analytical procedure for the calculation of face load distribution factor. The iterative solution that is described is compatible with the definitions of the term face load distribution of AGMA standards and longitudinal load distribution of the ISO standards. The procedure is easily programmable and flow charts of the calculation scheme, as well as examples from typical software are presented.

ISBN: 1-55589-779-7 Pages: 31

AGMA 931-A02 ***Calibration of Gear Measuring Instruments and Their Application to the Inspection of Product Gears***

Provides guidelines for the alignment of such instrument elements as centers, ways and probe systems. The instrument accuracy requirements needed to meet the accuracy of product gears is discussed. It also covers the application of gear artifacts to determine instrument accuracy. This involved the calculation of U95 uncertainty at all steps from the artifact to the final product gears. This document serves to supplement current calibration standards ANSI/AGMA 2110-A94, ANSI/AGMA 2113-A97, and ANSI/AGMA 2114-A98

ISBN: 1-55589-799-1 Pages: 29

!! NEW !!

AGMA 933-B03 ***Basic Gear Geometry***

This information sheet illustrates important geometrical relationships which provide a sound basis for a thoroughly logical and comprehensive system of gear geometry. **Replaces AGMA 115.01.**

ISBN: 1-55589-814-9 Pages: 18

ANSI/AGMA 1003-G93 (R1999) ***Tooth Proportions for Fine-Pitch Spur and Helical Gears***

Includes spur and helical gearing of 20 through 120 diametral pitch with tooth proportions of 20 degree pressure angle and having 7 or more teeth. Tooth proportions shown may also be suitable for gear designs of finer than 120 diametral pitch.

ISBN: 1-55589-015-6 Pages: 24

ANSI/AGMA 1006-A97 (R2003) ***Tooth Proportions for Plastic Gears***

Presents a new basic rack, AGMA PT, which, with its full round fillet, may be preferred in many applications of gears made from plastic materials. It contains a description, with equations and sample calculations, of how the proportions of a spur or helical gear may be derived from the design tooth thickness and the basic rack data. In several annexes, there are discussions of possible variations from the basic rack and also a procedure for defining tooth proportions without using the basic rack concept.

ISBN: 1-55589-684-7 Pages: 47

ANSI/AGMA 1010-E95 (R2000) ***Appearance of Gear Teeth - Terminology of Wear and Failure***

This standard provides nomenclature for general modes of gear tooth wear and failure. It classifies, identifies and describes the most common types of failure and provides information which will, in many cases, enable the user to identify failure modes and evaluate the degree or progression of wear. **Replaces ANSI/AGMA 110.04.**

ISBN: 1-55589-665-0 Pages: 40

ANSI/AGMA 1012-F90 ***Gear Nomenclature, Definitions of Terms with Symbols***

Provides the agreed upon definitions and usage for terms, symbols and abbreviations used by the gear industry, as well as terms commonly used in gear load rating.

ISBN: 1-55589-551-4 Pages: 64

!! NEW !!

ANSI/AGMA 1102-A03, ***Tolerance Specification for Gear Hobs***

Provides specifications for nomenclature, dimensions, equation based tolerances, and inspection practices for gear hobs. Defines a classification system for accuracy grades D through AAA, in order of increasing precision. The standard describes hob identification practices, manufacturing and purchasing considerations, and hob design parameters. An informative annex is included which provides the reader with a basic understanding of how the different elements of a hob can affect the accuracy of the gear being machined. **Revision of AGMA 120.01.**

ISBN: 1-55589-816-5 Pages: 49

ANSI/AGMA 1106-A97 (R2003) ***Tooth Proportions for Plastic Gears***

Presents a new basic rack, AGMA PT, which, with its full round fillet, may be preferred in many applications of gears made from plastic materials. It contains a description, with equations and sample calculations, of how the proportions of a spur or helical gear may be derived from the design tooth thickness and the basic rack data. In several annexes, there are discussions of possible variations from the basic rack and also a procedure for defining tooth proportions without using the basic rack concept. **Metric edition of ANSI/AGMA 1006-A97.**

ISBN: 1-55589-685-5 Pages: 47

ANSI/AGMA ISO 1328-1 ***Cylindrical Gears - ISO System of Accuracy - Part 1: Definitions and Allowable Values of Deviations Relevant to Corresponding Flanks of Gear Teeth***

Contains the ISO system of accuracy relevant to corresponding flanks of individual cylindrical gears. It provides definitions for gear tooth accuracy terms, the structure of the gear accuracy system and the allowable values of pitch, profile and helix deviations.

A normative annex for tangential composite tolerances and an informative annex for allowable values of profile form, profile slope, helix form and helix slope deviations are provided. **Identical adoption of ISO 1328-1:1995.**
ISBN: 1-55589-733-9 Pages: 28

ANSI/AGMA ISO 1328-2 ***Cylindrical Gears - ISO System of Accuracy - Part 2: Definitions and Allowable Values of Deviations Relevant to Radial Composite Deviations and Runout Information***

Contains the ISO system of accuracy relevant to radial (double flank) composite deviations of individual cylindrical gears. It provides definitions for gear tooth accuracy terms, the structure of the gear accuracy system and the allowable values of radial composite deviations. An informative annex is included that provides equations for determining allowable values of runout. **Identical adoption of ISO 1328-2:1997.**
ISBN: 1-55589-734-7 Pages: 11

ANSI/AGMA 2000-A88 ***Gear Classification and Inspection Handbook - Tolerances and Measuring Methods for Unassembled Spur and Helical Gears (Including Metric Equivalents)***

Correlates gear quality levels with gear tooth tolerances. Provides information on manufacturing procedures, master gears, measuring methods and practices. Appendix material provides guidance on specifying levels and information on additional methods of gear inspection. **Partial replacement of AGMA 390.03.**
ISBN: 1-55589-495-X Pages: 156

ANSI/AGMA 2001-C95 ***Fundamental Rating Factors and Calculation Methods for Involute Spur and Helical Gear Teeth***

Presents a comprehensive method for rating the pitting resistance and bending strength of spur and helical involute gear pairs. Includes detailed discussions of factors influencing gear survival and calculation methods. **Revision of ANSI/AGMA 2001-B88.**
ISBN: 1-55589-647-2 Pages: 70

ANSI/AGMA 2002-B88 (R1996) ***Tooth Thickness Specification and Measurement***

Presents procedures for determining tooth thickness measurements of external and internal cylindrical involute gearing. Includes equations and calculation procedures for commonly used measuring methods.
ISBN: 1-55589-503-4 Pages: 47

ANSI/AGMA 2003-B97 (R2003) ***Rating the Pitting Resistance and Bending Strength of Generated Straight Bevel, Zerol Bevel, and Spiral Bevel Gear Teeth***

Presents a method for rating the pitting resistance and bending strength of generated straight bevel, zerol bevel, and spiral bevel gear teeth. Includes a detailed discussion of factors influencing gear survival and a calculation method. **Revision of ANSI/AGMA 2003-A86.**
ISBN: 1-55589-692-8 Pages: 75

ANSI/AGMA 2004-B89 (R2000) ***Gear Materials and Heat Treatment Manual***

Provides information pertaining to engineering materials and material treatment used in gear manufacture. Includes definitions, selection guidelines, heat treatment, quality control, life considerations and a bibliography. Material selection includes ferrous, nonferrous and nonmetallic materials. Examines wrought, cast, and fabricated gear blanks. Includes heat treatment sections on through hardened, flame hardened, induction hardened, carburized, carbonitrided, and nitrided gears. Discusses quenching, distortion and shot peening. Also discusses quality control as related to gear blanks, process control, and metallurgical testing on the final products.
ISBN: 1-55589-524-7 Pages: 78

!! NEW !!

ANSI/AGMA 2005-D03 ***Design Manual for Bevel Gears***

Provides the standards for designing straight bevel, zerol bevel, spiral bevel and hypoid gears along with information on fabrication, inspection and mounting. Covers preliminary gear design parameters, blank design including standard taper, uniform depth, duplex taper and tilted root. Also includes drawing format, inspection, materials, lubrication, mountings and assembly. An Annex contains examples for ease of understanding. **Revision of ANSI/AGMA 2005-C96.**
ISBN: 1-55589-667-7 Pages: 94

ANSI/AGMA 2007-C00 ***Surface Temper Etch Inspection After Grinding [Same as New ISO 14104]***

Explains the materials and procedures to determine and evaluate localized overheating on ground surfaces. Includes a system to describe and classify the indications produced during this inspection. However, does not provide specific acceptance or rejection criteria. **Revision of ANSI/AGMA 2007-B92.**
ISBN: 1-55589-761-4 Pages: 6

ANSI/AGMA 2008-C01 ***Assembling Bevel Gears***

Prepared expressly for the assembly man in the factory and the service man in the field. Each definition, explanation, and instruction is directed toward the physical appearance of the gears as they are inspected and assembled by these personnel. **Supersedes ANSI/AGMA 2008-B90.**
ISBN: 1-55589-795-9 Pages: 30

ANSI/AGMA 2009-B01 ***Bevel Gear Classification, Tolerances, and Measuring Methods***

Establishes a classification system which may be used to communicate geometrical accuracy specifications of unassembled bevel gearing. It also provides information on measuring methods and practices to promote uniform measurement procedures. Eight accuracy grades are defined, numbered B3 through B10, in order of DECREASING precision. Equations for the tolerances are provided in metric terms. **Supersedes ANSI/AGMA 2009-A98.**

ISBN: 1-55589-794-0 Pages: 68

ANSI/AGMA 2010-A94 (R2000) ***Measuring Instrument Calibration -- Part I, Involute Measurement***

Applies solely to the qualification of gear tooth profile inspection instruments. Provides procedures for the design, calibration and traceability of involute, pin and plane (flank) masters. Also covers condition evaluation of involute measuring instruments, such as probe location, gain, hysteresis, etc.

ISBN: 1-55589-630-8 Pages: 39

ANSI/AGMA 2011-A98 ***Cylindrical Wormgearing Tolerance and Inspection Methods***

Establishes a classification system for the geometrical accuracy specification of wormgearing. It also provides uniform measurement procedures including discussions on single and double flank composite testing and tooth thickness measurements. The standard establishes ten accuracy grades, W3 through W12, based on the relative effect of geometrical errors on conjugate action for wormgear sets.

ISBN: 1-55589-716-9 Pages: 43

ANSI/AGMA 2015-1-A01 ***Accuracy Classification System - Tangential Measurements for Cylindrical Gears***

This standard, for spur and helical gearing, correlates gear accuracy grades with gear tooth tolerances. It provides information on minimum requirements for accuracy groups as well as gear measuring practices. Annex material provides guidance on filtering and information on comparison of gear inspection methods. Users of this standard should have a copy of the companion information sheet, AGMA 915-1-A02. **Revision of ANSI/AGMA 2000-A88.**

ISBN: 1-55589-797-5 Pages: 37

!! NEW !!

Supplemental Tables for AGMA 2015/915-1-A02 ***Accuracy Classification System - Tangential Measurement Tolerance Tables for Cylindrical Gears***

Provides tolerance tables as a supplement to AGMA 2015-1-A01, *Accuracy Classification System - Tangential Measurements for Cylindrical Gears.*

ISBN: 1-55589-813-0 Pages: 101

ANSI/AGMA 2101-C95 ***Fundamental Rating Factors and Calculation Methods for Involute Spur and Helical Gear Teeth***

Presents a comprehensive metric method for rating the pitting resistance and bending strength of spur and helical involute gear pairs. Includes detailed discussions of factors influencing gear survival and calculation methods. **Metric edition of ANSI/AGMA 2001-C95.**

ISBN: 1-55589-648-0 Pages: 70

ANSI/AGMA 2110-A94 (R2000) ***Measuring Instrument Calibration -- Part I, Involute Measurement (Metric)***

Applies solely to the qualification of gear tooth profile inspection instruments. Provides procedures for the design, calibration, and traceability of involute, pin, and plane (flank) masters. Also covers condition evaluation of involute measuring instruments such as probe location, gain, hysteresis, etc. **Metric edition of ANSI/AGMA 2010-A94.**

ISBN: 1-55589-631-6 Pages: 39

ANSI/AGMA 2111-A98 ***Cylindrical Wormgearing Tolerance and Inspection Methods***

Establishes a classification system for the geometrical accuracy specification of wormgearing. It also provides uniform measurement procedures including discussions on single and double flank composite testing and tooth thickness measurements. The standard establishes ten accuracy grades, W3 through W12, based on the relative effect of geometrical errors on conjugate action for wormgear sets. **Metric edition of ANSI/AGMA 2011-A98.**

ISBN: 1-55589-717-7 Pages: 43

ANSI/AGMA 2113-A97 ***Measuring Instrument Calibration, Gear Tooth Alignment Measurement***

Provides procedures for the design, calibration and traceability of involute, pin and plane (flank) masters. It covers the condition evaluation of involute measuring instruments such as probe location, gain, hysteresis, etc. Recommendations are included for establishment of a proper environment and for statistical data evaluation procedures. This standard is applicable solely to the qualification of gear tooth profile inspection instruments.

ISBN: 1-55589-687-1 Pages: 33

ANSI/AGMA 2114-A98 ***Measuring Instrument Calibration, Gear Pitch and Runout Measurements***

Provides qualification procedures for gear measuring instruments that are used for evaluation of pitch and runout measurements. This includes instruments that measure runout directly, or compute it from index measurements. It also covers condition evaluation of the measuring instrument. Recommendations are included for establishment of a proper environment and for statistical data evaluation procedures.

ISBN: 1-55589-732-0 Pages: 33

ANSI/AGMA 6000-B96 (R2002) ***Specification for Measurement of Linear Vibration on Gear Units***

Presents a method for measuring linear vibration on a gear unit. Recommends instrumentation, measuring methods, test procedures and discrete frequency vibration limits for acceptance testing. Annexes list system effects on gear unit vibration and system responsibility. The ISO vibration rating curves from ISO 8579-2, Acceptance code for gears - Part 2: Determination of mechanical vibrations of gear units during acceptance testing are introduced.

ISBN: 1-55589-666-9 Pages: 21

ANSI/AGMA 6001-D97 (R2003) ***Design and Selection of Components for Enclosed Gear Drives***

Outlines the basic practices for the design and selection of components (other than gearing) which are used in commercial and industrial enclosed gear drives. Discusses bearings, bolting, keys and the most recent theories on shafting among other components. **Revision of ANSI/AGMA 6001-C88.**

ISBN: 1-55589-683-9 Pages: 41

ANSI/AGMA 6002-B93 (R2001) ***Design Guide for Vehicle Spur and Helical Gears***

A guide to the design, fabrication, and inspection of spur and helical gears for vehicles and for power transmission on vehicles.

ISBN: 1-55589-616-2 Pages: 38

ANSI/AGMA 6004-F88 (R1996) ***Gear Power Rating for Cylindrical Grinding Mills, Kilns, Coolers and Dryers***

Covers open and semi-enclosed gear drives. Does not include enclosed speed reducers or gearmotors.

ISBN: 1-55589-499-2 Pages: 27

ANSI/AGMA 6005-B89 (R1996) ***Power Rating for Helical and Herringbone Gearing for Rolling Mill Service***

Specifies a method for rating the pitting resistance and bending strength of herringbone, double helical and helical involute gear pairs as applied to metal rolling mills.

ISBN: 1-55589-530-1 Pages: 33

!! NEW !!

ANSI/AGMA/AWEA 6006-A03, ***Standard for Design and Specification of Gearboxes for Wind Turbines***

This standard is intended to apply to wind turbine gearboxes. It provides information for specifying, selecting, designing, manufacturing, procuring operating and manufacturing reliable speed increasing gearboxes for wind turbine generator system service.

Annex information is supplied on: wind turbine architecture, wind turbine load description, quality assurance, operation and maintenance, minimum purchaser gearbox manufacturing ordering data, lubrication selection and monitoring, determination of an application factor from a load spectrum using equivalent torque, and bearing stress calculations. Replaces AGMA 921-A97.

ISBN: 1-55589-817-3 Pages: 94

ANSI/AGMA 6008-A98 ***Specifications for Powder Metallurgy Gears***

Defines the minimum detailed information to be included in the powder metallurgy gear specifications submitted by the gear purchaser to the gear producer. Specifications on gear tooth geometry are described in detail for external spur and helical gears and for straight bevel gears. In addition, there are discussions on specifications for gear drawings and gear material data. The standard applies to gears made by the conventional P/M process consisting of compaction followed by sintering and, in some cases, by post sintering treatments.

ISBN: 1-55589-713-4 Pages: 17

ANSI/AGMA 6009-A00 ***Standard for Gearmotor, Shaft Mounted and Screw Conveyor Drives***

Defines a rating and selection practice for the entitled gear units. It provides information on pitting resistance and bending strength rating, lubrication, component ratings, thermal ratings, storage and installation. Annex material includes application classification and class numbers, detail rating examples, and recommended bore sizes for shaft mounted units. **Supersedes ANSI/AGMA 6019-E89 and ANSI/AGMA 6021-G89.**

ISBN: 1-55589-759-2 Pages: 61

ANSI/AGMA 6010-F97 (R2003) ***Standard for Spur, Helical, Herringbone, and Bevel Enclosed Drives***

Presents a method for rating the pitting resistance and bending strength of spur, helical, herringbone and bevel gears used for enclosed speed reducers and increasers. Includes information on unit rating, lubrication, components, thermal rating, storage and installation. **Replaces ANSI/AGMA 6010-E88.**

ISBN: 1-55589-690-1 Pages: 56

!! NEW !!

ANSI/AGMA 6011-I03 ***Specification for High Speed Helical Gear Units***

This standard includes information on design, lubrication, bearings, testing and rating for single and double helical external tooth, parallel shaft speed reducers and increasers. Units covered include those operating with at least one stage having a pitch line velocity equal to or greater than 35 meters per second or rotational speeds greater than 4500 rpm and other stages having pitch line velocities equal to or greater than 8 meters per second. Annex material includes discussions on service factors, rotor dynamics, efficiency and newly configured purchaser's data sheets. **Supercedes ANSI/AGMA 6011-H98.**

ISBN: 1-55589-819-X Pages: 51

ANSI/AGMA 6022-C93 (R2000) ***Design Manual for Cylindrical Wormgearing***

Covers the design of general industrial coarse-pitch cylindrical worms and throated gears mounted with axes at a 90 degree angle and having axial pitches of 3/16 inch and larger.

