GEAR TECHNOLOGY

JANUARY/FEBRUARY 1999

The Journal of Gear Manufacturing

GEAR SOFTWARE

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- SOLID MODELING AND GEAR DESIGN
- SOFTWARE BITS—NEW PRODUCTS

GRINDING

- POWER HONING— THE BEST OF BOTH WORLDS?
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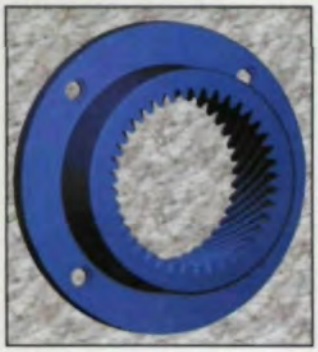

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The Journal of Gear Manufacturing

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1999 *and* Counting

Have you ever watched the odometer on your car as you approach 100,000 miles? Something about human nature compels us to watch the odometer roll over. It may be just a fascination with numbers: Seeing all those nines line up is rare, and we don't want to miss it. But it may also have to do with the feeling of being on the verge of something that won't come again.

When I look at the new year's calendar, I get the same feeling. We're looking at 1999 with a lot of anticipation. Much is happening in the world, in our industry, and right here at *Gear Technology*. We have exciting plans for 1999, and we've made changes you should know about.

We've added a new technical editor, Dan Thurman, to our panel of experts. Thurman joins Robert Errichello, Don McVittie and Robert E. Smith, whose articles, suggestions and other contributions have been invaluable over the years. Thurman comes to us with 35 years of practical experience in gear design and manufacturing from his career at Caterpillar, Inc., where he was responsible for gear and spline standards development, design and manufacturing specifications and the development of gear design and analysis programs. Thurman served on several AGMA and ISO technical committees, and he was chairman of the SAE/ANSI involute spline committee and the AGMA epicyclic gearing committee. He's a past member of the AGMA board of directors, the AGMA Foundation board of directors and the AGMA Technical Division executive committee. We're confident that his extensive gear knowledge and his enthusiasm and eagerness to serve the industry will be of great benefit to you, our readers.

We're always looking for ways to better serve our readership. We have a lot of topics to cover, and with only six issues per year, we often can't get to everything. With that in mind, we've added a new column, "Revolutions," to the magazine. We realize that the gear industry isn't all formulas and tables. We've created this column to give you a selection of lighter, easy to read feature-type articles on the people and technologies of the gear industry. It will appear toward the front of the magazine, and it will give us a chance to bring you many of the topics we can't cover in as much depth with full feature or technical articles.

We chose the name "Revolutions" both because we'll be covering breakthrough ideas or approaches and because the word expresses the continual, the mundane, the passage of time. So we'll be bringing you both the extraordinary and the everyday—but always the interesting.

"Revolutions" won't be stealing space in the magazine from our other editorial features. We'll continue bringing you the top-notch technical articles that have become the staple of *Gear Technology* for nearly 15 years. If anything, we're committed to increasing our editorial content. Over the past several years, this magazine has grown, with the help of our advertisers, from a 48-page publication to one that normally runs anywhere from 56 to 80 pages. As long as you continue to let those advertisers know that you value this magazine and the information we provide, this trend should continue.

We're also committed to finding new and better ways to present the information you need. One of the areas with the most possibilities is on the Internet. For example, you can read about the next generation of gear machines and cutting tools in the magazine. But imagine being able to see the chips flying and the cutting fluid spraying, all without having to leave your desk. The reality of these experiences is much closer than you think.

In fact, *Gear Technology* is committed to being a pioneer in these areas. In conjunction with our upcoming 1999 "Show Central" version of AGMA's Gear Expo, we're already working with some of our key advertisers to explore new and exciting ways to use this technology.

If any of you have any ideas that will help us serve you better, we'd like to hear about them. Drop us an email at *people@geartechnology.com* or call (847) 437-6604.

We've a lot in store for you this year. We hope that you share our anticipation. So happy new year, gear industry, and don't blink, because you might miss something that won't happen again.

Michael Goldstein

Sincerely, Michael Goldstein, Publisher & Editor-in-Chief

Welcome to* Revolutions*, the column that brings you the latest, most up-to-date and easy-to-read information about the people and technology of the gear industry.* Revolutions *welcomes your submissions. Please send them to* Gear Technology, *P.O. Box 1426, Elk Grove Village, IL 60009, fax (847) 437-6618 or e-mail* people@geartechnology.com. *If you'd like more information about any of the articles that appear, please circle the appropriate number on the Reader Service Card.

RIT Names Kate Gleason College of Engineering

Rochester Institute of Technology has announced the naming of its engineering school after Kate Gleason, one of the gear industry's pioneering ladies. The daughter of Gleason Corp. founder William Gleason, Kate Gleason went to work for her father at age 11. By 25, she was secretary-treasurer and chief salesperson for the company. She was America's first female engineering student and the first woman to be elected to membership in the American Society of Mechanical Engineers.

"Kate Gleason was a remarkable woman, and her story will be an inspiration to every student, male or female," says RIT president Albert Simone. "She is an example of the determination, hard work and creative spirit that RIT would like to instill in all of our students."

Kate Gleason, who died in 1933, was a lifelong supporter of RIT, and the naming of the school comes shortly after the Gleason Foundation presented $10 million to the college of engineering, bringing the total contributions to RIT by Gleason family members, the Gleason Foundation and Gleason Corp. to more than $25 million.

For more information about the life of Kate Gleason see "The First Lady of Gearing" in the September/October 1997 issue of *Gear Technology*.

Circle 250

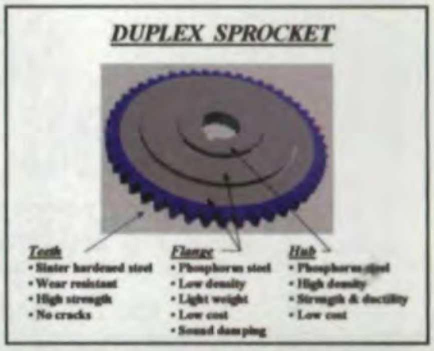
Duplex Sprocket Technology

The 'Duplex' process being developed by Zenith Sintered Products enables the manufacture of sprockets or gears that have reduced weight and rotational inertia, increased sound damping properties and reduced overall costs.

The process uses different materials for the teeth and core, sintering them together into a single component. The teeth require high hardness and strength to transmit torque and resist wear, while the inner core can use a lower-cost, lower duty material. The two materials are simultaneously charged into the tool set and properly distributed to their respective regions.

Zenith has used this patent pending process to produce an engine sprocket with increased tooth strength, compared with conventional parts, and a core that takes advantage of the sound damping properties of low density powder metal materials.

Circle 251



The Duplex process uses different materials for teeth and core.

Above: Kate Gleason

Left: Fun Fest celebrating the opening of the Kate Gleason College of Engineering

Integrated Surface Finish Software

M&M Precision Systems has introduced a multi-sensor technology to its 3500 series metrology system. The new system gives gear manufacturers a tool that can be used for a wide range of external spur and helical gears.

Using a skidded stylus sensor along with an automatic rotating probe, the system automatically scans tooth surfaces along the lead and profile path on both flanks and analyzes the surface finish parameters according to ANSI/ASME B46.1.

The sensor and application software are integrated into the M&M system. The software for surface finish analysis runs in the Windows environment.

Circle 252

Integrated surface finish software from M&M Precision Systems.

Computing Stresses in Spur Gears

DANST-PC is a computer program for the parametric analysis of the statics and dynamics of spur gear systems. It can be used to predict static transmission error, dynamic load and tooth bending stress as they are influenced by operating speed, torque, stiffness, damping, inertia and tooth profile. DANST-PC performs geometric modeling and dynamic analysis for low- or high-contact ratio spur gears with ratios ranging from one to three.

DANST-PC is based on a four-degree-of-freedom, lumped-mass model of a gear transmission. The model includes driving and driven gears, connecting shafts, motor and load. The equations of motion were derived from basic gear geometry and elementary vibration principles.