ISBN: 1-55589-041-5 Pages: 10

ANSI/AGMA 6023-A88 (R2000) ***Design Manual for Enclosed Epicyclic Gear Drives***

Covers designs for drives employing epicyclic gear arrangements. Includes descriptions of epicyclic drives, nomenclature, application information, and design guidelines with reference to other AGMA Standards. See ANSI/AGMA 6123-A88.

ISBN: 1-55589-504-2 Pages: 50

ANSI/AGMA 6025-D98 ***Sound for Enclosed Helical, Herringbone and Spiral Bevel Gear Drives***

Describes a recommended method of acceptance testing and reporting of the sound pressure levels generated by a gear speed reducer or increaser when tested at the manufacturer's facility. The results obtained through the use of this standard should represent only the sound of the gear unit, as other system influences, such as prime mover or driven equipment are minimized. Annexes to the standard present sound power measurement methods for use when required by specific contract provisions between the manufacturer and purchaser. **Replaces ANSI/AGMA 6025-C90.**

ISBN: 1-55589-718-5 Pages: 21

ANSI/AGMA 6032-A94 (R2000) ***Standard for Marine Gear Units: Rating***

Considers rating practices for marine main propulsion, power take-off and auxiliary propulsion service. Allowable contact stress numbers and allowable bending stress numbers for materials are included. Also addresses bearings, clutches, lubricating oil systems, shafts and certain aspects of vibration.

ISBN: 1-55589-633-2 Pages: 57

ANSI/AGMA 6033-B98 ***Materials for Marine Propulsion Gearing***

Identifies commonly used alloy steels, heat treatments and material inspection requirements for main propulsion marine service through hardened, case hardened and surface hardened gearing for over 1500 horsepower. Forged and hot rolled alloy steel bar stock are specified to three metallurgical quality grades (I, II and III) according to cleanliness and test requirements. Cast steel gearing is specified to a single metallurgical quality level. Mechanical, metallurgical and nondestructive test requirements are provided for various heat treat processes and metallurgical quality grades of gearing. **Replaces ANSI/AGMA 6033-A88.**

ISBN: 1-55589-711-8 Pages: 48

ANSI/AGMA 6034-B92 (R1999) ***Practice for Enclosed Cylindrical Wormgear Speed Reducers and Gearmotors***

Covers the design and rating of cylindrical- wormgear speed reducers, having either solid or hollow output shafts of the following specific types: single reduction; double reduction incorporating cylindrical wormgearing for each reduction; and double reduction incorporating cylindrical wormgearing as final and helical gearing as initial reduction.

ISBN: 1-55589-494-1 Pages: 37

ANSI/AGMA 6035-A02 ***Design, Rating and Application of Industrial Globoidal Wormgearing***

This standard provides guidelines for the design, rating and application of globoidal wormgearing mounted at a 90 degree angle. Specific definitions for globoidal wormgearing terms are presented, along with formulas for determining the geometric sizes of the major features for the worm and gear. Design considerations, design procedures, gear blanks and self-locking conditions are also discussed. Procedures for rating the load capacity of globoidal wormgearing are included. **Replaces ANSI/AGMA 6017-E86 and ANSI/AGMA 6030-C87.**

ISBN: 1-55589-792-4 Pages: 45

ANSI/AGMA 6109-A00 ***Standard for Gearmotor, Shaft Mounted and Screw Conveyor Drives***

Defines a rating and selection practice for the entitled gear units. It provides information on pitting resistance and bending strength rating, lubrication, component ratings, thermal ratings, storage and installation. Annex material includes application classification and class numbers, detail rating examples, and recommended bore sizes for shaft mounted units. **Metric version of ANSI/AGMA 6009-A00. Supersedes ANSI/AGMA 6019-E89 and ANSI/AGMA 6021-G89.**

ISBN: 1-55589-760-6 Pages: 61

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ANSI/AGMA 6110-F97 (R2003) ***Standard for Spur, Helical, Herringbone, and Bevel Enclosed Drives***

Presents a method for rating the pitting resistance and bending strength of spur, helical, herringbone and bevel gears used for enclosed speed reducers and increasers. Includes information on unit rating, lubrication, components, thermal rating, storage and installation. **Metric version of ANSI/AGMA 6010-F97.**

ISBN: 1-55589-691-X Pages: 56

ANSI/AGMA 6123-A88 (R2000) ***Design Manual for Enclosed Epicyclic Metric Module Gear Drives***

Provides guidelines for designing drives employing epicyclic gear arrangements. Includes descriptions of epicyclic drives, nomenclature, application information and design guidelines, with reference to other AGMA Standards. See ANSI/AGMA 6023-A88.

ISBN: 1-55589-505-0 Pages: 50

ANSI/AGMA 6133-B98 ***Materials for Marine Propulsion Gearing***

Identifies commonly used alloy steels, heat treatments and material inspection requirements for main propulsion marine service through hardened, case hardened and surface hardened gearing for over 1500 horsepower. Forged and hot rolled alloy steel bar stock are specified to three metallurgical quality grades (I, II and III) according to cleanliness and test requirements. Cast steel gearing is specified to a single metallurgical quality level. Mechanical, metallurgical and nondestructive test requirements are provided for various heat treat processes and metallurgical quality grades of gearing. **Metric edition of ANSI/AGMA 6033-B98.**

ISBN: 1-55589-712-6 Pages: 48

ANSI/AGMA 6135-A02 ***Design, Rating and Application of Industrial Globoidal Wormgearing (Metric Version)***

This standard provides guidelines for the design, rating and application of globoidal wormgearing mounted at a 90 degree angle. Specific definitions for globoidal wormgearing terms are presented, along with formulas for determining the geometric sizes of the major features for the worm and gear. Design considerations, design procedures, gear blanks and self-locking conditions are also discussed. Procedures for rating the load capacity of globoidal wormgearing are included. **Replaces ANSI/AGMA 6017-E86 and ANSI/AGMA 6030-C87. Metric edition of ANSI/AGMA 6035-E02.**

ISBN: 1-55589-793-2 Pages: 45

ANSI/AGMA 9000-C90 (R2001) ***Flexible Couplings - Potential Unbalance Classification***

Offers standard criteria for the unbalance classification of flexible couplings. Considers the effects of hardware and eccentricity to give a more accurate value. Presents revised examples in the appendices that illustrate the calculation methods. **Revision of AGMA 515.02.**

ISBN: 1-55589-549-2 Pages: 41

ANSI/AGMA 9001-B97 (R2003) ***Flexible Couplings - Lubrication***

Examines proper lubrication and why it is an essential element for satisfactory performance and long life. Looks at the requisites for proper lubrication, including: selection of proper lubricant, a well-designed lubrication system, and an adequate maintenance program, are discussed in this standard. **Revision of ANSI/AGMA 9001-A86.**

ISBN: 1-55589-686-3 Pages: 6

ANSI/AGMA 9002-A86 (R2001) ***Bores and Keyways for Flexible Couplings (Inch Series)***

Provides designers and users standard dimensions and tolerances for inch bores, keys and keyways for flexible couplings. Includes dimensions that represent the dimensions and tolerances used within the industry for pre-engineered couplings, but that can also be used for custom engineered coupling products.

ISBN: 1-55589-175-6 Pages: 24

ANSI/AGMA 9003-A91 (R1999) ***Flexible Couplings - Keyless Fits***

Presents information on design, dimensions, tolerances, inspection, mounting, removal and equipment that is in common use with keyless tapered and keyless straight (cylindrical) bore hubs for flexible couplings.

ISBN: 1-55589-572-7 Pages: 21

ANSI/AGMA 9004-A99 ***Flexible Couplings - Mass Elastic Properties and Other Characteristics***

Provides information and calculation methods to system designers for the selection of system components and natural frequency calculations. Mass elastic properties discussed include coupling weight, WR^2, center of gravity, axial stiffness, axial natural frequency, lateral stiffness, lateral natural frequency and torsional stiffness.

ISBN: 1-55589-715-0 Pages: 39

ANSI/AGMA 9005-E02 ***Industrial Gear Lubrication***

This standard provides the end user, original equipment builder, gear manufacturer and lubricant supplier with guidelines for minimum performance characteristics for lubricants suitable for use with enclosed and open gearing which is installed in general industrial power transmission applications. It provides recommendations for selecting lubricants based on current theory and practice in the industry, and attempts to align with current ISO standards. It is not intended to supplant specific instructions from the gear manufacturer. Replaces ANSI/AGMA 9005-D94.

ISBN: 1-55589-800-9 Pages: 31

ANSI/AGMA 9008-B00 *Flexible Couplings – Gear Type – Flange Dimensions, Inch Series*

Defines the North American industry practice for the interface dimensions of the sleeve and rigid hubs of both shrouded and exposed bole, inch series, gear type couplings.

ISBN: 1-55589-736-3 Pages: 3

ANSI/AGMA 9009-D02 *Flexible Couplings - Nomenclature for Flexible Couplings*

Presents the nomenclature common to flexible couplings as used in mechanical power transmission drives. It was prepared to reduce the language barriers that arise between designers, manufacturers and users when attempting to designate various types of flexible couplings and their elements. It does not address nomenclature for flexible shafts, quill shafts, universal joints or devices which exhibit slip such as clutches, fluid couplings, magnetic couplings or torque converters.

ISBN: 1-55589-796-7 Pages: 17

AGMA ISO 10064-1 *Cylindrical Gears - Code of Inspection Practice - Part 1: Inspection of Corresponding Flanks of Gear Teeth*

Provides a code of practice dealing with the tangential measurements of cylindrical involute gear tooth flanks (pitch deviations, profile deviations, helix deviations and tangential composite deviations), and serves as a supplement to ANSI/AGMA ISO 1328-1, Cylindrical Gears - ISO System of Accuracy - Part 1: Definitions and Allowable Values of Deviations Relevant to Corresponding Flanks of Gear Teeth. This AGMA Information Sheet is an identical adoption of ISO/TR 10064-1.

ISBN: 1-55589-735-5 Pages: 26

AGMA ISO 10064-2 *Cylindrical Gears - Code of Inspection Practice - Part 2: Inspection Related to Radial Composite Deviations, Runout, Tooth Thickness and Backlash*

Provides a code of practice dealing with inspection relevant to radial composite deviations, runout, tooth thickness and backlash of cylindrical involute gear (measurements referred to double flank contact), and serves as a supplement to ANSI/AGMA ISO 1328-2, Cylindrical Gears - ISO System of Accuracy - Part 2: Definitions and Allowable Values of Deviations Relevant to Radial Composite Deviations and Runout Information. This AGMA Information Sheet is an identical adoption of ISO/TR 10064-2.

ISBN: 1-55589-737-1 Pages: 25

!! NEW !!

AGMA ISO 14179-1, *Gear Reducers - Thermal Capacity Based on ISO/TR 14179-1*

This information sheet utilizes an analytical heat balance model to provide a means of calculating the thermal transmittable power for a single- or multi-stage gear drive lubricated with mineral oil. The calculation is based on standard conditions of 25C maximum ambient temperature and 95C maximum oil sump temperature in a large indoor space, but provides modifiers for other conditions. This document is not identical to ISO/TR 14179-1 as a) errors were identified and corrected, b) text was added to clarify the calculation methods, and c) an illustrative example was added to assist the reader.

ISBN: 1-55589-821-1 Pages: 26

ISO Standards by Technical Committee 60

Technical Committee 60 is responsible for the development of all international gear–related standards.

Many standards require additional documents for their proper use. A list of these standards are normally supplied after the scope, in the normative references section of a document. Be sure to inquire whether the standard you need requires other documents listed herein.

53:1998 Cylindrical gears for general and heavy engineering – Standard basic rack tooth profile

54:1996 Cylindrical gears for general engineering and for heavy engineering – Modules

677:1976 Straight bevel gears for general engineering and heavy engineering – Basic rack

678:1976 (1996) Straight bevel gears for general engineering and heavy engineering – Modules and diametral pitches

701:1998 International gear notation – Symbols for geometric data

1122–1:1998 Glossary of gear terms – Part 1: Definitions related to geometry

1122–2:1999 Vocabulary of gear terms – Part 2: Definitions related to worm gear geometry

1328–1:1995 Cylindrical gears – ISO system of accuracy – Part 1: Definitions and allowable values of deviations relevant to corresponding flanks of gear teeth **(See ANSI/AGMA ISO 1328–1)**

1328–2:1997 Cylindrical gears – ISO system of accuracy – Part 2: Definitions and allowable values of deviations relevant to radial composite deviations and runout information **(See ANSI/AGMA ISO 1328–2)**

1340:1976 Cylindrical gears – Information to be given to the manufacturer by the purchaser in order to obtain the gears required

1341:1976 Straight bevel gears – Information to be given to the manufacturer by the purchaser in order to obtain the gears required

2490:1996 Single–start solid (monoblock) gear hobs with tenon drive or axial keyway, 1 to 40 module – Nominal dimensions

TR4467:1982 Addendum modification of the teeth of cylindrical gears for speed–reducing and speed–increasing gear pairs

4468:1982 Gear hobs – Single start – Accuracy requirements

6336–1:1996 Calculation of load capacity of spur and helical gears – Part 1: Basic principles, introduction and general influence factors

6336–2:1996 Calculation of load capacity of spur and helical gears – Part 2: Calculation of surface durability (pitting)

6336–3:1996 Calculation of load capacity of spur and helical gears – Part 3: Calculation of tooth bending strength

6336–5:2003 Calculation of load capacity of spur and helical gears – Part 5: Strength and quality of materials

8579–1:2002 Acceptance code for gears – Part 1: Determination of airborne sound power levels emitted by gear units

8579–2:1993 Acceptance code for gears – Part 2: Determination of mechanical vibration of gear units during acceptance testing

9083:2001 Calculation of load capacity of spur and helical gears – Application to marine gears

9084:2000 Calculation of load capacity of spur and helical gear – Application to high speed gears and gears of similar requirements

9085:2002 Calculation of load capacity of spur and helical gears – Application for industrial gears

TR10064–1:1992 Cylindrical gears – Code of inspection practice – Part 1: Inspection of corresponding flanks of gear teeth **(See AGMA ISO 10064–1)**

TR10064–2:1996 Cylindrical gears – Code of inspection practice – Part 2: Inspection related to radial composite deviations, runout, tooth thickness and backlash **(See AGMA ISO 10064–2)**

TR10064–3:1996 Cylindrical gears – Code of inspection practice – Part 3: Recommendations relative to gear blanks, shaft centre distance and parallelism of axes

TR10064–4:1998 Cylindrical gears – Code of inspection practice – Part 4: Recommendations relative to surface texture and tooth contact pattern checking

10300–1:2001 Calculation of load capacity of bevel gears – Part 1: Introduction and general influence factors

10300–2:2001 Calculation of load capacity of bevel gears – Part 2: Calculation of surface durability (pitting)

10300–3:2001 Calculation of load capacity of bevel gears – Part 3: Calculation of tooth root strength

10347:1999 Worm gears – Geometry of worms – Name plates for worm gear units, centre distances, information to be supplied to gear manufacturer by the purchaser

TR10495:1997 Cylindrical gears– Calculation of service life under variable loads – Conditions for cylindrical gears according to ISO 6336

10825:1995 Gears – Wear and damage to gear teeth – Terminology

TR10828:1997 Wormgears – Geometry of worm profiles

TR 13593:1999 Enclosed gear drives for industrial applications

13691:2001 Petroleum and natural gas industries – High speed special–purpose gear units

TR 13989–1:2000 Calculation of scuffing load capacity of cylindrical, bevel and hypoid gears – Part 1: Flash temperature method

TR 13989–2:2000 Calculation of scuffing load capacity of cylindrical, bevel and hypoid gears – Part 2: Integral temperature method

14104:1995 Gears – Surface temper etch inspection after grinding

TR 14179–1:2001 Gears – Thermal capacity – Part 1: Rating gear drives with thermal equilibrium at 95°C sump temperature

TR 14179–2:2001 Gears – Thermal capacity – Part 2: Thermal load–carrying capacity

14635–1:2000 Gears – FZG test procedures – Part 1: FZG method A/8, 3/90 for relative scuffing load carrying capacity of oils

Gear Software

ISO 6336 Software by AGMA

The ISO 6336 standard is being adopted by countries throughout the world. It is the most massive and complex gear standard ever. Because of the large number of inputs and formulas and because of the choices in methodology, the new standard is definitely not for the beginning engineer. Calculating by method B requires more than 80 input values!

Fortunately, the American Gear Manufacturers Association is ready with valuable new software, which lets you master ISO 6336.

Developed and tested over several years by a group of fourteen AGMA men and women working closely with the developers by the international standard, the software addresses ISO 6336 method B, the most comprehensive, analytical calculation method. It enables you to:

- determine gear capacity in accordance with the ISO 6336 standard quickly and accurately;
- compare your own design and practices with ISO 6336 results;
- understand your competitor's ratings.

The time this program will save you is exponential. Don't spend days pouring over documents and running calculations! AGMA's clear, logical Windows screens lead you through all the necessary inputs, grouping geometry, materials and operating characteristics. The DOS program even allows you to calculate multiple gear sets with a batch input file!

The manual alone is worth the price! In addition to explaining the software, this handy document is a great tool for learning how to use ISO 6336, guiding you through the complexities and teaching you the correct inputs, especially in the exacting areas of tooth geometry and tooling.

AGMA's Gear Rating Suite

Two of the most recognized standards in the world today for determining the rating of spur and helical gears are ANSI/AGMA 2001–C95 and ISO 6336. Now for the first time, software to calculate ratings in accordance with each standard is available in one package from AGMA. Entitled the ***Gear Rating Suite***, the software allows the user to input data once for each gearset, and obtain ratings to both standards.