DANST-PC is available from COSMIC, NASA's Software Technology Transfer Center, on a 3.5" diskette. Log on to *www.cosmic.uga.edu* for more information.

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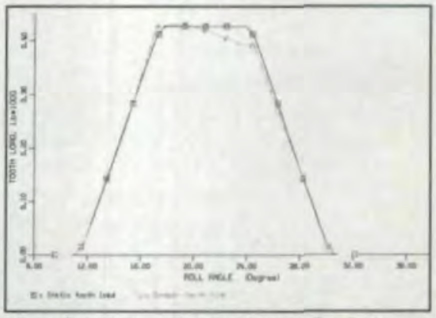

Plot of static and dynamic tooth loads generated by DANST data files.

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An Experimental Study on the Effect of Power Honing on Gear Surface Topography

N. Amini, H. Westberg, F. Klocke and T. Kollner

Introduction

Gear noise associated with tooth surface topography is a fundamental problem in many applications. Operations such as shaving, gear grinding and gear honing are usually used to finish the gear surface. Often, gears have to be treated by a combination of these operations, e.g. grinding and honing. This is because gear honing operations do not remove enough stock although they do create a surface lay favorable for quiet operation. See Fig. 1 for typical honing process characteristics. Gear grinding processes, on the other hand, do remove stock efficiently but create a noisy surface lay.

A combination of several complementary operations is expensive, often involving heavy instruments, maintenance, operation costs and longer lead times in gearbox fabrication. Power honing is one way to reduce gear manufacturing costs by reducing the number of process sequences.

According to Amini et al. (Ref. 1), gear surface topography can be characterized, due to the noise, by three parameters that describe the profile undulation. Undulation occurs on gear surfaces irrespective of the gear finishing process used, the differences appearing in amplitude, wavelength and the direction of the undulation. According to Amini and Rosen (Ref. 2), these three parameters significantly affect the noise characteristics. Moreover, they are directly correlated to the noise level, noise perception in the human ear and vibratory performance of the entire system in which the gear works.

Gear grinding operations (Fig. 2) create the worst conditions for these parameters. They produce undulations with the highest amplitude level, the longest wavelength and direction almost perpendicular to the path of contact. Conventional gear honing operations are used today to reduce the undulation amplitude and to create a new, more favorable direction of undulation (for more extensive discussion see Ref. 1).

A few companies have recently introduced new honing machines on to the market. Most published papers on the technology of gear honing or shave grinding describe both the principle of such a process (Ref. 3) as well as the surface topography obtained. However, they do not discuss the surface topography in detail in terms of surface undulation parameters. The interesting question arises: What are the characteristics of this operation with respect to noise-related surface parameters?

The objective of this article is to evaluate gears manufactured using this kind of operation, particularly power honing, in terms of the three parameters mentioned. To do that, a set of gears with different operational conditions were produced in the Laboratory for Machine Tools and Production Engineering (WZL) of Aachen University of Technology (RWTH), Germany. These gears were then evaluated in the laboratory of Chalmers Surface Geometry Group (CSGG), Sweden. The surface evaluation was carried out using three-dimensional (3D) devices and 3D surface topography analysis.

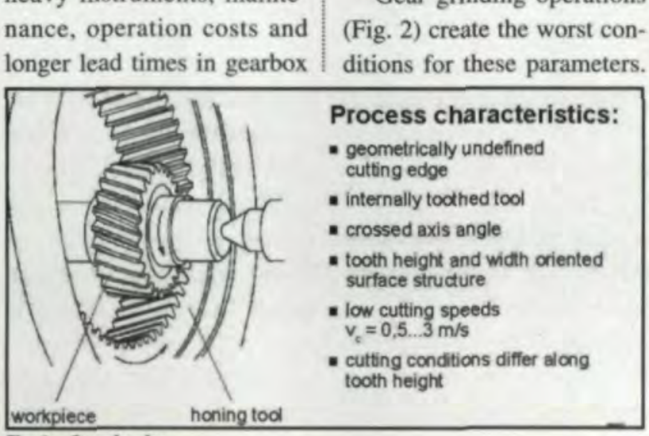

Fig. 1—Gear honing.