Beginning with AGMA's ISO6336 Software, which has gained international acceptance since its release in 1998, the ***Gear Rating Suite*** adds an equally comprehensive module to calculate ratings per ANSI/AGMA 2001–C95. Among the many features of the software package are:

- An in–depth User's Manual, and all required AGMA and ISO standards.
- User friendly I/O that provides an intuitive user interface, with drop–down boxes, look–up tables, and graphical guides used to assist in data entry.
- Dual input units which allow the user to switch between SI and inch units.
- Error and warning messages are provided within both the input and rating routines to help identify problems.
- A help program is incorporated within the software.
- Long and short form outputs are provided.

In addition to the gear rating routines and aids, the package also provides:

- A Geometry Checker for checking input data to ensure they are within allowable ranges. The Geometry Checker will help identify data entry errors and unusual gear designs.
- Tolerance worksheets which allow the user to calculate tooth tolerances from quality numbers, convert quality numbers between AGMA and ISO, and to display tolerances for adjacent grades.

The potential of the ***Gear Rating Suite*** to improve your efficiency and save you time in performing these rigorous calculations makes this a "must have" tool for all gear engineers.

Fall Technical Meeting Papers: 1990 – 2002

2002 PAPERS

02FTM1. *The Effect of Chemically Accelerated Vibratory Finishing on Gear Metrology*
Authors: **Lane Winklemann, Mark Michaud, Gary Sroka, Joseph Arvin and Ali Manesh**

Chemically accelerated vibratory finishing is a commercially proven process that is capable of isotropically superfinishing metals to an Ra < 1.0 ìin. Gears have less friction, run significantly cooler and have lower noise and vibration when this technology is applied. Scuffing, contact fatigue (pitting), and bending fatigue are also reduced or eliminated both in laboratory testing and field trials. This paper presents studies done on aerospace Q13 spiral bevel gears showing that the amount of metal removed to superfinish the surface is both negligible and controllable. Media selection and metal removal monitoring procedures are described ensuring uniform surface finishing, controllability and preservation of gear metrology.

ISBN: 1–55589–801–7 Pages: 18

02FTM2. *Development and Application of Computer–Aided Design and Tooth Contact Analysis of Spiral–Type Gears with Cylindrical Worm*
Authors: **V.I. Goldfarb and E.S. Trubachov**

This paper presents the method of step–by–step computer–aided design of spiroid–type gears, which involves gear scheme design, geometric calculation of gearing, drive design, calculation of machine settings and tooth–contact analysis. Models of operating and generating gearing have been developed, including models of manufacture and assembly errors, force and temperature deformations acting in real gearing, and drive element wear. Possibilities of CAD–technique application are shown to solve design and manufacture tasks for gearboxes and gear–motors with spiroid–type gears.

ISBN: 1–55589–802–5 Pages: 15

02FTM3. *The Application of Statistical Stability and Capability for Gear Cutting Machine Acceptance Criteria*
Author: **T.J. (Buzz) Maiuri**

Over the years the criteria for gear cutting machine acceptance has changed. In the past, cutting a standard test gear or cutting a customer gear to their specification was all that was expected for machine acceptance. Today, statistical process control (SPC) is required for virtually every machine runoff. This paper will cover the basic theory of stability and capability and its application to bevel and cylindrical gear cutting machine acceptance criteria. Actual case studies will be presented to demonstrate the utilization of these SPC techniques.

ISBN: 1–55589–803–3 Pages: 26

02FTM4. *Multibody–System–Simulation of Drive Trains of Wind Turbines*
Author: **Berthold Schlecht**

During the last years a multitude of wind turbines have been put into operation with continuously increased power output. Wind turbines with 6 MW output are in the stage of development, a simple extrapolation to larger dimensions of wind turbines on the basis of existing plants and operational experiences is questionable. This paper deals with the simulation of the dynamic behavior of the complete drive train of a wind turbine by using a detailed Multi–System–Model with special respect of the gear box internals. Starting with the model creation and the analysis of the natural frequencies, various load cases in the time domain will be discussed.

ISBN: 1–55589–804–1 Pages: 13

02FTM5. *Crack Length and Depth Determination in an Integrated Carburized Gear/Bearing*
Authors: **Raymond Drago and James Kachelries**

In an effort to determine if processing cracks posed a safety of flight concern, several gears that contained cracks were designated to undergo a rigorous bench test. Prior to the start of the test, it was necessary to document, nondestructively, all of the crack dimensions. This paper will present a specially modified magnetic rubber inspection technique to determine crack lengths as short as 0.006 inch, and a unique, highly sensitive, laboratory eddy current inspection technique to estimate crack depths up to +/– 0.003 inch.

ISBN: 1–55589–805–X Pages: 9

02FTM6. *Contemporary Gear Hobbing – Tools and Process Strategies*
Author: **Claus Kobialka**

Gear manufacturing without coolant lubrication is getting more and more important. Modern hobbing machines are designed to cope with dry hobbing. In the last years, carbide hobs were prevailing in high–speed hobbing due to their excellent thermal stability. Today, this high performance rate is confronted with rather high tool costs and critical tool handling. Powder metallurgical HSS combined with extremely wear resistant coating on the base of (Ti, Al)N offer interesting alternatives for dry hobbing. It is evident that existing conventional hob geometries can be optimized respecting limiting factors like maximum chip thickness and maximum depth of scallops.

ISBN: 1–55589–806–8 Pages: 11

02FTM7. *Selecting the Best Carburizing Method for the Heat Treatment of Gears*

Authors: **Daniel Herring, Gerald Lindell, David Breuer and Beth Madlock**

Vacuum carburizing has proven itself a robust heat treatment process and a viable alternative to atmosphere carburizing. This paper will present scientific data in support of this choice. A comparison of atmosphere carburized gears requiring press quenching to achieve dimensional tolerances in a "one piece at a time" heat treating operation, with a vacuum carburized processing a full load of gears that have been high gas pressure quenched within required tolerances.

ISBN: 1-55589-807-6 Pages: 13

02FTM8. *Compliant Spindle in Lapping and Testing Machines*

Author: **Bill McGlasson**

This paper presents theory, analysis and results of a novel spindle design with application to bevel gear lapping and testing machines. The spindle design includes a rotationally compliant element which can substantially reduce the dynamic forces induced between the gear members while rolling under load. The theory of this spindle concept is presented using simplified models, providing the explanation for the process benefits it brings. Analysis and simulations give additional insight into the dynamics of the system. Finally, actual lapping and testing machine results are presented.

ISBN: 1-55589-808-4 Pages: 11

02FTM9. *Gear RollScan for High Speed Gear Measurement*

Author: **Andreas Pommer**

This presentation features a revolutionary new method for the complete topographical measurement of gears. The Gear RollScan system is similar to one-flank gear rolling inspection. However, the master gear has measuring tracks on selected flanks. With two master gears in roll contact, both the left and right flanks of the specimen can be inspected simultaneously. After a specified number of rotations, every measuring track on the master gears will contact every flank of the specimen this measuring device will always find the worst tooth.

ISBN: 1-55589-809-2 Pages: 10

02FTM10. *Comparing the Gear Ratings from ISO and AGMA*

Author: **Octave LaBath**

In the early 1980's several technical papers were given comparing gear ratings from ISO and AGMA showing some interesting and diverse differences in the trends when the gear geometry was changed slightly. These changes included addendum modification coefficients and helix angle. Differences also existed when the hardness and hardening methods were changed. This paper will use rating programs developed by an AGMA committee to compare AGMA and ISO ratings while having the same gear geometry for both ratings. This will allow consistent trend analysis by only changing one gear geometry parameter while holding other geometry items constant.

ISBN: 1-55589-810-6 Pages: 17

02FTM11. *Gear Design Optimization Procedure that Identifies Robust, Minimum Stress and Minimum Noise Gear Pair Designs*

Author: **Donald Houser**

Typical gear design procedures are based on an iterative process that uses rather basic formulas to predict stresses. Modifications such as tip relief and lead crowning are based on experience and these modifications are usually selected after the design has been considered. In this process, noise is usually an after thought left to be chosen by the designer after the geometric design has been established. This paper starts with micro-topographies in the form of profile and lead modifications. Then, evaluations are made on the load distribution, bending and contact stresses, transmission error, film thickness, flash temperature, etc. for a large number of designs. The key to this analysis is the rapid evaluation of the load distribution.

ISBN: 1-55589-811-4 Pages: 15

02FTMS1 *Design and Stress Analysis of New Version of Novikov-Wildhaber Helical Gears*

Author: **Ignacio Gonzalez-Perez**

This paper covers design, generation, tooth contact analysis and stress analysis of a new type of Novikov-Wildhaber helical gear drive. Great advantages of the developed gear drive in comparison with the previous ones will be discussed, including: reduction of noise and vibration caused by errors of alignment, the possibility of grinding, and application of hardened materials and reduction of stresses. These achievements are obtained by application of: new geometry based on application of parabolic rack-cutters, double-crowning of pinion and parabolic type of transmission errors.

ISBN: 1-55589-812-2 Pages: 25

2001 PAPERS

01FTM1. *Carbide Hobbing Case Study*
Author: **Yefim Kotlyar**

Carbide hobbing improves productivity and cost, however many questions remain regarding the best application, carbide material, hob sharpening, coating and re-coating, hob handling, consistency and optimum hob wear, best cutting conditions, and concerns for the initial cutting tool investment. This paper is a case study of a successful implementation of carbide hobbing for an annual output of 250,000 gears, average lot size of about 200-300 gears, producing gears of about 150 different sizes and pitches, with 4 setups per day on average.

ISBN: 1-55589-780-0 Pages: 16

01FTM2. *The Ultimate Motion Graph for "Noiseless" Gears*
Authors: **Hermann J. Stadtfeld and Uwe Gaiser**

Gear noise is a common problem in all bevel and hypoid gear drives. A variety of expensive gear geometry optimizations are applied daily in all hypoid gear manufacturing plants, to reduce gear noise. In many cases those efforts have little success. This paper will present "The Ultimate Motion Graph", a concept for modulating the tooth surfaces that uses modifications to cancel operating dynamic disturbances that are typically generated by any gear types.

ISBN: 1-55589-781-9 Pages: 16

01FTM3. *Automated Spiral Bevel Gear Pattern Inspection*
Authors: **S.T. Nguyen, A. Manesh, K. Duckworth and S. Wiener**

Manufacturing processes for precision spiral bevel gears are operator intensive, making them particularly costly in today's small lot production environment. This problem is compounded by production requirements for replacement parts that have not been produced for many years. The paper will introduce a new closed loop system capable of reducing development costs by 90% and bevel gear grinder setup time by 80%. In addition, a capability to produce non-standard designs without part data summaries is reviewed. Advancements will also be presented for accepting precision gears using an electronic digital master in lieu of a physical master.

ISBN: 1-55589-782-7 Pages: 15

01FTM4. *How to Inspect Large Cylindrical Gears with an Outside Diameter of More Than 40 Inches*
Author: **Güenter Mikoleizig**

This paper discusses the design and function of the relevant machines used for individual error measurements such as lead and profile form as well as gear pitch and runout. The author will cover different types of inspection machines such as: stationary, CNC-controlled gear measuring centers, and transportable equipment for checking individual parameters directly on the gear cutting or gear grinding machine.

ISBN: 1-55589-783-5 Pages: 20

01FTM5. *Traceability of Gears -- New Ideas, Recent Developments*
Authors: **Frank Härtig and Franz Wäldele**

Some national standard tolerances for cylindrical gears lie in, and even below, the range of instrument measurement uncertainties. This paper presents a concept based on three fundamental goals: reduction of measurement uncertainty, construction of workpiece-like standards, and shortening of the traceability chain. One of the focal points is the development of a standard measuring device as an additional metrological frame integrated into a coordinate measuring machine.

ISBN: 1-55589-784-3 Pages: 6

01FTM6. *Performance-Based Gear-Error Inspection, Specification, and Manufacturing-Source Diagnostics*
Authors: **William D. Mark and Cameron P. Reagor**

This paper will show that a frequency-domain approach for the specification of gear tooth tolerance limits is related to gear performance and transmission errors. In addition, it is shown that one can compute, from detailed tooth measurements, the specific tooth error contributions that cause any particularly troublesome rotational harmonic contributions to transmission error, thereby permitting manufacturing source identification of troublesome operation.

ISBN: 1-55589-785-1 Pages: 15

01FTM7. *Chemically Accelerated Vibratory Finishing for the Elimination of Wear and Pitting of Alloy Steel Gears*
Authors: **Mark Michaud, Gary Sroka and Lane Winkelmann**

Chemically accelerated vibratory finishing eliminates wear and contact fatigue, resulting in gears surviving higher power densities for a longer life compared to traditional finishes. Studies have confirmed this process is metallurgically safe for both through hardened and case carburized alloy steels. The superfinish can achieve an Ra < 1.5 minch, while maintaining tolerance levels. Metrology, topography, scanning electron microscopy, hydrogen embrittlement, contact fatigue and lubrication results are presented.

ISBN: 1-55589-786-X Pages: 16

01FTM8. *The Effect of Spacing Errors and Runout on Transverse Load Sharing and the Dynamic Factor of Spur and Helical Gears*
Authors: **Husny Wijaya, Donald R. Houser and Jonny Harianto**

This paper addresses the effect of two common manufacturing errors on the performance of spur and helical gears; spacing error and gear runout. In

spacing error analysis, load sharing for two worst-case scenarios are treated, one where a tooth is out of position and the second where stepped index errors are applied. The analyzed results are then used as inputs to predict gear dynamic loads, dynamic tooth stresses and dynamic factors for gear rating.
ISBN: 1-55589-787-8 Pages: 16

01FTM9. *New Opportunities with Molded Gears*
Authors: **Roderick E. Kleiss, Alexander L. Kapelevich and N. Jack Kleiss Jr.**
Unique tooth geometry that might be difficult or even impossible to achieve with cut gears can be applied to molded gears. This paper will investigate two types of gears that have been designed, molded and tested in plastic. The first is an asymmetric mesh with dissimilar 23 and 35 degree pressure angles. The second is an orbiting transmission with a 65 degree pressure angle. Both transmissions have higher load potential than traditional design approaches.
ISBN: 1-55589-788-6 Pages: 11

01FTM10. *Design Technologies of High Speed Gear Transmission*
Author: **Jeff Wang**
This paper discusses a few critical factors and their effects on high speed gear transmissions. The first factor is centrifugal force and its effect on tooth root strength, tooth expansion and backlash and the interference fit between gear and shaft. The second is system dynamics, including critical speed, dynamic balancing and the torsional effects of flexible couplings. The third is the windage loss with different combinations of helix and rotation direction, lubricant flow rate, flow distribution and their effects on tooth bulk temperature field and tooth thermal expansion.
ISBN: 1-55589-789-4 Pages: 8

01FTM11. *Kinematic and Force Analysis of a Spur Gear System with Separation of Sliding and Rolling between Meshing Profiles*
Author: **D. E. Tananko**
This paper describes a comprehensive study of the novel gear design with physical separation between sliding and rolling motions of the mesh gear contact point. The sliding motion is accommodated by shear deformation of a thin-layered rubber-metal laminate allowing very high compression loads. Several important advantages will be presented when comparing the composite gear design to the conventional involute profile.
ISBN: 1-55589-790-8 Pages: 50

01FTMS1. *Optical Technique for Gear Contouring*
Author: **Federico Sciammarella**
This paper presents an optical technique (projection moiré) that is compact and can provide a quick full field analysis of high precision gears. Comparisons are made between mechanical and optical profiles obtained of a gear tooth.
ISBN: 1-55589-791-6 Pages: 12

2000 PAPERS

2000FTM1. *Minimization of In-Process Corrosion of Aerospace Gears*
Authors: **S.T. Nguyen, A. Manesh, and J. Reeves**
This paper discusses problems and root causes associated with the corrosion of aerospace gears during the manufacturing process.