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F. Klocke & T. Kollner

are researchers at the Gear Research Group of the Laboratory for Machine Tools and Production Engineering (WZL) at the Aachen University of Technology (RWTH) in Aachen, Germany.

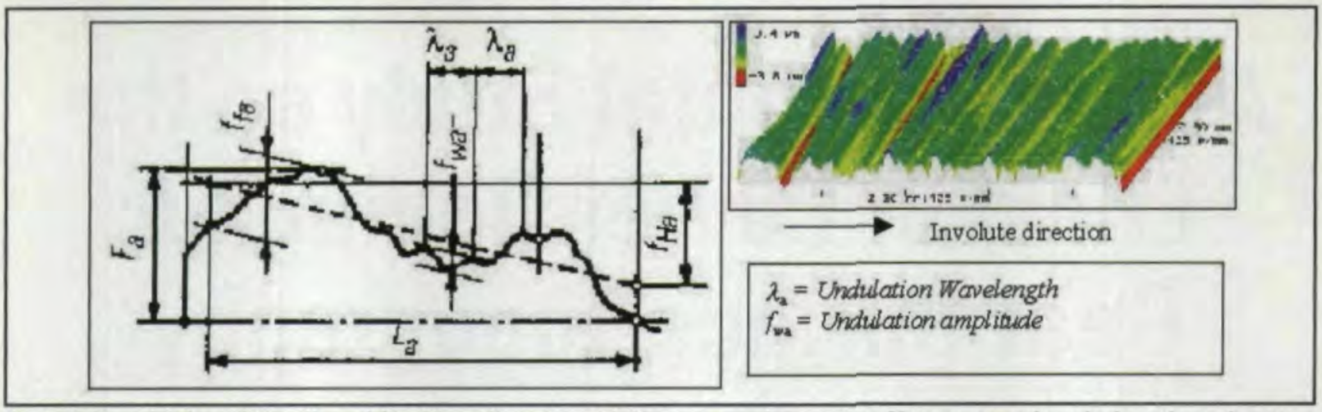


Fig. 2—Profile undulation definition. Upper right subfigure illustrates undulations on a ground gear surface. Measurement performed using stylus equipment.

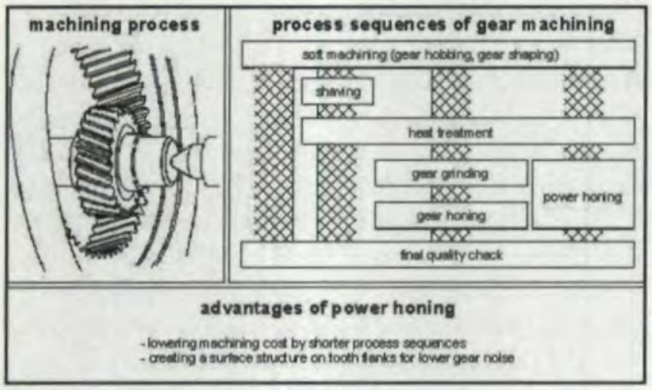
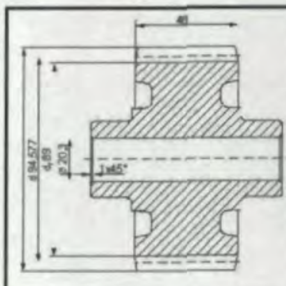


Fig. 3—Process sequences of gear machining.



number of teeth:	z_2=41
normal module:	m_n=2,2 mm
normal pressure angle:	α_n=17,5°
helix angle:	β_2=17,5°
flank direction:	right
base circle diameter:	d_b=89,798 mm
usable root diameter:	d_{Nf}=92,021 mm
addendum modification coefficient:	x_2=0,44826
face width:	b_2=48 mm
span measurement of 6 teeth:	W_6=37,79 - 37,74 mm
stock allowance:	Δs=70 μm/flank
material:	17CrNiMo6
surface hardness:	61 ± 1 HRC
case hardening depth:	Eht_{550} = 0,9 mm

Fig. 4—Workpiece.

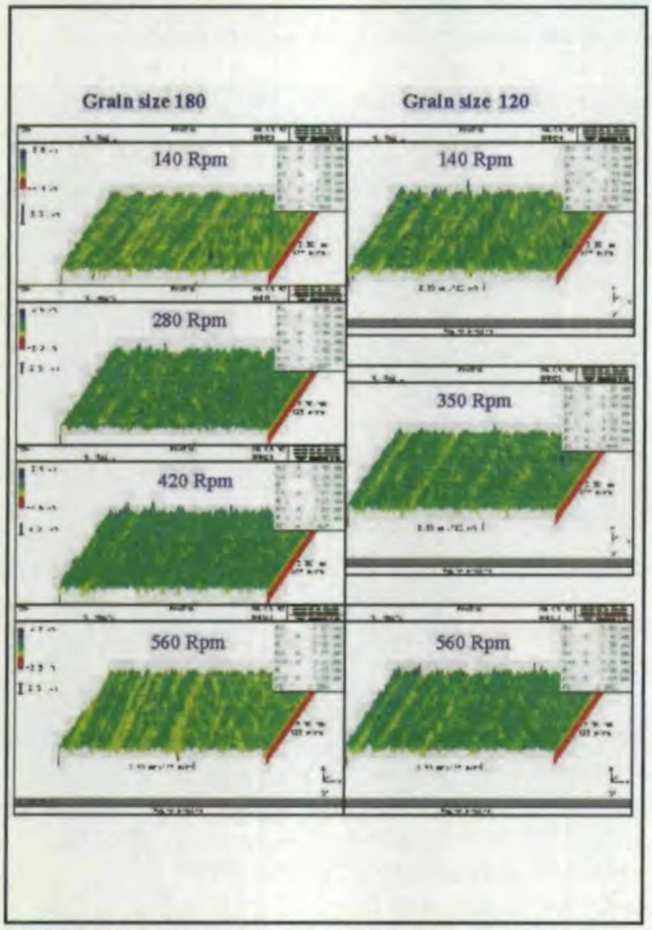


Fig. 5—Surfaces measured by stylus technique, sampling length 8 μm. Subfigures to the left were produced by a grain size of 180, while those to the right were produced with 120 grains. Different subfigures are the result of different tool speeds.

Gear Honing

Principles. Gear honing is a manufacturing process that uses geometrically undefined cutting edges for hard finishing gears. The tool forms an axis intersection angle with the workpiece axis. The resulting grinding motion, running at a cutting speed in the 0.5 to 3 m/s range, has an axial component in the tooth trace direction and a tangential component in the profile direction. This produces a tip-root-oriented surface structure that has improved noise qualities. This is in contrast to the gear grinding method that only produces machining marks in the tooth trace direction.

Because of minute periodic ripples in the tooth contact direction, ground gears tend to produce intensive narrow band upper harmonics in the tooth contact frequency. The machining marks run square with the generating motion, and this is seen today as a problem because it can lead to dynamic vibration and whistling noises (Refs. 14, 15). Because of this problem, gear honing is frequently employed subsequent to gear grinding to achieve a surface structure that produces less noise (Refs. 5, 6, 9, 13).

The kinematics of gear honing are similar to those of shaving (Refs. 5–7). Both methods use gear wheel shaped tools and are crossed helical gears with shallow axis intersection angles. They are also both based on rotation-symmetric workpiece and tool part-bodies that are spatially cross meshed. This leads to a relative sliding movement in tooth depth and face width directions, which results in machining marks that are typical for this machining method and run in the tooth depth direction. The work wheel flanks can be generated with both line and point contact (Ref. 14). In spite of these similarities, a normal

shaving tool cannot be used for machining hardened tooth flanks because of its geometrically defined cutting edges. All cutting edges would have to penetrate the hardened workpiece elasto-plastically along the line of contact, resulting in very high contact pressures. For this reason, tools with geometrically undefined cutting edges must be used for gear honing in order to reduce the surface contact between the tool and the workpiece flank, thus also reducing the contact pressure (Refs. 5–7).