Specimens of common base materials used in precision gearing were subjected to process conditions that contribute to corrosion initiation including: different coolant types and concentrations, material heat treat conditions, base material magnetism, surface finish and iron particles in coolant.
ISBN: 1-55589-762-2 Pages: 7

2000FTM2. *The Calculation of Optimum Surface Carbon Content for Carburized Case Hardened Gears*
Author: **P.C. Clarke**
At present, there is not a method to calculate eutectoid carbon from chemical analysis and the eutectoid carbon is not the best element upon which to base surface carbon requirements. This paper will define the conditions and propose a method to calculate an optimum carbon level to minimize the possibilities of retained austenite, cementite and bainite.
ISBN: 1-55589-763-0 Pages: 8

2000FTM3. *Comparison of New Gear Metallurgy Documents, ISO 6336-5 and AGMA 923 with Gear Rating Standards AGMA 2001 and 2003*
Author: **A.A. Swiglo**
This paper will compare and contrast these four documents. What's new, what's different and what's hidden in the footnotes. Knowing the differences will be important to the users of these documents.
ISBN: 1-55589-764-9 Pages: 110

2000FTM4. *Parametric Influences in the ISO Project Concerning Worm Gear Rating*
Author: **M. Octrue**
This paper analyzes the influence of different parameters in CD ISO 14561 Load Capacity Calculation of Worm Gears such as; efficiency, wear load capacity, pitting, deflection and tooth root stress. The influencing parameters are divided into different categories such as external parameters of loading conditions, environmental parameters of lubricant temperature and driving and driven machines.
ISBN: 1-55589-765-7 Pages: 10

2000FTM5. *Systematic Investigations on the Influence of Viscosity Index Improvers on EHL-Film Thickness*
Authors: **B.-R. Hohn, K. Michaelis and F. Kopatsch**
This paper compares film thickness calculations to measurements taken using polymer containing oils in a twin disk machine. Results will show all polymer containing oils form lower film thicknesses than straight mineral oils of the same viscosity after shearing. A polymer correction factor is derived from test results improving the accuracy of film thickness calculation.
ISBN: 1-55589-766-5 Pages: 11

2000FTM6. *Did the Natural Convection Exist in Mechanical Power Transmissions? Theoretical and Experimental Results*
Author: **M. Pasquier**
ISO TR14179 parts 1 and 2, give values of total heat exchange coefficients in the case of natural convection and forced convection. This paper will compare the values of total heat exchange obtained from a theoretical study to the values given in the ISO Technical Reports.
ISBN: 1-55589-767-3 Pages: 10

2000FTM7. *An Analytical - FEM Tool for the Design and Optimization of Aerospace Gleason Spiral Bevel Gears*
Author: **C. Gorla, F. Rosa, and P.G. Schiannini**
To save time and money during the design process a tool based on analytical algorithms and on FEM models is introduced. As a first step, the conjugate surfaces theory is applied to a bevel set. An analytical tooth contact analysis is performed to determine the theoretical contact points on flank surfaces versus the meshing points. Information is then derived by the contact analysis and used to generate Finite Element models of the gear pair on the basis of the theoretical contact pattern. A final simulation by means of FEM models takes into account load sharing between tooth pairs.
ISBN: 1-55589-768-1 Pages: 12

2000FTM8. *Stock Distribution Optimization in Fixed Setting Hypoid Pinions*
Author: **C. Gosselin and J. Masseth**
This paper presents an algorithm used to optimize the stock distribution between the roughing and finishing cuts for fixed setting spiral bevel and hypoid members. The optimization is based on the Surface Match algorithm, where differences between the roughing and finishing spiral angle, pressure angle and tooth taper are minimized in order to obtain rough and finished tooth flanks that are parallel.
ISBN: 1-55589-769-X Pages: 8

2000FTM9. *Cylindrical Gear Inspection and Bevel Gear Inspection - A Simple Task by Means of Dedicated CNC-Controlled Gear Inspection Machines*
Author: **G. Mikoleizig**
This paper will discuss the design, function, software management and probe systems of the inspection machines. Analytical tooth contact analysis of a cylindrical gear set by means of the combined effects of gear and pinion is shown on the basis of individual profile and alignment measurements. A fully automatic correction system will be introduced for checking the flank form on spiral bevel gears.
ISBN: 1-55589-770-3 Pages: 25

2000FTM10. *Bending Fatigue Investigation under Variable Load Conditions on Case Carburized Gears*
Authors: **B.-R. Hohn, P. Oster, K. Michaelis,**

Th. Suchandt and K. Stahl
Variable load spectrum tests are carried out at different load levels in a step program and at random loading. The results of step programmed tests show a substantial influence of the period of the programmed subsequence of fatigue life. Fatigue life decreases when the subsequence period is shortened. With substantially shortened subsequences in step programmed test nearly the same fatigue life is reached as in random load tests.
ISBN: 1-55589-771-1 Pages: 14

2000FTM11. *UltraSafe Gear Systems - Single Tooth Bending Fatigue Test Results*
Authors: **R.J. Drago, A. Isaacson and N. Sonti**
This paper will discuss a system from a point of view of "what happens when a failure occurs". Gears were manufactured with seeded faults to simulate unexpected defects in various portions of the highly loaded gear tooth and rim sections. Crack propagation was monitored by measuring effective mesh stiffness and applied loading to provide both warning of an impending failure and a reasonable period operation after initiation of a failure for a safe landing.
ISBN: 1-55589-772-X Pages: 9

2000FTM12. *The Finite Strips Method as an Alternative to the Finite Elements in Gear Tooth Stress and Strain Analysis*
Authors: **C. Gosselin and P. Gagnon**
The Finite Strip Method (FSM), which may be considered a subset of the Finite Element Method (FEM), is presented as an alternative to (FEM) that requires very little meshing effort and can be applied to virtually any tooth geometry while offering precision comparable to that of Finite Elements. This paper will cover the (FSM) model for spur and helical gears, plates of variable thickness

such as the teeth of face gear members and for spiral bevel and hypoid gears.
ISBN: 1-55589-773-8 Pages: 11

2000FTMS1. *Effects of Helix Slope and Form Deviation on the Contact and Fillet Stresses of Helical Gears*
Authors: **R. Guilbault**
An investigation is conducted on the effects of helix slope and form deviation tolerances specified for grades 5 and 7 of the ANSI/AGMA ISO 1328-1 for cylindrical gears. The results show and almost linear correspondence between deviation amplitude and tooth load and fillet stress increases: using grade 7 instead of grade 5 can double the tooth flank load increase and associated fillet stress increase. Results also show that effects are even more significant on the maximum contact pressure.
ISBN: 1-55589-774-6 Pages: 21

1999 PAPERS

99FTM1. *The Barkhausen Noise Inspection Method for Detecting Grinding Damage in Gears*
Authors: **J.S. Ceurter, C. Smith and R. Ott**
When grinding hardened steel there is always the possibility for surface damage in the form of residual stress and microstructural changes. Methods for detecting this sort of damage may have drawbacks, such as production time, complexity, subjectivity and use of hazardous chemicals. The authors present a relatively new method, known as the Barkhausen noise analysis, that may meet the demand for measuring defects in ground steels.
ISBN: 1-55589-739-8 Pages: 10

99FTM2. *Traceability Strategies for the Calibration of Spline and Serration Gauges*
Author: **W. Beyer**
Form and shape of running gears are often toleranced. The same features of splines and serration gauges may need to have the same permissible geometrical tolerances as those for running gears. Examples are given in the paper which prove that, in view of often small required tolerances, it will often be necessary to calibrate splines and serration gauges with the smallest possible uncertainty.
ISBN: 1-55589-740-1 Pages: 5

99FTM3. *Measurement Uncertainty for Pitch and Runout Artifacts*
Author: **B. Cox**
Primary-level calibration of pitch and runout artifacts require quantifying the measurement uncertainty on the artifact being calibrated by a method that does not rely on a transfer comparison. The measurement decompo-sition method, developed jointly by (NIST) and (ORMC) personnel, is used to determine the uncertainty of each component of the measurement task.
ISBN: 1-55589-741-X Pages: 14

99FTM4. *Gear Oil Micropitting Evaluation*
Authors: **A.B. Cardis and M.N. Webster**
Besides operating conditions such as load, speed, sliding and specific film thickness, the chemical composition of a lubricant has been found to influence micropitting of case hardened gears. The development of micropitting resistant lubricants has been limited both by a lack of mechanism understanding and a lack of a readily available lubricant micropitting test. This paper reports efforts to develop alternate methods to study micropitting performance of individual additives and combinations of additives with a roller disc machine. Concurrently, a full-scale gear test using "real world" gearing is covered.
ISBN: 1-55589-742-8 Pages: 16

99FTM5. *Analysis of Micropitting on Prototype Surface Fatigue Test Gears*
Author: **M.R. Hoeprich**
Experimental gears designed for surface fatigue studies by the AGMA Helical Gear Rating Committee and tested in a FZG test rig were evaluated by the author. This paper presents results obtained through optical profilometry, SEM and metallographic examinations.
ISBN: 1-55589-743-6 Pages: 11

99FTM6. *The Submerged Induction Hardening of Gears*
Author: **D.W. Ingham**
With examples of field failures directly attributable to the Tooth by Tooth Induction Hardening, there has been a negative feeling against the use of this process. This paper shows successes of the process founded on Process Development and Quality Control. The author presents a case for and against Tooth by Tooth Induction Hardening.
ISBN: 1-55589-744-4 Pages: 12

99FTM7. *Ductile Iron as a Material for Open Gearing*
Author: **P. Graham**
This paper covers an outline of ductile iron and the physical properties that can be expected from different grades. The types of heat treatment, properties that can be expected and also hardness values are provided for typical gear blanks.
ISBN: 1-55589-745-2 Pages: 15

99FTM8. *Power-Dry-Cutting of Bevel Gears*
Author: **H.J. Stadtfeld**
High speed machining using carbides has been known for some decades for milling and turning operations. Improvements in carbide grades and sintering processes in combination with new coating methods and the use of CNC machines has lead to a significantly new trend in cutting bevel gears. This paper discusses bevel gear dry cutting

methods with surface cutting speeds of 1000 ft./min. for continuous face hobbing and plunge cutting single index face milling.
ISBN: 1-55589-746-0 Pages: 10

99FTM9. *Dry Hobbing Process Technology Road Map*
Authors: **G. Schlarb and K. Switzer**
Technology in today's gear cutting industry makes it impossible to assume that there is one process capable of meeting the requirements of each application. This paper discusses extensive tool developments that have taken place in recent years as well as the explosion of new technology with both coatings as well as new materials. The author discusses how to determine the best combination possible for a given application.
ISBN: 1-55589-747-9 Pages: 10

99FTM10. *Design and Testing of a Marine Gearbox*
Author: **J. Bos**
This paper gives an overview of design and back-to-back testing results for gearboxes that are designed for low noise and vibration levels. Design aspects such as tooth corrections, tooth loading, gear lay-out, balancing, lubricating systems and a resilient mounting system will be discussed. Specific attention for the design was given to minimize the number of rotating elements under load, to have optimal corrections for loaded conditions and to optimize the tooth loading.
ISBN: 1-55589-748-7 Pages: 13

99FTM11. *Performance Study of Nitrided Gears in High Speed Epicyclic Gearbox Used in Gas Turbogenerators - A Case Study*
Author: **A.K. Rakhit**
Nitrided gears are preferred in some designs due to their low heat treat distortion characteristics and resistance to scuffing under low oil-film thickness, an inherent phenomenon at sun gear mesh-planet mesh in epicyclics. This paper discusses and verifies these properties plus the tendency of these gears to fail under heavy shock loads.
ISBN: 1-55589-749-5 Pages: 4

99FTM12. *Gearbox Field Performance from a Rebuilder's Perspective*
Author: **C. Schultz**
The focus of this paper is the actual field performance of a variety of over 2000 different gearboxes that have been repaired over the last 15 years. The information presented consists of a statistical review of the types of gearboxes repaired and the typical failure modes. Among the problems described in detail are tooth breakage, tooth wear, housing bore damage, seal wear and lube system failure.
ISBN: 1-55589-751-7 Pages: 6

99FTM13. *Failures of Bevel-Helical Gear Units on Traveling Bridge Cranes*
Author: **J.M. Escanaverino**
Frequent failures of bevel gear units in traveling drives of bridge cranes pose a difficult problem for maintenance and discussions on the necessary gear unit Service or Application Factor selection. This paper focuses on the origin of the troubles, with an insight on the dynamics of the drive train.
ISBN: 1-55589-750-9 Pages: 6

99FTM14. *The Effect of Material Defects on Gear Performance - A Case Study*
Authors: **R.J. Drago and A.F. Filax**
The mechanism by which failures occur due to material defects is often circuitous and not readily apparent. In this case study, the authors examine the failure of a medium-sized pinion used in a mining application. The mode of failure was rather catastrophic in nature but did not follow any of the typically understood mechanisms such as tooth bending, surface distress, wear, etc. This paper presents a summary of the failure, its investigation and the methods proposed for its resolution.
ISBN: 1-55589-752-5 Page 7

99FTM15. *Theoretical Model for Load Distribution on Cylindrical Gears: Application to Contact Stress Analysis*
Authors: **J.I. Pedrero, M. Pleguezuelos, M. Artés, A. Fuentes, and C. García-Masiá**
The elastic models of gear tooth behavior are usually based on the hypothesis of uniform load distribution along the line of contact. The calculation methods of ISO and AGMA assume that the load per unit of length is equal to the total load divided by the length of contact. In this paper, the load sharing along the line of contact is determined from the hypothesis of minimum elastic potential. From this nonuniform load distribution and Hertz's equation, a method for determining both the value and the location of the critical contact stress is described.
ISBN: 1-55589-753-3 Pages: 13

99FTM16. *The Multi-Objective Optimization of Nonstandard Gears Including Robustness*
Authors: **D.R. Houser, A.F. Luscher, I.C. Regalado**
The design of gears involves the optimization of different objectives, and the presence of errors in the manufacturing and operating conditions affects the performance of the gears; therefore, a robust optimization procedure applying Taguchi methods was used as a tool in the design of nonstandard cylindrical gears. This paper presents an outline of the procedure and discusses some of the results.
ISBN: 1-55589-754-1 Pages: 14

99FTM17. *Synthetic Oils for Worm Gear Lubrication*
Author: **U. Mann**
This paper shows several synthetic gear oils and their influence on wear and efficiency of highly

loaded worm gears. The results are based on measurements carried out on the Kluber worm gear test rig. This test rig allows the measurement of input speed, input torque, output torque, bulk and sump temperature. The measured results are compared with other investigations such as measurements of friction coefficients and DIN 3996.
ISBN: 1-55589-755-X Pages: 9

99FTM18. *Effects of Wear on the Meshing Contact of Worm Gearing*
Authors: **D. Houser, M. Vaishya and X. Su**
Worm gear contact stresses are the major contributor to worm gear wear and durability failures. In this paper, a combination of loaded tests, coordinate measurements, surface reverse engineering and a special finite element method is employed to study the effect of break-in wear on meshing contact between the mating surfaces of worm gearing parts. Three different wheel tooth geometries are investigated in this paper.
ISBN: 1-55589-756-8 Pages: 11

99FTMS1. *Modeling and Measurement of Sliding Friction for Gear Analysis*
Authors: **M. Vaishya and D.R. Houser**
This student paper discusses background studies needed for the prediction of sliding resistance on gear teeth. Various elastohydrodynamic and mixed lubrication theories for coefficient of traction are examined. These theories are evaluated with respect to experimental results from two-disk tests for several parameters that simulate the continuously varying properties during gear engagement. Based on the comparison of theoretical predictions and test results on a spur gear pair, the lubrication models are evaluated, with special emphasis being placed on the dynamic modeling of friction.
ISBN: 1-55589-757-6 Pages: 12

1998 PAPERS

98FTM1. *A Method for Predicting the Dynamic Root Stresses of Helical Gear Teeth*
Authors: **D.R. Houser and J. Harianto**
The AGMA dynamic factor has traditionally been treated as a "dynamic" load factor where tooth load is the sum of all the tooth forces that are applied along the plane of action at any instant of time. Knowing the total load, however, says little about the degree of load sharing or the load position on a tooth where the dynamic load is a maximum. The paper describes a method that merges the capabilities of sophisticated load distribution and dynamic excitation routines with a time domain gear dynamics simulation. The effects of tooth surface modifications, misalignments and spacing errors may be analyzed.
ISBN: 1-55589-719-3 Pages: 10

98FTM2. *Mesh Friction in Gearing*
Author: **C.M. Denny**
Plastic gears are often run dry in their applications. The subsequent tooth sliding friction forces have a sizable effect on the magnitude of tooth root bending in both the driving and driven gears and the point of tooth-load application. A calculation method is given for the solution of these frictional effects.
ISBN: 1-55589-720-7 Pages: 11

98FTM3. *Basic Studies on Fatigue Strength of Case-Hardened Steel Gear - Effects of Shot Peening and/or Barrelling Processes*
Authors: **S. Hoyashita, M. Hashimoto and K. Seto**
The paper presents testing results on the effects of a barrelling finishing process on the fatigue strength of shot peened, carburized and carbo-nitrided gears. The enhancement of surface durability rating especially after performing post-peening operations to improve the surface finish was extensively evaluated and is discussed, along with shot peened bending fatigue.
ISBN: 1-55589-721-5 Pages: 9

98FTM4. *Effect of Uncontrolled Heat Treat Distortion on the Pitting Life of Ground, Carburized and Hardened Gears*
Author: **A.K. Rakhit**
The amount of grinding to correct uncontrolled distortion produced during the carburizing and hardening process can result in a reduction of the surface hardness of the tooth flanks and ultimately decreased pitting life of the gear teeth. The results present an evaluation that yields pitting life derating factors as a function of hardness versus case depth gradient and severity of distortion for a number of materials.
ISBN: 1-55589-722-3 Pages: 5

98FTM5. *Low Vibration Design of a Helical Gear Pair*
Author: **K. Umezawa**
The paper presents recent findings dealing with tooth surface modifications that can be implemented to realize quiet running, low vibration helical gear sets. The investigation looked at the effects of tooth deviations and modifications on performance that are based upon bias-in and bias-out observations. Experimental results indicate that there is an asymmetrical feature in the relation between vibration magnitude and direction of each deviation of a gear pair in mesh.
ISBN: 1-55589-723-1 Pages: 13

98FTM6. *Calibration of Master Gears on Coordinate Measurement Machines*
Authors: **B. Cox, B. Rasnick, B. Adkins and E. Walker**
Primary-level calibration of master gears requires quantifying the measurement uncertainty of a three

dimensional surface in space by a method that does not rely on a transfer comparison. The paper describes a measurement composition method developed at NIST and ORMC that is used to determine the uncertainty of each component of the measurement task.
ISBN: 1-55589-724-X Pages: 18

98FTM7. *Checker of 3D Form Accuracy of Hypoid & Bevel Gear Teeth for the New Generation of Quality Control*
Authors: **A. Kubo, Y. Saito, S. Kato, N. Kondo, and N. Aoyama**
Knowing the three dimensional geometry of bevel gear teeth is critical to evaluating manufacturing processes and ultimately performance. The paper discusses advancements made to design and produce a practical and reliable gear checker that can measure parameters such as the tooth profile curve and tooth lead curve.
ISBN: 1-55589-725-8 Pages: 13

98FTM8. *Evaluation of Wear, Scuffing and Pitting Capacity of Gear Lubricants*
Authors: **K. Michaelis, B.-R. Höhn and P. Oster**
For maximum energy savings, low viscosity lubricants are frequently used. The trend toward increased transmitted power has lead to higher operating temperatures, resulting in thinner lubricating films. New test methods are described that have been developed which use modified FZG test rigs to evaluate low speed wear, scuffing and pitting. Test results on various lubricants are discussed.
ISBN: 1-55589-726-6 Pages: 10

98FTM9. *Studies on Improvement of Surface Durability of Case-Carburized Steel Gear - Effects of Surface Finish Processes upon Oil Film Formation*
Authors: **M. Hashimoto, S. Hoyashita and J. Iwata**
The results of an extensive test program conducted to analyze the effects of surface finish enhancements on the formation of gear mesh oil films of surface hardened gears are discussed. The use of an electric resistance method for determining conditions of oil film formation relative to changes in tooth profile, crowning and surface roughness are evaluated.
ISBN: 1-55589-727-4 Pages: 9

98FTM10. *Local Coefficients of Friction in Worm Gear Contacts*
Authors: **K. Steingröver and B.-R. Höhn**
Because the friction conditions of worm gears cannot be determined directly, a special three disk test rig was designed to simulate the contact conditions for discrete points along the contact lines of a worm gear. The results are presented of tests employing various lubricant types and material combinations.
ISBN: 1-55589-728-2 Pages: 8

98FTM11. *Current Technologies of P/M Gearing*
Authors: **S. Haye and G. Moore**
Powder metallurgy gears have offered a cost effective, near net shape alternative to wrought steel gears, but buyers had to be content with a sacrifice in quality and performance. Improvement efforts have focused on P/M tool geometry and better control of the P/M process. The paper discusses the recent efforts to improve gear quality without forfeiting the P/M cost advantage - through secondary gear tooth finishing processes.
ISBN: 1-55589-729-0 Pages: 7

98FTM12. *Gear Refurbishment, An Economical Approach for Aerospace Overhaul and Repair*
Authors: **A. Meyer and T. Johnson**
The paper describes a successful program that is being deployed to re-work power reduction and accessory gears used in Coast Guard helicopter transmissions. The development and implementation of the critical stages of this process - incoming inspection and evaluation, special machining techniques, qualification testing and final certification - are discussed.
ISBN: 1-55589-730-4 Pages: 19

1997 PAPERS

97FTM1. *Calibration of Gear Measuring Instruments and Their Application to the Inspection of Product Gears*
Authors: **B.L. Cox and R.E. Smith**
Discusses the instrument conditions, alignment and calibration requirements for measurement to meet accuracy specifications of today's product gears. Also offers guidelines for the alignment of instrument elements such as centers, ways and probe systems; and the application of gear artifacts to determine instrument calibration, including the determination of measurement uncertainty.
ISBN: 1-55589-695-2 pages: 67

97FTM2. *Determining Sound Power Levels of Enclosed Gear Drives Using the Sound Intensity Method*
Author: **C. Burriss**
Presents highlights of a practical case study illustrating how sound power level data was used to validate a design improvement of an enclosed drive. The practical use of sound intensity measurements for the determination of enclosed drive sound power under full load is compared with ANSI/AGMA 6025-C90 methods. Also reviews important characteristics of the measurement environment.
ISBN: 1-55589-696-0 pages: 7

97FTM3. *Detection of Fatigue Cracks in Gears with the Continuous Wavelet Transform*

Authors: **D. Boulahbal, M.F. Golnaraghi and F. Ismail**

In the past, traditional machinery condition monitoring and gear fault detection focused either on time or frequency domain vibration analysis. The sensitivity of the newly developed wavelet transform technique allows the user to look at the evolution in time of a vibration signal's frequency content for fatigue crack detection. Paper compares this new technique against more conventional methods.

ISBN: 1-55589-697-9 pages: 6

97FTM4. *Measurement and Predictions of Plastic Gear Transmission Errors with Comparison to the Measured Noise of Plastic and Steel Gears*

Authors: **L. Liauwnardi, D.R. Houser and A. Luscher**

This paper takes transmission error and sound pressure level measurements of plastic gear sets, and compares them to experimental static transmission measurements and computer predictions. Also compares transmission error and sound pressure levels of plastic gears with large deflections and steel gears of similar geometries.

ISBN: 1-55589-698-7 pages: 11

97FTM5. *Improved Finite Element Model for Calculating Stresses in Bevel and Hypoid Gear Teeth*

Authors: **L.E. Wilcox, T.D. Chimner and G.C. Nowell**

When spiral bevel and hypoid gear results are compared with the predicted fillet strain of a three dimensional tooth model with experimental strain gage data using H-adaptive and P-adaptive finite element theory, preliminary results indicate agreement within 10%. This paper discusses refinement in tooth support regions, and a precise model that correctly predicts the range of strain from tensile to compressive values as the gear teeth roll through mesh.

ISBN: 1-55589-699-5 pages: 11

97FTM6. *On the Location of the Tooth Critical Section for the Determination of the AGMA J-Factor*

Authors: **J.I. Pedrero, C. García-Masiá and A. Fuentes**

Describes a modification to the AGMA J-factor definition for determining the point of maximum root bending stress. The condition where the Navier's stress is maximum, defined by the point of intersection of the root trochoid and the thinnest parabola containing a point of the trochoid, is used. The occurrence on its involute as well as in the root trochoid with a non-iterative calculation is also covered.

ISBN: 1-55589-700-2 pages: 7

97FTM7. *Bending Load on Internal Gears of Planetary Gear Sets*

Authors: **H. Linke and C. Jahn**

This paper presents the results of investigations regarding a more precise determination of bending stress in the tooth root of internal gear rims used in planetary drives. This method includes the effects of the gear rime design and mounting, which is essential in almost all cases. Also proposes a practical calculation method using generalized stress concentration factors, which has been tested by actual measurements on planetary gearing.

ISBN: 1-55589-701-0 pages: 10

97FTM8. *New Guidelines for Wind Turbine Gearboxes*

Authors: **R.L. Errichello and B. McNiff**

Collectively, mush has been learned about the unique operation and gear unit loading in wind turbine applications. This paper will present an overview of AGMA/AWEA 921-A97, Recommended Practices for Design and Specification of Gearboxes for Wind Turbine Generator Systems. This Information Sheet is dedicated to procurement specifications, quality assurance, design, manufacturing, lubrication, maintenance and other subjects related to reliable wind turbine gear unit applications.

ISBN: 1-55589-702-9 pages: 5

97FTM9. *Relations Between Wear and Pitting Phenomena in Worm Gears*

Author: **M. Octrue**

Describes the influence of different parameters (geometry, contact pattern, contact pressure, sliding velocity, etc.) on the wear and pitting of worm gearing. The paper proposes new criteria for comparing capacity of different worm gear geometries to predict performance. In addition, it discusses the prediction of wear and pitting behavior based on experimental results with long endurance test measurements.

ISBN: 1-55589-703-7 pages: 8

97FTM10. *UltraSafe Gear Systems for Critical Applications - Initial Development*

Authors: **R.J. Drago, A.D. Sane, F.W. Brown**

This paper presents a basic paradigm shift required to design and develop ultra-safe power transmission gears. It also describes the initial results of a new program that developed a set of guidelines to improve the fail-safe operation of helicopter transmissions, while not affecting either the required performance or weight characteristics.

ISBN: 1-55589-704-5 pages: 22

97FTM11. *Non-Dimensional Characterization of Gear Geometry, Mesh Loss and Windage*

Author: **J.P. Barnes**

New relationships for involute spur gear geometry are introduced and integrated with new methods of correlating lubricant traction and windage test data. Compact math models for lubricant density and viscosity under contact pressure are proposed. A modern approach to dimensional analysis is introduced to characterize lubricant traction data and gear windage data with dimensionless terms

which apply to gear systems which may have a configuration and/or size different from those tested. Finally, system considerations for optimal gearbox efficiency are proposed.
ISBN: 1-55589-705-3 pages: 12

97FTM12. *Introduction of a Jobbing System for Bevel and Hypoid Gears*
Author: **H.J. Stadtfeld**
The paper describes a new manufacturing system that enables the flexibility to produce bevel and hypoid gears of any size and specification, including gear sets produced on old equipment with different cutting methods, with an extremely low investment. This system includes a new PC program that performs calculations of tooth contact analysis, ease off and machine settings, and a newly developed carbide tool skiving process.
ISBN: 1-55589-706-1 pages: 13

97FTM13. *Three Innovations Advance the Science of Shot Peening*
Authors: **J.S. Eckersley and T.J. Meister**
Three recent innovations have been developed to extend the effective shot peening state of the art to prolong the fatigue life of gears: 1) a process that provides a smooth surface after peening to increase the resistance to surface fatigue; 2) a computer program that makes a reasonable prediction of residual stress curves, and 3) a coupon system that makes actual x-ray diffraction curves to monitor production shot peening possible.
ISBN: 1-55589-707-X pages: 10

97FTM14. *Refinements in Root Stress Predictions or Edges of Helical Gear Teeth*
Authors: **A. Dziech and D.R. Houser**
Presents an analysis method for high power density gear units, where load distribution is critical. Compares this method with the combination of Wellauer-Seireg moment image with two dimensional boundary element analysis, three dimensional finite element analysis, and experimental results for tooth root bending stresses. This new prediction method considers the changes in stiffness in the normal plane and edge effects of helical gear teeth.
ISBN: 1-55589-708-8 pages: 9

97FTM15. *Design, Generation, Stress Analysis and Test of Low-Noise, Increased Strength Face-Milled Spiral Bevel Gears*
Authors: **F.L. Litvin, A.G. Wang, Z. Henry, R.F. Handschuh and D.G. Lewicki**
This paper discusses the design of modified geometry face milled spiral bevel gears with uniform and tapered teeth, based on the application of specially developed machine tool settings. Optimization of the geometry to reduce transmission errors and produce the desired contact ellipse was developed and tested, which reduced noise level by 18 decibels, reduced vibration 50% and increase operated torque capacity.
ISBN: 1-55589-709-6 pages: 15

97FTMS1. *Coordinate Measurement and Reverse Engineering of ZK Type Worm Gearing*
Authors: **X. Su and D.R. Houser**
A comprehensive model for the measurement, inspection, performance prediction and reverse engineering of ZK type of worm gearing is developed. The measurements and the best fit processes both for the worm thread and for the gear tooth flank are discussed in detail. A CMM measurement strategy free of tip compensation which applies to many types of tools and parts in the gear industry is proposed. A real case of ZK type of worm gearing with the parabolic profile modification on the hob is studied to illustrate the reverse engineering process.
ISBN: 1-55589-710-X pages: 14

1996 PAPERS

96FTM1. *A Computer Based Approach Aimed at Reproducing Master Spiral Bevel and Hypoid Pinions and Gears*
Authors: **C. Gosselin, Y. Shiono, T. Nonaka and A. Kubo**
In the spiral bevel and hypoid gear manufacturing industry, master pinions and gears are usually developed from initial machine settings obtained from computer software, which are then developed from initial machine settings obtained from computer software, which are then modified until a satisfactory bearing pattern is obtained, as "the target tooth flank form" to compensate for heat treatment distortions and to consider lapping cannot be accounted for by existing computer software.

Once a satisfactory combination of master pinion and gear is obtained, their actual tooth surfaces may not correspond to those of the theoretical model. In this case, corrective machine settings calculated from the measurement of the production tooth flanks by a Coordinate Measuring Machine are applicable only in relation to the actual target tooth flank measurement data, as the theoretical tooth flank definition is unknown.

This paper presents a computer based approach used to find the machine settings producing a theoretical tooth surface closest to that of a measured surface, which incidentally can be the target tooth flank, in order to effectively use corrective machine settings in reference to the theoretical surface.
ISBN: 1-55589-668-5 pages: 10

96FTM2. *The New Way of Manufacturing Bevel and Hypoid Gears in a Continuous Process*
Author: **H. Stadtfeld**

Much attention has been paid to face hobbing in the last decade. The CNC technology made a quantum step in this period which was beneficial especially for the continuous bevel gear cutting process. Parallel to the CNC technology a new method of face hobbing was subsequently developed and is introduced today as the different and new way of face hobbing. The basis is a new gear theoretical approach to design the blank geometry, the ease off and the tooth contact. The tools are different in design than regular cutting blades and enable a high economical procedure of roughing and finishing in one chucking. The process kinematic was completely redesigned, benefitting from the free form concept of today's cutting machines. All the aspects of precision, flexibility and economy make the new face hobbing also popular for the gearbox manufacturer and jobber.

ISBN 1-55589-669-3 pages: 11

96FTM3. *Noise Reduction Through Generated Engagement Relief Modification*
Authors: **W. Kieß and S. Price**

For years, the international gear manufacturing industry has been pushing machine manufacturers to develop an economical realizable tooth flank modification that is made in contact direction, with a soft transfer from the modified to unmodified sections of the tooth.

To meet these demands, Höfler has developed, and is already implementing, Generated Engagement Relief Modifications. The tooth flank is modified at the areas of engagement only as apposed to the entire tooth flank as is the case with conventional modifications. The paper discusses the advantages of this new technology over conventional modifications and discusses how to produce generated engagement relief modifications.

ISBN: 1-55589-670-7 pages: 9

96FTM4. *Traceable Calibration of Master Gears at PTB*
Author: **W. Beyer**

The PTB (Physikalisch-Technische Bundesanstalt) is able to measure (calibrate) master gears for industry traceable to national gear standards and in compliance with the International System of Units (SI).

For this purpose primary gear standards and standard measuring devices for the reference values F, $F_{ß}$, $F_{ó}$ (total profile deviation, total helix deviation, total cumulative pitch deviation) are available.

To calibrate the master gears of industry, PTB uses coordinate measuring machines which are traceable by instrument-specific calibration methods. With the aid of the PTB's primary standards, a task specific uncertainty of measurement is determined for all gearing calibrations carried out for industry, which is taken into account as a correction value when the transfer measurement uncertainty is stated.

ISBN: 1-55589-671-5 pages: 6

96FTM5. *Differential Crowning: A New Weapon Against Gear Noise and Dynamic Load*
Authors: **M. Wyeth and W. Rouverol**

As the power density of gear sets increases, mesh deflections increase, and the variations in those deflections, which result primarily from mesh stiffness variation, become increasingly significant.

To minimize these undesirable effects, designers of power train gear pairs have traditionally specified various forms of profile modification, the most common of which is tip and/or root relief.

A new system of modifications has been devised that substantially eliminates mesh stiffness variations throughout the entire engagement angle regardless of what torque load is being transmitted. By substantially eliminating gear noise and dynamic increment, the new modifications make it possible to replace costly helical gear sets with better performing spur sets in many applications. This new system of modifications is described and confirmatory test results are reported.

ISBN: 1-55589-672-3 pages: 4

96FTM6. *The F-22 AMAD Gear Drive Optimization of Resonance Characteristics by Detuning, Coulomb Damping & Damped Force Response Analyses*
Author: **R. Drago, F. Brown, A. Sane, and D. Stremick**

Finite element analyses were performed during design and development of the F22 AMAD gearbox to ensure a design free of damaging resonant responses within its operating speed range. Ideally, design with respect to resonance characteristics would have no natural frequencies within the operating speed range. However, the wide speed range (from 1445 to 17931 rpm) combined with the weight and geometric constraints imposed by the application (the F-22 is an advanced technology, next generation, fighter aircraft) made it impossible to attain this goal directly in the F-22 AMAD design.

This paper discusses the overall analytical approach, analytical methods and evaluation of gear response to achieve acceptable accessory gear designs. Design modifications, including developments in the modeling techniques required to accommodate the unique characteristics of these relatively small (compared to the usual helicopter

main power gear) gears are also discussed. Test and analytical results are also presented and compared.
ISBN: 1-55589-673-1 pages: 16

96FTM7. *Dynamic Distribution of Load and Stress on External Involute Gearings*
Authors: **J. Börner and D. Houser**

The influence of additional dynamic loads on the distributions of load, flank pressure and tooth root stress are shown. The additional dynamic loads excited by the variations of mesh stiffness and influenced by tooth deviations and modifications are calculated and used as input for the calculation of the distributions of load and stresses in the plane of action. Very efficient calculations are obtained by using specially developed calculation algorithms. An extensive graphic presentation of the calculation results is included. The same connection of the calculation of load distribution with the calculation of dynamic loads is also possible in principle on the basis of very similar programs (LDP & DYTEM) developed at the Ohio State University.

The calculation results are compared with dynamic loads and transmission errors measured on test rigs in the gear lab at the Ohio State University.
ISBN: 1-55589-674-X pages: 12

96FTM8. *Thermal Rating of Gear Drives Balance Between Power Loss and Heat Dissipation*
Authors: **B. Höhn, K. Michaelis, and T. Vollmer**

From the balance between the generated heat in a gear box and the dissipated heat from the gear case surface the mean value for the expected lubricant temperature can be evaluated. The maximum oil temperature in a splash lubricated enclosed gear drive limits the transmittable power. High oil temperatures influence wear, scuffing, micropitting and pitting load capacity of the gears as well as the gear oils' service life.

Experimental investigations of no-load and load dependent gear losses in cylindrical and bevel gears as a function of lubricant type and viscosity, load, speed and temperature are reported. The mean value for the coefficient of friction in a gear mesh is evaluated and compared to measurements in twin disk machines. A rating method for gear mesh power loss is derived.

Investigations, using model and actual gear boxes, show the influence of radiation, free and forced connection as well as conduction to the foundation on the heat dissipation from the gear case surface. The influence of design, size, air velocity, surface finish of the housing, etc., is reported.

The results of such investigations together with accepted rating methods for bearing and seal power loss are introduced into a calculation method for the evaluation of the oil temperature in the sump of a gear box. In sample calculations the possibilities as well as the limits of this thermal rating method is shown.
ISBN: 1-55589-675-8 pages: 12

96FTM9. *The Development of a Practical Thermal Rating Method for Enclosed Gear Drives*
Author: **A. Phillips**

This thermal rating method balances the sum of the load-independent losses and the load-dependent losses against the heat dissipation capability of the gear case. Empirical factors are determined which calibrate the calculations against the test results for assembled gear reducers. The results of this calculation method are compared to the test results from 251 gear reducer tests. In addition, since losses are calculated, this method can be used to calculate the efficiency of the gear drive for the operating conditions.
ISBN: 1-55589-676-6 pages: 8

96FTM10. *Scuffing Resistance of Vehicle Transmission Gears*
Authors: **F. Joachim and H. Collenberg**

In many transmission types, the lubricant fulfills other functions apart from lubricating the gearing, for example in friction elements (synchronizer unit, clutch) in vehicle transmissions, or as a hydraulic fluid (torque converter, retarder, steering system). The modern trends are now high contact ratio gearing as well as the use of low viscosity lubricants to reduce churning losses. Therefore, at the gear design and lubricant additive stages, compromises are now necessary which require the most precise information possible on scuffing resistance of the gearing and lubricant.

It will be demonstrated that the normal test procedures for determining scuffing resistance are not suitable for lubricant classification for vehicle transmissions (GL 4 and GL 5). By reducing the tooth width as well as doubling the speed, the scuffing test to DIN 51354 standards was increased in severity to such an extent, that the parameters necessary for transmission dimensioning could be determined for even higher scuffing resistant oils. The oil data necessary for sufficient scuffing resistance will be shown for different transmission design types.