Generally, the grid materials used for tooth flank grinding can also be used for honing tools. Conventional internally toothed honing stones are made up of grains of refined aluminum oxide which are synthetic resin bound. The contact pressure causes the grinding grains to penetrate into the workpiece and remove very fine particles from the tooth flanks. The conventional honing stone is dressed with a diamond dressing tool before machining the first workpiece and whenever it starts losing its original form after machining a specific number of gears (Refs. 8, 16).

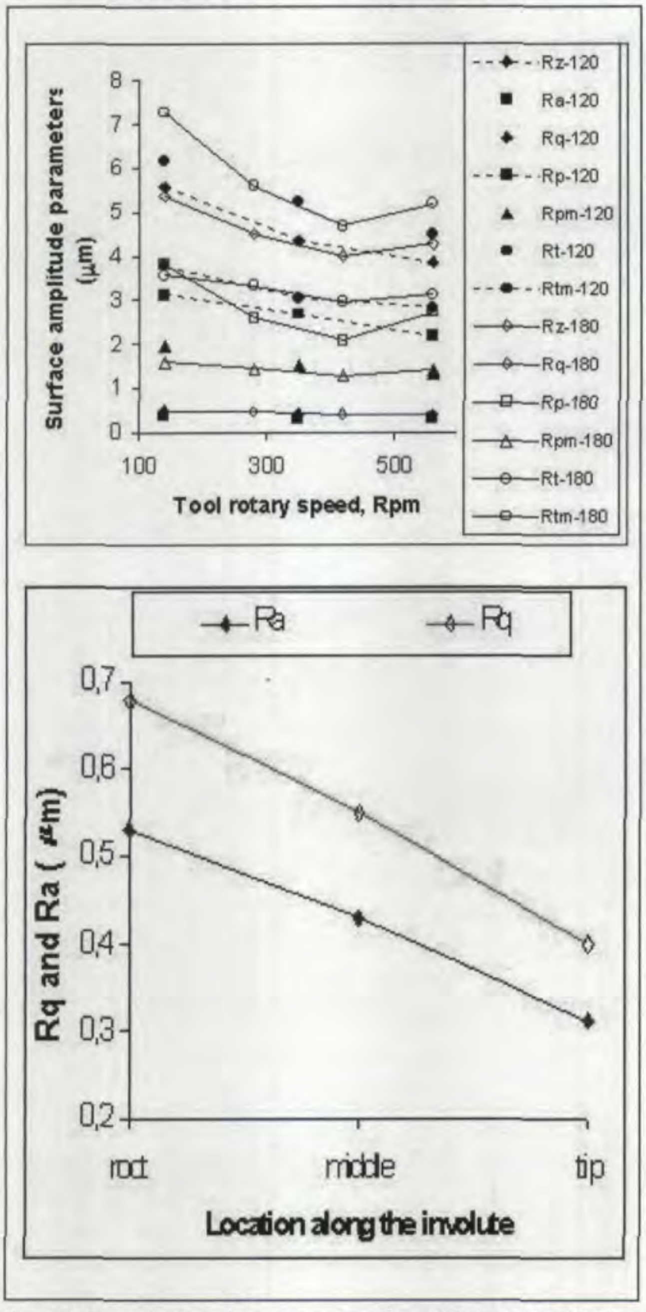


Figure 6: Conventional surface parameters. The subfigure to the left illustrates parameter variation as a function of tool speed. The subfigure on the right shows parameter variations along the involute.

The longitudinal table can be oscillated (longitudinal honing) to improve the regularity of the workpiece surface. The workpiece is driven parallel to its center of rotation, backwards and forwards, on the honing stone. The oscillation has a smoothing effect on the surface quality and results in less surface irregularities than plunge honing, a method that does not use oscillation.