A process is presented, in which scuffing resistance is calculated for every point on the tooth flank, based on the "flash temperature method", and taking all variations and corrections into account. It will be demonstrated with practical examples, that, as early as the design stage, this method can be

used to detect flank areas at risk, and to eliminate them with a specific correction design.
ISBN: 1-55589-677-4 pages: 8

96FTM11. *DIN 3996: A New Standard for Calculating the Load Capacity of Worm Gears*
Authors: **B Höhn and K. Steingröver**

During the last years the load capacity of worm gears was raised about 30%. The reasons for this are the introduction of synthetic oils, optimization of the worm gear geometry and manufacturing improvements. The forthcoming new standard DIN 3996 "Calculation of load capacity of cylindrical worm gear pairs" takes into account these developments. This standard contains the following load capacity limits: wear, pitting, tooth breakage, temperature and worm deflection. Also, efficiency was taken into consideration. In most cases the calculation methods are based on results of recent investigations, which were performed on worm gear test rigs at the FZG. In the case of wear, pitting and tooth breakage test results and their influence on DIN 3996 are shown.

The calculation method for wear resistance is based on the fact that the wear intensity of a material/lubricant combination is a function of the lubricant film thickness and the lubricant structure. The main influence parameter on pitting resistance is the Hertzian stress. For tooth root strength the calculation method is based on a nominal shear stress theory, in case of worm deflection on the deflection curve of a cylindrical shaft.

The application of this new standard for gears in practice is discussed by recalculating some examples.
ISBN: 1-55589-678-2 pages: 14

96FTM12. *An Investigation of Globoidal Wormgear Drives*
Author: **N. Chen**

This paper investigates the following present globoidal wormgear drives: (1) original and modified Hindley wormgear drives; (2) Wildhaber wormgear drive with inclined plane teeth of wormgear; (3) inclined plane and cone enveloping globoidal wormgear drives; (4) plane, cone and inverted cone enveloping globoidal wormgear drives based on Sakai's theory. Meanwhile, a new approach for generation of Hindley wormgearing, and plane and cone enveloping globoidal wormgear drives is developed in this paper. Contact lines, dual and single contact ratios, relative curvature radii, meshing angles between tangents of contact lines and relative velocities, and sliding ratios of wormgear tooth surfaces of the above globoidal wormgear drives are studied by computerized simulation for numerical examples.
ISBN: 1-55589-679-0 pages: 15

1995 PAPERS

95FTM1. *Detection of Hidden Runout*
Authors: **Robert Smith, Irving Laskin and Dan Bailey**

There is a gear geometry variation, called "hidden runout", which resembles runout in it's effect on transmission error and the resulting vibration, noise and positional accuracy of a drive train, but which is not revealed in the standard runout measurements by ball-check or double flank composite testing. This paper describes this often unrecognized inspection methods than can be used to illustrate the manufacturing and inspection issues.
ISBN: 1-55589-649-9 Pages: 10

95FTM2. *Separation of Runout from Elemental Inspection Data*
Authors: **Irving Laskin and Ed Lawson**

Runout due to eccentricity influences index, pitch and profile inspection data for spur and helical and profile inspection data for spur and helical gears and tooth alignment inspection data for helical gears. This paper reviews the numerical procedure used with index and pitch data to determine the magnitude and direction of the runout. It re-plots the inspection data with runout influence removed. This new numerical procedure is effective in the presence of such tooth geometry features as slope variation (e.g., pressure angle variation in profile and helix angle variation in tooth alignment), non-linearity (e.g., tip relief in profile and crown in tooth alignment), and waviness. The numerical procedure is shown for index, pitch and profile inspection data taken from a test gear (also see AGMA 93FTM6).
ISBN: 1-55589-650-2 Pages: 15

95FTM3. *The Effect of Manufacturing Errors on the Predicted Dynamic Factors of Spur Gears*
Authors: **Jonny Harianto and Donald Houser**

This paper studies the effect of manufacturing errors on predicted dynamic factors of spur gears. Three dynamic factors are defined and studied: dynamic load factors, dynamic tooth force factors, and dynamic bending moment factors. Three computer programs for predicting dynamics are discussed; a forced vibration analysis using six degrees of freedom, a multi-degree Dynamic Transmission Error Program (DYTEM) using a six degree of freedom model, and a Geared Rotor Dynamics Program that uses a finite element method. Using experimental data provided by National Aeronautics and Space Administration the DYTEM program is used for dynamic factors

prediction. The effects of AGMA 10, 12 and 14 profile tolerances are shown.
ISBN: 1-55589-651-0 Pages: 12

95FTM4. *An Experimental Test Stand to Measure Loaded Transmission Error in Fine-Pitch Plastic Gears*
Authors: **Sivakumar Sundaresan, David Castor and Kenneth Price**
This paper describes an experimental test stand to measure transmission error in fine-pitch gears. It covers the importance of transmission error control in office equipment. Transmission error is computed by measuring the phase difference between the driver shaft and the driven shaft using optical encoders. The test stand has a variable operating center distance and shaft alignment in both parallel and skew directions. Results show the effects of gear elemental errors, transmitted load, and shaft misalignment on transmission error in fine-pitch plastic gears.
ISBN: 1-55589-652-9 Pages: 9

95FTM5. *The Surface Fatigue Life of Contour Induction Hardened AISI 1552 Gears*
Authors: **Dennis Townsend, Alan Turza, and Mike Chaplin**
Two groups of spur gears manufactured from two different materials and heat treatment were endurance tested for surface fatigue life. One group was manufactured from AISI 1552 and was finished ground then dual frequency contour hardened and the second was CEVM AISI 9310 carburized hardened then finished ground. The gear pitch diameter was 8.89 cm (3.5 in.). Test conditions were at maximum Hertz stress of 1.71 GPa (248 ksi) and a speed of 10 000 RPM. The lubricant used for the tests was a synthetic paraffinic oil with an additive package. The results showed that surface fatigue life of the contour hardened AISI 1552 was 1.7 times that of AISI 9310 gears.
ISBN: 1-55589-654-5 Pages: 9

95FTM6. *Development of an Epicyclic Gearbox for Reduced Sub-Synchronous Vibrations in Gas Turbo-Generator Sets*
Author: **A. Rakhit**
In star epicyclic gearboxes, low frequency subsynchronous (below turbine speed) vibrations can be predominant. Turbo-generator gear unit testing shows that these low frequency vibrations may occur even when the rotating components are balanced precisely. In star epicyclic gearboxes of Stoeckicht design, splined couplings between the ring gears and output shaft are used to float the ring gears for load sharing. The sub-synchronous vibrations that arise from such components are transmitted along with the mesh frequency vibrations to the turbine rotor bearings. When the amplitude levels of these vibrations and their harmonics exceed a certain limit, the life of these bearings is significantly reduced. To reduce the vibrations from the dynamic eccentricity of ring gears and splined couplings the design is changed.
ISBN: 1-55589-655-3 Pages: 7

95FTM7. *Experimental and Analytical Assessment of the Thermal Behavior of Spiral Bevel Gears*
Authors: **Robert Handschuh and Thomas Kicher**
An experimental and analytical study of spiral bevel gears operating in an aerospace environment has been performed. Tests were conducted within a closed loop test stand at 537 kW (720 hp) and 14400 rpm. The effects of various operating conditions on spiral bevel gear steady state and transient temperature are presented. A three-dimensional analysis of the thermal behavior was conducted using a nonlinear finite element analysis computer code. The analysis was compared to the experimental results. The results agreed within 10 percent.
ISBN: 1-55589-656-1 Pages: 19

95FTM8. *Miner's Rule - A More Definitive Approach*
Author: **Al Meyer**
ANSI/AGMA 2001-B88, Appendix B presents the fundamental method for evaluating Miner's Rule. To analyze the load spectrum, stress values are calculated for a given load and then modified using "K" or "C" factors. When computing the stresses for other points, the stress values are usually simply ratioed rather than recomputing the stresses using new "K" and "C" for each point. In this paper, the effect of using a dynamic and load distribution factor for each load point is evaluated and compared with the simple ratioing approach. Comparisons are made for various applications.
ISBN: 1-55589-657-X Pages: 6

95FTM9. *Bending and Compressive Stress Analysis of External Helical Gearsets of Varying Contact Ratios*
Author: **David Wenthen**
In an attempt to better understand how the durability of a helical gearset is affected by changes in profile (m_P) and face contact ratio (m_F), an analytical investigation was done in which m_P was varied. Thirty-two combinations were studied in total. The gears were modeled using the hybrid finite element computational method Contact Analysis Programming Package (CAPP), of Advanced Numerical Solutions. The results of this analysis suggest that for a given level of face contact ratio, an advantage in bending and compressive stress exists at the m_P=2.1 level over all of the others considered. Increasing both m_P and m_F had the effect of smoothing out the bending and compressive stresses when viewed as a function of roll angle.
ISBN: 1-55589-658-8 Pages: 10

95FTM10. *Efficiency of High Contact Ratio Planetary Gear Trains*
Author: **John Colbourne**

A new method is described for calculating the efficiency of planetary gear trains. An example, showing how the method can be applied to the case of a fixed differential gear train is given.

ISBN: 1-55589-659-6 Pages: 8

95FTM11. *Feature-Based Definition of Bevel Gears*
Author: **Robert E. Brown**

The complex shape of a bevel gear tooth surface must be defined mathematically for the CMM, but the mathematical definition tends to be difficult for direct use in gear design and manufacture. The mathematical definition may be condensed into a "feature-based" definition which is more convenient for gear design and manufacture. The feature-based definition may easily be described on the engineering drawings and toleranced. Development and application of the feature-based definition is described.

ISBN: 1-55589-660-X Pages: 10

95FTM12. *Flank Modifications in Bevel Gears Using a Universal Motion Concept*
Author: **Hermann Stadtfeld**

The use of free form bevel gear generators was limited by the processes currently available to cut bevel and hypoid gears with face cutter heads. Since a free form cutting or grinding machine has three rotational and three linear freedoms it is possible to perform all possible relative movements between the cutter and the work during the generation process. The universal motion concept is applied to axes of the basic gear generation model only. It allows each of them to change the setting during the generation process according a higher order function. This approach enables a free form gear machine to produce an entire variety of modifications to the flank surfaces.

ISBN: 1-55589-661-8 Pages: 10

95FTM13. *Powder Metallurgy Gears - Expanding Opportunities*
Authors: **W. Brian James and Howard Sanderow**

Powder metallurgy (P/M) is a precision metal forming technology for producing simple or complex parts to net shape or near net shape with little, if any machining. The mechanical properties of P/M materials are a direct function of density, composition, and microstructure. A systems approach to material and process selection permits the development of a microstructure suitable for the intended application. The technology as related to gear design and applications is reviewed. New materials and process technologies are reviewed for the comparability of P/M steel gears with cast or wrought steel. The strengths and weaknesses of the powder metallurgy process are examined, along with the challenges facing the industry.

ISBN: 1-55589-662-6 Pages: 12

95FTM14. *Study of Effect of Machining Parameters on Performance of Worm Gears*
Authors: **Anand Narayan, Donald Houser and Sandeep Vijayakar**

This paper studies the effect of machining parameters on the performance of worm gears using a special purpose finite element technique. Algorithms are presented to determine the worm and gear geometries by simulating the grinding action of the grinding wheel and cutting action of the hob. Results are presented delineating the effect of machining parameter such as the hob oversize, hob swivel angle, profile modification etc., on performance parameters such as the contact location and size, stresses and transmission error of worm gears.

ISBN: 1-55589-663-4 Pages: 9

95FTMS1. *Determination of the Dynamic Gear Meshing Stiffness of an Acetal Copolymer*
Author: **Connie P. Marchek**

The objective of this work was to determine the dynamic gear meshing stiffness of an acetal copolymer (plastic). The torsional resonant speed of an operating gear pair was determined experimentally. Using the theoretical model, it was possible to determine the dynamic gear meshing stiffness from the experimental resonant speed and compare it to the values calculated from available empirical formulas.

ISBN: 1-55589-653-7 Pages: 34

1994 PAPERS

94FTM1. *Fatigue Analysis of Shafts for Marine Gearboxes*
Author: **E. William Jones, Anying Shen and Robert E. Brown**

Designs are presented for the design of shafts for marine gearboxes, which may include the effects of torsional vibration. The influence of the vibratory torque on the values of shaft diameter and safety factor is discussed. Use of the Finite Element Method to evaluate unknown stress concentration factors is illustrated. A program for the design of shafts, which are subjected to fatigue, has been developed.

ISBN: 1-55589-635-9 Pages: 14

94FTM2. *An Analytical Method for the Calculation of the Efficiency of Planetary Gears*
Author: **Michel Pasquier and Pierre Foucher**

Presents a synthesis of an analytical method for the calculation of the efficiency of simple or compound planetary gear trains based on fundamental formulae. It is intended to improve the accuracy of

the rating of the efficiency of planetary gears to be included in a calculation of the thermal capacity.
ISBN: 1-55589-636-7 Pages: 6

94FTM3. *Application of Ausforming to Gear Finishing - Process, Design and Manufacturability Issues*
Author: **N. Sonti, A.J. Lemanski and S.B. Rao**

Discusses the potential applications of ausform finishing of spur and helical gears, including process design and related manufacturability issues. Examples are presented describing the flexible tooling arrangements possible to process a variety of gear geometries. Machine design, controls and material handling features of the production-capable double die gear ausform finishing machine currently being built are briefly described.
ISBN: 1-55589-637-5 Pages: 7

94FTM4. *Load Carrying Capacity of Nitrided Gears*
Author: **L. Albertin, R.L. Frolich, H. Winter, B.-R. Höhn and K. Michaelis**

Investigates the pitting and bending strength of gas nitrided steel gears made of modified 39CrMoV13.9 (a 3% CrMoV type alloy). Characteristics of the compound layer and the diffusion zone are examined. Residual stresses in the nitrided case are shown after long nitriding times. For bending strength, additional damage line investigations were performed. The load carrying capacity of the modified 39CrMoV13.9 steel is discussed and compared with other carburized, gas, and ion nitrided gears.
ISBN: 1-55589-638-3 Pages: 10

94FTM5. *A Special CVT for a New Power Train Concept*
Author: **B.-R. Höhn and B. Pinnekamp**

Describes the Autark Hybrid power train vehicle capable of inner city driving with zero emissions and also suited to long distance driving. Combines internal combustion engine (IC engine) and small electric engine. Enables significant reductions of fuel consumption at constant power by avoiding the partial load operation areas with high specific fuel consumption and reducing the engine speed. The new power transmission has a wide range and continuously variable ratio. The requirements, principle function and the progress in development of the i^2-CVT is described, as well as the application in the hybrid power train.
ISBN: 1-55589-639-1 Pages: 7

94FTM6. *A Boundary Element Procedure for Predicting Helical Gear Root Stresses and Load Distribution Factors*
Author: **M. L. Clapper and D. Houser**

Explores a method to accurately predict gear root stress for parallel axis gears using a combination of three analysis techniques: boundary elements, elastic body contact analysis, and the moment-image method. The three techniques are combined to predict the stresses through the mesh cycle for both spur and helical gears. Predictions are compared with strain gage results and finite element modeling. Results present the prediction of load distribution factors as a function of misalignment, comparing with AGMA factors.
ISBN: 1-55589-640-5 Pages: 8

94FTM7. *Allowable Surface Compressive Stresses of Gear Teeth Made of Cast Iron, Tempered Carbon Steels and Tempered Alloy Steels*
Author: **Hirofumi Kotorii**

Load endurance tests were conducted to obtain allowable surface compressive stresses for various materials: spheric graphite cast iron, G5502; carbon steel, G4051 and steel G4502. Load endurance tests were conducted, and data concerning tooth damage was accumulated. The results of these tests and comparison of the durability of the materials are presented.
ISBN: 1-55589-619-7 Pages: 13

94FTM8. *Reference Point, Mesh Stiffness and Dynamic Behavior of Solid, Semi-Solid and Thin-Rimmed Spur Gears*
Author: **Jean Brousseau, Claude Gosselin and Louis Clotier**

Many models for predicting the dynamic behavior of gears do not take into account the blank flexibility and modes of vibration. The paper presents results for solid, semi-solid and thin rimmed spur gears. The analysis is made for the natural frequencies, when finite element models of meshing spur gears are referenced. Results show that a reference point inside the gear blank yields excellent correlation between the natural frequencies extracted from the RD-FT and F.E.A. models.
ISBN: 1-55589-643-X Pages: 8

94FTM9. *Analytical and Experimental Vibration Analysis of a Damaged Gear*
Author: **F. Choy, M. Braun, and V. Polyshchuk, J. Zakrajsek, D. Townsend and R. Handschuh**

Develops a comprehensive analytical procedure for predicting faults in gear transmission systems. A model is developed to simulate the effects of pitting and wear on the vibration signal under operating conditions. The model uses gear mesh stiffness changes to simulate the effects of gear tooth faults. The predicted results were compared with experimental results obtained from a spiral bevel gear fatigue test. The Wigner-Ville Distribution (WVD) method applied to the results were compared to other fault detection techniques to verify the WVD's ability to detect the pitting damage and determine relative performance.
ISBN: 1-55589-644-8 Pages: 8

94FTM10. *Computerized Design and Generation of Low-Noise Gears With Localized Bearing Contact*
Author: **F. Litvin, N. Chen, J. Chen and J. Lu**

Presents results of research projects directed at reduction of noise caused by misalignment of various gear drives: double-circular arc helical gears, modified involute helical gears, face-milled spiral bevel gears and face-milled formate cut hypoid gears. A parabolic function of transmission errors was developed and successfully tested for a set of spiral bevel gears. The noise was reduced 12-18 decibels. The effectiveness of the proposed approach was investigated by developed TCA (Tooth Contact Analysis) programs. Manufacturing of helical gears with new topology by hobs and grinding worms was investigated.

ISBN: 1-55589-645-6 Pages: 10

94FTM11. *Development of Transfer Gear Noise of 4X4 Transmission for Recreational Vehicles*
Author: **Yoshiki Kawasaki**

Developed new methods to reduce transfer gear noise, which consisted of gear developments making use of tooth contact patterns, a new regrinding system for shaving cutters, quality control, improvement activities for gear production processes, etc. Succeeded in reduction in the reject rate from 4.5% to 0.5% and improving the transfer gear noise rating from 4.0-6.0 to 8.0-10.0.

ISBN: 1-55589-646-4 Pages: 6

94FTMS1. *Computer-Aided Numerical Determination of Hofer, Lewis, Niemann and Colbourne Points*
Author: **Chang H. Park**

In rating the bending strength of gear teeth, the critical point located where the fracture occurs must be determined. Hofer, Lewis, Niemann and Colbourne use methods to find the point approximately, in which numerical iteration is needed to solve nonlinear one-variable equations to find their critical points. This paper presents equations expressed easily and in a similar way for finding the critical point as well as the general gear tooth profile equations derived by a vector analysis method. Position comparison of points was achieved with computer-aided graphical and numerical output.

ISBN: 1-55589-642-1 Pages: 17

1993 PAPERS

93FTM1. *Undercutting in Worms and Worm-Gears*
Author: **John R. Colbourne**

Develops an equation for worms that can be used to ensure that there is no undercutting. Explains that for wormgears, the possibility of undercutting depends on many variables, and no simple criterion has been found. Describes procedures for checking for undercutting and other potential problems, such as interference or non-conjugate contact.

ISBN: 1-55589-594-8 Pages: 10

93FTM2. *Topological Tolerancing of Worm-Gear Tooth Surfaces*
Author: **Vadim Kin**

Proposes a method for determining surface deviations of the wormgear tooth that result from cutting edge deviations of the hob used to cut the gear. Demonstrates how to obtain tolerance tables for wormgear tooth profiles from the tolerance tables for the corresponding worm threads and hob cutting edges. (Such tables can be an important first step towards a wormgear inspection standard.)

ISBN: 1-55589-595-6 Pages: 6

93FTM3. *A Rayleigh-Ritz Approach to Determine Compliance and Root Stresses in Spiral Bevel Gears Using Shell Theory*
Authors: **Sathya Vaidyanthan, Henry Busby and Donald Houser**

Proposes a mathematical model for predicting deflections and root stresses in spiral bevel gears. Shows a shell model is more representative of the spiral bevel tooth geometry as compared to a beam or plate model. Integrates the compliance computations based on the shell model into existing computer codes for bevel gear design to determine the load distribution, transmission error, and root stresses on a personal computer. Concludes that computationally, this procedure is much more efficient than the finite element method.

ISBN: 1-55589-596-4 Pages: 9

93FTM4. *Stress Analysis of Spiral Bevel Gears: A Novel Approach to Tooth Modelling*
Authors: **Ch. Rama Mohana Rao and G. Muthuveerappan**

Proposes a geometrical approach for generating tooth surface coordinates of spiral bevel gears. Demonstrates how this versatile can be adapted, with appropriate modifications, to any type of spiral bevel gear. Analyzes various types of spiral bevel gears (logarithms, circular cut and zerol types). Offers a new procedure, using the three-dimensional finite element method, for theoretical determination of exact tooth load contact line on the surface of the spiral bevel gear tooth.

ISBN: 1-55589-597-2 Pages: 14

93FTM5. *Optimal Gear Design for Equal Strength Teeth Using Addendum Modification Coefficients*
Author: **C. H. Suh**

Defines the addendum modification coefficient (shift factor) and explains it in terms of gear design terminology. Shows the derivation of two types of helical gear design equations, one with the true generating shift factor, and the other with an addendum modification factor. Reviews a cantilever beam equation used to design equal

bending strength teeth. Presents a design method, along with numerical examples, to synthesize equal strength teeth between mating a pinion and gear that may have different material properties.
ISBN: 1-55589-598-0 Pages: 12

93FTM6. *Effect of Radial Runout on Element Measurements*
Authors: **I. Laskin, R. E. Smith and E. Lawson**
Proposes that radial runout in a gear can contribute substantially to measured values of variations in profile, pitch and index, and in helical gears, to tooth alignment (lead) variations. For each variation, gives the equation that relates the measured value to the radial runout in an otherwise ideal gear. Demonstrates the relationship by comparing the result of actual measurement with the calculated value. Describes how the equations can: aid the interpretation of gear inspection data and explain differences between measurement methods.
ISBN: 1-55589-599-9 Pages: 16

93FTM7. *New Developments in Design, Manufacturing and Applications of Cylkro- (Face) Gears*
Authors: **Guus Basstein and Anne Sijtstra**
Calculates and optimizes the geometry of both Cylkro-gear and pinion, concerning contact ratio, lines of action and contact. Using F.E.M. analysis and a load distribution program, adapts the DIN 3990 (ISO/DIS 6336) calculation methods (for bending strength and pitting resistance) to include Cylkro-gear calculations. Tests this method on a back test bench.
ISBN: 1-55589-619-7 Pages: 12

93FTM8. *Single Flank Testing and Structure-Born Noise Analysis*
Author: **Hermann J. Stadtfeld**
Proposes that testing the running behavior of an installation-ready gearset must take place on bevel and hypoid gear testers. Describes single flank generation testing and structure-borne noise analysis of gear pairs, based on a highly modern real-time analysis device for which software was specially developed for the transmission testing of gearsets. Explains the new possibilities and offers a trouble shooting example.
ISBN: 1-55589-620-0 Pages: 11

93FTM9. *Gear Tooth Bending Fatigue Crack Detection by Acoustic Emissions and Tooth Compliance Measurements*
Authors: **Jeffrey Wheitner, Donald Houser and Craig Blazakis**
Presents the results of gear tooth bending fatigue tests. Explores whether the combination of two types of measurement -- acoustic emissions and tooth compliance -- can help detect cracks early on (single tooth bending fatigue tests for several different gear materials were performed). Uses the two crack detection methods to describe fatigue test characteristics, such as the probable time of crack initiation, rate of crack propagation, and percent of total fatigue life spent in crack propagation phase. Presents the effects of materials and processing. Shows how crack detection can reveal the results of surface finish on fatigue.
ISBN: 1-55589-621-9 Pages: 7

93FTM10. *High Speed, Heavily Loaded and Precision Aircraft Type Epicyclic Gear System Dynamic Analysis by Using AGMA Gear Design Guidelines Enhanced by Exact Definition of Dynamic Loads*
Authors: **K. Buyukataman and K. Kazerounian**
Dynamic analysis of reliable, lightweight, high speed and high power density epicyclic gears requires special effort to predict their maximum power transmitting capacity. Focuses on single-stage epicyclic gears of this category. Presents an overview of key design considerations with proper application of AGMA standards. Uses a state-of-the-art, elastodynamic simulation that responds to input data much as a fully-instrumented test cell. Demonstrates that an epicyclic gear system can be a fully reliable aircraft propulsion component.
ISBN: 1-55589-622-7 Pages: 19

93FTM11. *The Relative Noise Levels of Parallel Axis Gears Sets with Various Contact ratios and Gear Tooth Forms*
Authors: **R. J. Drago, J. W. Lenski , R. H. Spencer, M. Valco and F. Oswald**
Describes the design and testing of nine sets of gears which are as identical as possible except for their basic tooth geometry. Measures noise at various combinations of load and speed for each gear set in order to make direct comparisons. Analyzes resultant data, including that gear geometry is an important parameter for designing low weight, high reliability gear systems for aircraft.
ISBN: 1-55589-623-5 Pages15

93FTM12. *The Generation of Precision Spur Gears Through Wire Electrical Discharge Machining*
Authors: Roderick Kleiss, Jack Kleiss, and Scott Hoffmann
Maximizes the accuracy and repeatability of wire Electrical Discharge Machines (EDM) through fixturing and controlled cutting methods. Also optimizes mathematical algorithms for the cutting path. Presents results slowing the verified generation of precise spur gears in pitches ranging from 5 to 41 DP. Demonstrates the advantage of this method, including short lead times (with accuracy approaching form ground gears) at a competitive cost. Concludes this method is suitable for producing small to medium lots of accurate spur gears in any electrically conductive material.
ISBN: 1-55589-624-3 Pages: 11

93FTM13. *CAGE – Computer Aided Engineering Software*
Author: **Enrico Esposito**
Describes CAGE, a UNIX–based set of computer programs that uses an industry standard, windows–based graphical user interface for efficient and logical gear design and analysis. Includes manufacturing data and inspection data. Highlights special features, including: file folders containing gear–set development information, multi–window display and processing, international language support, connections to manufacturing and inspection machines, and a field, screen and an on–line help facility and user guide.
ISBN: 1–55589–625–1 Pages: 14

93FTMS1. *Spur Gear Bending Strength Geometry Factors: A Comparison of AGMA and ISO Methods*
Author: **E. R. teRaa**
Presents the necessity of comparing ISO and AGMA power rating standards. Gives the results of using computer software to compare the behavior of the bending geometry factor (J–factor) values for 135 spur–gear meshes. Shows that differences exist between the results given by ISO and AGMA standards, both in the geometry factor values and the effects of profile shift (which is of particular interest).
ISBN: 1–55589–626–X Pages: 8

1992 PAPERS

92FTM1. *Experimental Characterization of Surface Durability of Materials for Worm Gears*
Author: **M. Octrue and M. Guingand**
Presents the methodology used for testing materials with a worm gear set–up and with a disc–roller machine. Discusses and analyzes several experimental results. Draws a correlation between metallurgical analyses of the structure of bronzes and experimental observations of subsurface cracks. Explains specific method of for measuring wear and describes results.
ISBN: 1–55589–581–6 Pages: 7

92FTM2. *Face Gear Drives: Design, Analysis, and Testing for Helicopter Transmission Applications*
Authors: **F. Litvin, J. Wang, R. Bossler, Y. Chen, G. Heath and D. Lewicki**
Examines a variety of topics including tooth generation, limiting inner and outer radii, tooth contact analysis, contact ratio, gear eccentricity, grinding and structural stiffness. Shows that the face gear drive is relatively insensitive to gear misalignment with respect to transmission error, but that tooth contact is affected by misalignment. Explores a method of localizing the bearing contact to permit operation with misalignment. Investigates two new methods for grinding face gear tooth surfaces.
ISBN: 1–55589–582–4 Pages: 11

92FTM3. *Reduced Fuel Consumption and Emissions Due to Better Integration of Engine and Transmission*
Author: **B. Höhn**
Discusses how better integration of engine and transmission can help reduce fuel consumption and emissions from combustion. Demonstrates that gears with a wider ratio range offer three advantages: 1) reduced engine speed; 2) improved acceleration without enlarging the engine; 3) optimal configuration for a new hybrid drive line for passenger cars.
ISBN: 1–55589–583–2 Pages: 7

92FTM4. *The Design, Development and Manufacture of Advanced Technology Gearing for Hot Strip Rolling Mill Applications*
Authors: **R. Drago and L. Scott**
Describes the initiation and process of a program which addresses very large gears (approaching 200 inches in diameter) and a number of pinion configurations. Configurations range from long, integral, solid on–shaft designs to multiple shell pinion designs. Most are carburized and hard finished; all meet or exceed AGMA Quality Class 10. Presents the general design procedures and overall implementation of the design and manufacturing program. Describes the results in terms of improved mill gear system experience.
ISBN: 1–55589–584–0 Pages: 21

92FTM5. *Main Advantages of Non–Involute Spur Gears*
Author: **J. Hlebanja**
Identifies scuffing as the main cause for limiting gear durability in highly loaded and high speed working gears. Notes that the principal way to avoid scuffing of tooth flanks is to apply an oil film of sufficient thickness between the mating flanks. Asserts that the shape of the flanks determine the curvature radius and sliding velocity. In turn, the curvature radius and sliding velocity decisively affect the forming of the oil film between flanks. Proposes that by shaping the line of action properly results in better gear flank shapes and improved durability.
ISBN: 1–555889–585–9 Pages: 6

92FTM6. *Comparison of Carburized Gear Materials in Pitting*
Authors: **L. Faure, J. Vasseur, and C. Lefleche**
Compares the pitting resistance of five different steels commonly used for case carburized gears. Bases the comparison on the test results obtained on the CETIM gear benches. Describes how the tests were set up the test results interpreted for each steel. Draws representative curves of pitting

performance. Describes, in detail, the appearance of these curves and all the deviations encountered.
ISBN: 1-55589-586-7 Pages: 7

92FTM7. *Differences in the Local Stress of the Gear Tooth Root Based on Hobbing Cutters and Pinion Cutters*
Authors: **H. Linke and J. Börner**
Proposes that use of a pinion-shaped cutter, instead of a hob, causes differences in tooth root geometry. Asserts that these differences lead to different stress concentrations in the tooth root. Uses the Singularity Method for both types of product to calculate, exactly, tooth root stresses. Discusses differences in both approaches. Proves that it is possible to calculate stress concentration using the stress parameter $2\rho_{Fn}/s_{Fn}$ (on 30° tangent).
ISBN: 1-55589-587-5 Pages: 10

92FTM8. *The Role of Reliability for Bearings and Gears*
Author: **C. Moyer**
Details the experimental basis for the relationship between stress (load), life and reliability for bearings and gears considering the similarity and differences of their respective systems. Addresses the role of stress level and life scatter in terms of the Weibull distribution. Develops the background and equations to calculate reliability factors, as included in both bearing and gear standards.
ISBN: 1-55589-588-3 Pages: 7

92FTM9. *Representative Form Accuracy of Gear Tooth Flanks on the Prediction of Vibration and Noise of Power Transmission*
Authors: **A. Kubo, T. Nonaka, N. Kato, S. Kato, and T. Ohmori**
Begins with the premise that gear noise and vibration are troublesome problems in power transmission systems. Reviews recent research that shows accuracy in three dimensional tooth flank form, usually represented by tooth form and tooth lead form, are important factors in noise and vibration. Discusses investigation into what form accuracy of gear tooth flank has a good correlation with gear vibration and noise, when the scattering of accuracy in tooth flank form cannot be avoided.
ISBN: 1-55589-589-1 Pages: 6

92FTM10. *The Influence of the Kinematical Motion Error on the Loaded Transmission Error of Spiral Bevel Gears*
Authors: **C. Gosselin, L. Cloutier, and Q. Nguyen**
Presents the basis of a Loaded Tooth Contact Analysis program predicting the motion error of spiral bevel gear sets under load. Shows amplitude and shape of the unloaded motion error curve can affect the kinematical behavior under load. Evaluates the effects of tooth composite deflection, tooth contact deformation, and initial profile separation due to motion error.
ISBN: 1-55589-590-5 Pages: 11

92FTM11. *New Findings on the Loading of Plastic Spur Gear Teeth*
Authors: **J. Bessette and H. Yelle**
Proposes that tooth breakage at the tip of plastic gears is the result of interference on the back of the tooth. Provides verification of this interference through experiments. Explains how CAD software and plastic gear calculating software can simulate the kinematics of a gear pair to predict and localize interference on the back of the tooth.
ISBN: 1-55589-591-5 Pages: 8

92FTM12. *Noise Reduction in a Plastic and Powder Metal Gear Set Through Control of "Mean Involute Slope"*
Authors: **R. Smith and I. Laskin**
Recognizes mismatched involute profiles as a cause of tooth meshing noise. Traces a noise reduction process applied to a consumer product with a noisy gearset. (Gearset consists of a powder metal pinion driving a molded plastic gear.) Notes that measurements of profiles on both gears showed a mismatch of pressure angles. Proposes that such a mismatch could be related to "mean involute slope'. Shows that when the mismatch is reduced, noise components drop to acceptable levels.
ISBN: 1-55589-592-1 Pages: 8

92FTMS1. *Spur Gears - A New Approach to Tooth Design*
Author: **B. Srinivasulu**
Studies a new spur gear tooth design in which each tooth has a through hole made on its center line parallel to the gear axis. Studies the effect of hole size and location. Reports that the same load contact stresses in a hollow-solid mesh are lower than that of a solid-solid mesh. Further reports that dynamic loads in a hollow-solid mesh are the same as that of a solid-solid mesh with the same damping.
ISBN: 1-55589-593-X Pages: 25

1991 PAPERS

91FTM1. *CNC Bevel Gear Generators and Flared Cup Formate Gear Grinding*
Author: **T. Krenzer**
Full CNC bevel generators are positioned relatively between the tool and work with simple mechanisms and electronic controls. As a result, the gear engineer has new freedoms for the control of gear tooth shapes and contact characteristics. This paper defines the flared cup Formate gear grinding process and the motions that can be applied to the process. Surface comparison charts and tooth contact analysis are used to demonstrate the

effects of the freedoms. Comparisons of jobs designed with and without the motions are included.
ISBN: 1-55589-574-3 Pages: 14

91FTM2. *CNC Technology and New Calculation Methods Permit Efficient System Independent Manufacturing of Spiral Bevel Gears*
Author: **D. Weiner**
A strictly applied CNC technology on machines for cutting or grinding spiral bevel gears allows the machining of different gearing systems on one machine. Based on this, the selection of the most favorable gearing system is possible, considering economic issues, load bearing capacity and noise characteristics.
ISBN: 1-55589-602-2 Pages: 10

91FTM3. *High Efficiency Gear Hobbing*
Authors: **G. Ashcroft and B. Cluff**
Discusses the design advances of disposable gear cutting tools, specifically those which have produced the non-resharpenable Wafer hob, the application of the tools, and the benefits derived from applying these tools in gear manufacturing. The concurrent development of hobbing machines capable of efficiently applying these tool designs is also detailed.
ISBN: 1-55589-600-6 Pages: 17

91FTM4. *Low Noise Marine Gears*
Author: **W. Haller**
Reduction gears for frigates, corvettes, destroyers and submarines have to be reliable, durable, easy to maintain, small in size and as light as possible. In principle, there are two ways of reducing structure borne noise emission of gearboxes: primary and secondary. This paper deals with primary measures, those which tend to eliminate the generation of noise at its source.
ISBN: 1-55589-601-4 Pages: 13

91FTM5. *Machine Tool Condition Monitoring*
Author: **L.E. Stockline**
Actual production applications of computer assisted Tool Condition Monitoring Systems are reviewed from case studies over the last several years. New applications are being encouraged by the aircraft and automotive industries which, due to the development of new sensors and microprocessor strategy, allow untended manufacturing. There is a major impact on quality control, maintenance and machine uptime when tool wear, tool breakage and missing tool or forces can be accurately measured.
ISBN: 1-55589-573-5 Pages: 8