Conventional Honing. The stock removal and machining quality of gear honing are dependent on preliminary quality, desired final quality, gear geometry and machining time. Comparative studies carried out within the framework of a research project (Ref. 12) using different hard finishing processes showed that gear honing possesses a high performance potential with respect to the quality achieved, influence on the workpiece surface zone, noise qualities and economic viability. It was also noted that this method was capable of generating a profile mismatch, in addition to improving the surface structure of the tooth flank. Owing to the above-described advantages, the importance of the process has increased, and it is currently used in various production chains with low stock removal of some 5-10 µm per tooth flank.

Power Honing. The pressure of international competition forces industrial users to reduce their number of manufacturing programs. The latest efforts aim at employing gear honing directly after case hardening with increased stock removal as a substitute for gear grinding and/or shaving, dependent on the prior manufacturing programs, in order to lower manufacturing costs (Fig. 3). This method is called "power honing" to distinguish it from conventional gear honing because stock removal rates of 20 to 40 µm are aimed at (Ref. 10). With power honing, it is possible to minimize the existing process chains and reduce production costs while producing high-quality, low-noise gear systems. The success of power honing depends both on appropriate process control for gear cutting with the gear hobbing process and on suitable gear honing machines with optimized technology.

Experiments—Test Setup and Manufacturing

Workpieces. The parts used for the surface topography tests were machined on a Fässler K-400 gear honing machine. This unit has five numerically-controlled axes of motion—two linear axes and three axes of rotation. The specimen workpieces were case-hardened industrial gears prepared by hobbing, the kind used as intermediate gears in highly-stressed utility vehicle gear systems. As will be apparent from Fig. 4, they were helical gears with z_2=41 teeth, normal module m_n=2.2 mm and a normal pressure angle α_n=17.5°. The helix angle is

β_2=17.5°. The specimen workpieces had a face width of b_2=48 mm and the flanks were modified with a tip relief of 9 µm and a crowning 7 µm.

The specimen workpieces were machined from 17CrNiMo6, a common material for highly-stressed large module gears. The surface hardness of the gears was approximately 61 HRC with a case hardening depth of Eht_{550}=0.9 mm. The hardness of the substrate was only about 39 HRC.

Internally toothed honing stone. An internally toothed honing stone with number of teeth z_0=145 was used to machine the specimen gears. As with the gears, the honing stone had a normal module of m_n=2.2 mm and a normal pressure angle of α_n=17.5°. The helix angle of the honing stone was, however, β_0=27.5°, resulting in an axis intersection angle of η=10° for the gear honing process. The honing stone is 12 mm wider than the workpiece, ensuring constant contact between the tool and the workpiece flanks in spite of the axial pendulum motion of the honing stone that typifies longitudinal honing.

The grit material was a mixture of refined aluminum oxide (70%) and Sol-Gel-Corundum (30%) with a grain size of 180. A mix with a grain size of 120 was used for comparison in order to determine the extent to which the surface roughness of the machined tooth flanks is influenced by the grain size. The grains in both mixtures were bonded in a synthetic resin.

Manufacturing. The gears were machined by longitudinal continuous-infeed honing with a honing time of 170 seconds. The honing stone was dressed after each test in order to ensure uniform constraints. The gears were machined with an axis intersection angle η=10°, a pendulum distance of ±2 mm, an oscillation speed of 72 mm/min and an infeed rate of 90 µm/min. The number of rotations of the honing stone was varied at values of n_0=140 (cutting speed vc=1 m/s), 280, 420 and 560 min^{-1} in order to establish influence on the surface structure.

Surface Topography Measurements

The Testing Machines. Two 3D measuring machines were utilized during the study, one stylus machine and one white-light interferometric measurement machine. The stylus machine was used to evaluate surface roughness parameters. It utilized a stylus with 2 µm tip radius set at a 90° con-angle. The sampling length in these measurements was 8 µm in both directions. The optical machine was used to investigate parameter variations on different parts of the surface and investigate the surface itself with a finer resolution than the stylus can provide. The sampling length in these measurements was 3.20 µm.