91FTM6. *Comparing Surface Failure Modes in Bearings And Gears: Appearances versus Mechanisms*
Author: **C. Moyer**
Contact fatigue modes are identified over a range of modified lambda values. Describes failure modes and interprets the wear, fracture and/or fatigue mechanisms that lead to the failure initiation. Considering the similarity in appearance of gear and bearing failure modes in light of the different relative surface motions and tractions of the two contacts, this comparison helps provide insight into the basic causes of the failures and suggests methods to avoid them.
ISBN: 1-55589-603-0 Pages: 13

91FTM7. *Low Cycle and Static Bending Strength of Carburized and High Hardness Through Hardened Gear Teeth*
Author: **W. Pizzichil**
Presents a summary of the testing methods employed and the results generated for unidirectional and reverse bending tests of very coarse and medium pitch gear teeth. Actual measured stresses were compared with FEM theoretical stresses and AGMA stress numbers. The purpose of this testing was to evaluate which type of hardening method would yield a gear tooth that could carry the highest load without catastrophic breakage failure in a single, or very low cyclic load application. This testing simulated the output pinion and a planet gear for a jack-up gear drive used on oil drilling platforms. Three separate tests were conducted over a period of time.
ISBN: 1-55589-604-9 Pages: 15

91FTM8. *Methods of Statistical Dynamics for the Calculation of Gear Stress Distribution and its Effect on Gear Failure Probability*
Author: **M. Haykin**
The process of most machine loading has a random character which is determined by external variation and dynamic qualities of the system. Such an approach was used to obtain the load spectrum for gears and the probability of its failure. Analysis and experiments showed that gain factor for gear is distinguished by the similar parameter of the entire drive system. This is explained by the uniform distribution of gear stress even for cases of static loading. Method of gear strength calculation with the statistical parameter is discussed.
ISBN: 1-55589-613-8 Pages: 10

91FTM9. *Rerating Damaged Naval Ship Propulsion Gears*
Authors: **R. Coblenz and C. Reeves**
When naval ship propulsion gear teeth break, the affected teeth are "field dressed", so that the units can be put back into service. Then the gears are rerated to a lower rating and used reliably, at least

until replacement elements become available. Using sketches or computers, an estimate is made of the instantaneous total length of contact as the damaged sections go through mesh with the results being used as a basis of rerating the unit. Consideration is given to end reliefs, the location of the damage on the helix and the nature of the field dressing, and actual material properties. The results of this analysis, together with analysis of the causes of the original failure, provide limits within which the unit can be operated with the same reliability as new.
ISBN: 1-55589-606-5 Pages: 9

91FTM10. *Dynamic Measurements of Gear Tooth Friction and Load*
Authors: **B. Rebbechi, F. Oswald, and D. Townsend**
A program to experimentally and theoretically study fundamental mechanisms of gear dynamic behavior is being conducted at the NASA Lewis Research Center in support of a joint research program between NASA and the U.S. Army. This paper presents the results of dynamic tooth-fillet strain gage measurements from the NASA gear-noise rig, and it introduces a technique for using these measurements to separate the normal and tangential (friction) components of the load at the tooth contact.
ISBN: 1-55589-607-3 Pages: 13

91FTM11. *Initial Design of Gears Using Artificial Neural Net*
Authors: **T. Jeong, T. Kicher, and R. Zab**
Most mechanical engineering design problems require both computational and decision making aspects. Those decision making tasks can be performed by an artificial neural net. The adaptability of the artificial neural net for initial gear design was demonstrated and the detailed application is explained throughout the paper.
ISBN: 1-55589-608-1 Pages: 11

91FTM12. *The Combined Mesh Stiffness Characteristics of Straight and Spiral Bevel Gears*
Authors: K. Yoon, J.W. David, and M. Choi
The combined mesh stiffness of spiral bevel gears is one important factor for dynamic analysis. The total deflection on the contact line of a tooth pair is composed of bending, shear and tooth contact deflections. The bending and shear deflections on the contact line of the gear tooth are evaluated by the finite element method with isoparametric shell elements, and the tooth contact deflections are evaluated using Hertzian contact theory. Based on these deflections, stiffness is obtained using the so called flexibility method, and then the combined mesh stiffness is obtained by applying contact and load sharing ratios.
ISBN: 1-55589-609-X Pages: 9

91FTM13. *Separation of Lubrication and Cooling in Oil-Jet Lubricated Gears*
Authors: **J. Greiner and K. Langenbeck**
Results from tests on a high-speed back-to-back stand (vt = 70 m/sec = 13725 ft/min) show the influence of the separation of lubrication and cooling oil supply on gear temperatures (scuffing load capacity) and efficiency. The gear mesh is only given the minimum oil flow rate necessary for lubricating the working tooth flanks. Cooling is provided by spraying oil onto the inner surfaces of the rims. This leads to a reduction of up to 60% of the total oil flow rate compared to currently recommended flow rates. In spite of the reduced total oil flow rate the temperature level of the gears can be kept low while the efficiency slightly increases due to reduced hydraulic losses in the gear mesh.
ISBN: 1-55589-610-3 Pages: 19

91FTM14. *The Effect of Thermal Shrink and Expansion on Plastic Gear Geometry*
Author: **R. Kleiss**
When plastic gears are meshed with steel gears there can be the differences in thermal expansion between the two materials. If a particular gear mesh is expected to operate satisfactorily over a wide thermal range, the variations in mesh geometry due to temperature must be taken into account. These variable parameters can pose vexing problems to the plastics gear designer. This paper presents a straightforward way to consider the shrinkage of plastic gears both in molding and in operation.
ISBN: 1-55589-611-1 Pages: 6

91FTM15. *Gear Hardness Technology*
Authors: **M. Broglie and D. Smith**
As demands on the gear designer to make gearing that is smaller, lighter and more reliable increases so does the demand for better materials and heat treat processes. Proper hardness of a gear, both in the tooth and in the body is becoming increasingly critical since load carrying capacity is dependent on hardness. The scope of this paper is limited to the most common methods of heat treating steel gearing; however, there are many methods of heat treatment in wide use throughout the industry.
ISBN: 1-55589-612-X Pages: 14

91FTM16. *Contact Analysis of Gears Using a Combined Finite Element and Surface Integral Method*
Authors: **S.M. Vijayakar and D.R. Houser**
Describes a new method for solving the contact problem in gears. The method uses a combination of the finite element method and a surface integral form of the Bousinesq and Cerruti solutions. Numerical examples are presented for contacting hypoid, helical, and crossed axis helical gears.
ISBN: 1-55589-614-6 Pages: 12

91FTM17. *The Influence of Lubrication on the Onset of Surface Pitting in Machinable Hardness Gear Teeth*
Authors: **C. Massey, C. Reeves, and E. Shipley**

Tests have been run on machinable hardness helical gears to study the influence of changes in calculated oil film thickness in the operating gear teeth in regard to the onset of surface pitting. Control tests were run at constant load to develop typical pitting patterns on the gear teeth within a reasonable test period. Subsequent tests were carried out to evaluate the changes in resistance to pitting that occurred when the oil film thickness was varied. All the tests were operated with an ample controlled supply of a petroleum-based lubricant, symbol 2190 TEP, that meets the specifications of MIL-L-1 7331.

ISBN: 1-55589-605-7 Pages: 24

91FTMS1. *The Element Stress Analysis of a Generic Spur Gear Tooth*
Author: **E. A. Tennyson**

The prediction of bending stresses in a gear tooth, resulting from an externally applied torque, requires special consideration when designing spur gear systems. The tooth geometry is such that excess risers exist which must be accounted for. In addition, variables affecting the exact load point on the tooth and the direction of the applied load are critical. An interactive preprocessor is developed which generates all the information, including a detailed tooth profile, necessary to perform a finite element bending stress analysis of the gear system. To validate the procedure, a test group of spur gears is identified and analyzed. The results are compared to those obtained via the American Gear Manufacturers Association (AGMA) standards. The comparison revealed the finite element stresses to be slightly more conservative than corresponding AGMA standard stresses. A generalized stress equation and geometry factor, based on the finite element approach, are also introduced. This paper is intended only as a proof of concept.

ISBN: 1-55589-615-4 Pages: 12

1990 PAPERS

90FTM1. *Contact Stresses in Gear Teeth*
Author: **J.R. Colbourne**

It is shown that neither Hertz's fine contact theory nor his point contact theory are entirely adequate for the accurate calculation of contact stresses in gear teeth. A numerical procedure is described, which can be used to find the contact stress in cases where the relative curvatures in the contact region are not constant.

ISBN: 1-55589-553-0 Pages: 15

90FTM2. *An Industrial Approach for Load Capacity Calculation of Worm Gears (Verifying and Design)*
Author: **M. Octrue**

The method proposed in this paper is based on an analytical rating method which has been developed some years ago by the author (see AGMA paper 88FTM6). The calculation is based on the determination of the maximum of pressure between the mating teeth which is made by using a specific criteria for worm gears. The method can be used to verify the load capability of a worm gear but also to design a new gear covering several types of tooth profile. Calculations are provided as examples and comparisons have been made with results obtained by the initial analytical method, and by standardized methods (AGMA, BS).

ISBN: 1-55589-554-9 Pages: 10

90FTM3. *Simulation of Meshing, Transmission Errors and Bearing Contact for Single-Enveloping Worm-Gear Drives*
Authors: **F.L. Litvin, and V. Kin**

The authors have developed a computerized method for simulation of meshing and bearing contact (TCA) for single-enveloping worm-gear drives. The developed computer programs enable one to determine the transmission errors and the shift of bearing contact that are caused by worm and gear misalignment. An important theorem is proven for determination of the transfer point on the theoretical line of contact where the path of point contact starts for a misaligned worm-gear drive. A method of assembly for compensation of misalignment is proposed.

ISBN: 1-55589-555-7 Pages: 14

90FTM4. *Different Types of Wear - How to Classify?*
Author: **L. Faure**

In the first part, this document describes all the types and aspects of wear which can occur on the gear teeth in operation, with causes and explanations concerning their appearance. For each type of wear, the possible evolution and the limits which should not be passed to avoid a failure or severe damage to the tooth, thus reducing the life of the gear, are clearly specified. Aspects of wear types which can be considered as normal, medium or progressive are also described and solutions are presented as a guide for wear stabilizing.

ISBN: 1-55589-556-5 Pages: 17

90FTM5. *Polishing Wear*
Authors: **A. Milburn, R. Errichello and D. Godfrey**

Polishing wear has been known to occur on piston rings, cylinder bores, valve lifters, hydraulic components, rolling-element bearings and gear teeth. The bright, polished surfaces may look good, but polishing wear is detrimental because it is a high wear phenomenon which reduces the geometric accuracy of the components. A case history is presented of a gearbox which suffered extensive

polishing wear of the gear teeth and rolling-element bearings. The results of research into the basic mechanism of polishing wear, and laboratory analyses of materials and lubricants are presented. Polishing wear is shown to be due to fine-scale abrasion. It is promoted by a combination of a fine abrasive and a gear oil with chemically-active additives.
ISBN: 1-55589-557-3 Pages: 17

90FTM6. *Dynamic Responses of Aircraft Gears*
Author: **K. Buyukataman**
Rapid and destructive failures of high quality, high speed, light weight and highly loaded aircraft gears are indications of the vibrational energy (associated with neutral frequency modes) exceeding the fatigue endurance limit of advanced gear materials. The paper reviews: A) Experimental and analytical methods to identify and define resonant mode, B) Effects of gear design and manufacturing variables on the generation and damping of vibrational energy.
ISBN: 1-55589-558-1 Pages: 21

90FTM7. *Advanced Rotorcraft Transmission Program - A Status Review*
Authors: **R.J. Drago and J.W. Lanski**
The paper reports on Boeing Helicopters contract with the U. S. Army to conduct the Advanced Rotorcraft Transmission (ART) Technology Integration Demonstration program, The objectives of the program are to reduce transmission weight, reduce transmission noise and improve transmission life. The paper presents an overview of the planned program and a broad description of the major tasks to be accomplished.
ISBN: 1-55589-559-X Pages: 19

90FTM8. *Investigations on the Scuffing Resistance of High-Speed Gears*
Authors: **H. Winter and H. F. Collenberg**
Test results with a high speed four square gear test rig (nmax = 26 000 rpm) show the influence of speed, viscosity, base oil, type, and amount of additive on the scuffing load. In some cases at high speed the scuffing load can be more than twice the value calculated according to ISO/DIS 6336/4. The reason for the speed-dependency of the scuffing load is explained by the kinetics of the chemical reaction between the metal and the additive. It is described, how a calculation method could take account of the high scuffing load at high speed.
ISBN: 1-55589-560-3 Pages: 18

90FTM9. *A Procedure That Accounts for Manufacturing Errors in the Design Minimization of Transmission Error in Helical Gears*
Authors: **S. Sundareson, K. Ishii and D.R. Houser**
This paper deals with the design of helical gears that have minimum transmission error and, at the same time, are less sensitive to manufacturing errors. The paper addresses two stages in design: 1) Design generation stage where feasible designs are generated for a specification and 2) Design of profile and lead modifications that minimize transmission error and its sensitivity to manufacturing errors. The paper presents a brief discussion on how one can effectively minimize transmission error in helical gears by combining both lead and profile modifications
ISBN: 1-55589-561-1 Pages: 19

90FTM10. *The Mechanism of Failure With and Without Titanium Nitride Coating in Roller Tests*
Authors: **J. Vižintin**
To clarify the effect of Titanium Nitride (TiN) coating on failure resistance and frictional characteristics and compare this effect with that produced by heal treated coatings, two roller tests have been made and the stress resulting from the combination of the Hertzian stress field and frictional force field on and below the contacting surface as well as the flash temperature rise were calculated. The failure resistance of the TiN-coated roller pair was greater than that of the heat treated roller pair. The mechanism of failure resistance can be explained by the shearing stress (Hertzian stress + frictional force) acting on the contact surface. This stress modifies the structure in the vicinity below the TiN layer which is then sheared in the weak track direction.
ISBN: 1-55589-562-X Pages: 33

90FTM11. *Multiple Iteration - Respectable Trial-and-Error*
Author: **M.L. Baxter**
"Trial-and-error" was once a dirty word. Now, with computers, it has become the most valuable tool in engineering calculation. The procedure described in this paper permits any number of input variables (say A,B,C) to be systematically varied until an equal number of results (say X,Y,Z) are zero, regardless of the complexity of the equations relating A,B, C to X,Y,Z. It has been used successfully by the writer for up to seven variables. This paper is not concerned with the structure of the computer program representing this procedure, but rather with the kinds of engineering problems that can use it, and how it can be used as a subroutine in engineering programs. Two actual gear applications will be described.
ISBN: 1-55589-563-8 Pages: 15

90FTM12. *Design of New Systems of Controlled Speed Drives*
Authors: **M. Hirt, T. Weiss and P. Bolger**
Processes in chemical industries and power plant stations require, to a certain extent, variable speed drives of high power capacity. In contrast to controlled hydrodynamic or friction clutches, a new system of hydrostatic controlled superimposed planetary gears was developed. Design and

calculations as well as efficiency comparisons to other systems will be described. Practical experiences in the drive of large boiler feed pumps will be explained which prove the reliability of these drives.
ISBN: 1-55589-564-6 Pages: 14

90FTM13. *Face Milling or Face Hobbing*
Author: **Theodore J. Krenzer**
Face milling and face hobbing are the two principal processes used in the production of bevel and hypoid gears. A manufacturer must decide on one or the other. This paper defines the methods and the inherent characteristics they impose on the tooth design and manufacture. Geometric tooth design differences and the reasons for the differences are examined. TCA, finite element analysis and test results for the two processes are included. Cutting tools and processes are compared; advantages and disadvantages of each process are enumerated and criteria for the selection of one process over the other is proposed.
ISBN: 1-55589-565-4 Pages: 13

90FTM14. *A Closed and Fast Solution Formulation for Practice Oriented Optimization of Real Spiral Bevel and Hypoid Gear Flank Geometry*
Author: **H.J. Stadtfeld**
If a very specific and systematic method is applied to spiral bevel and hypoid gear correction, a new possibility exists to accurately and quickly design and manufacture high quality gearsets. All generated data can be archived on a diskette, saved in machine control memory or stored in a central host computer. The described algorithm is based on a differential geometry calculation which is to activate about simple and intuitive input graphics.
ISBN: 1-55589-566-2 Pages: 11

90FTM15. *Optimal Design of Straight Bevel Gears*
Authors: **Rajiv Agrawal, Gary L. Kinzer and Donald R. Houser**
Describes the design of a straight bevel gearset with the objective of minimizing the enclosed volume. The specifications for the design are the power requirements, the gear ratio, pinion speed and the material properties. The design variables are the number of pinion teeth, the diametral pitch, and the face width. Constraints are set on facewidth, minimum number of pinion teeth, and the safety factors for bending and pitting strength. The complete analysis for the gearset is based on the rating procedure described in the ANSI/AGMA 2003-A86 standard. The optimization procedure is illustrated through a numerical example and the design is also compared with a spur gear optimization method using Tregold's approximation.
ISBN: 1-55589-567-0 Pages: 11

90FTMS1. *Kinematic Analysis of Transmissions - Based on the Finite Element Method*
Author: **A.L. Sytstra**
In order to evaluate the kinematic properties of a design of a transmission in its early stages, a computer program has been developed. By means of geometric reasoning, a finite element model is deduced from the conceptual design which has been built using an experimental 3D object editor. Since the interrelations between the objects are not specified by the designer they are found by the computer by supplying a set of rules. The following kinematic analysis uses a mixed Euler/Lagrange description and detects mechanisms (possible infinitesimal displacements of the nodal points without causing strain in the elements) in the transmission. The mechanisms found are visualized by the object editor by means of alternating images of the design on the screen which gives a real idea of motion. A well-founded decision can be made whether the conceptual model has to be changed, rejected, or can be accepted. The method of analysis used gives a good start for a static and dynamic analysis.
ISBN: 1-55589-568-9 Pages: 18

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