Surface amplitude parameters are shown on the upper right side of every subfigure in Figure 5. The expression for one, namely the arithmetic mean deviation R_a, is recalled here. Other parameter definitions can be found in the reference section.

Filters and Error Estimates. To remove the macrogeometry, a high-pass

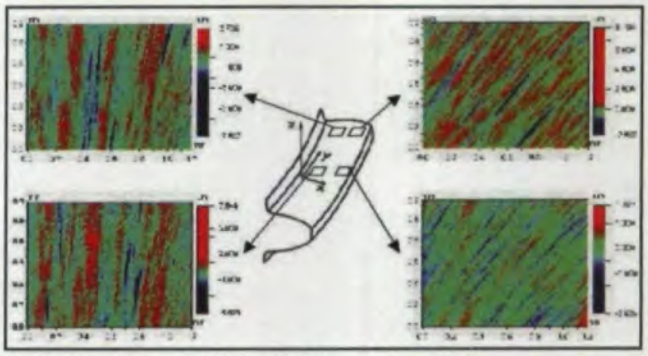


Fig. 7—Measurements performed by the optical machine.

gaussian filter with a cut-off length of 0.8 mm was used. Leveling (i.e. applying a least square plane removal of data) completed the filtering. The former was due to the removal of involute helix surface. The latter was due to the linear trend in the data. Trends originated from misalignment of the specimen during the measuring operation.

To estimate the profile undulation errors, spectral density analysis was used. The sampling strategy was optimized to increase the amount of information on the surface topography, focusing on the intrinsic information in the involute. The sampling length was shortened in the involute direction to 2 µm while the sampling length in the face width direction was increased to 100 µm. In "Optimization of Gear Tooth Surfaces" it was shown that the method, based on averaging 40 µm, is one of the most reliable ways of estimating profile undulations. It was also shown that parameters obtained by this kind of analysis are directly related to the surface amplitude parameters, i.e. the area under the spectral curve is linearly proportional to the surface Rq in square.

Results

Figure 5 shows measurements performed using the stylus technique. The surfaces are divided into two columns. The difference between the two columns is the grain size of the abrasive particles in the internally toothed honing stone. Each surface is the result of a different tool speed setting at the given grain size.

The overall view of the surfaces in Figure 5 indicates that they are dominated by undulations, especially in regions close to the root. This is typical behavior for a gear honing operation. It creates severe undulations close to the pitch line that diminish the further away they get. The pitch circle between the tool and the workpiece in this article was placed close to the root. The other important observation is that the pitch diameter is not located at the same place on these surfaces, although the tool's and the work's geometry had been the same. This is a consequence of the tool wear during its life cycle. As it redresses, the center distance between the work and the tool decreases; thus it changes the pitch between the two mating parts. Because of this, the conditions for making undulations on the surface change, altering the quality of the gear (see below).

Surface amplitude parameters versus the tool rotary speed, in Figure 6a, consistently decrease by increasing running speed. An alternation of running speed does not, however, change the surface parameters by more than 20% while the average error was estimated at 10% (parameter values were read from the subfigures in Figure 5). The grain size of the gear honing tool does not tend to affect these parameters significantly (changes in parameters were less than 10%). Therefore no figure is drawn for this reason.

Measurements performed by the optical measuring machine (Fig. 7, the subfigures) illustrate different parts of one tooth flank. In these figures the difference in the surface structure is highlighted. The surface lay (undulation direction) turns continuously from parallel to the face width at the root to almost perpendicular at the tip. Subfigures close to the root resemble ground surfaces, consisting of undulations only. Changes due to measuring locations in surface amplitude parameters, obtained from these measurements, are shown in Figure 6b. The Rq and the Ra value increased significantly by more than 40% from tip to root (x-direction) of the tooth, but these values did not indicate significant changes when they were compared to the face width direction (y-direction). The significance level for these parameters was estimated at 10%. The estimation was based on measurements on different teeth, but on the same location along the involute. Moreover, it was worth mentioning that all other surface amplitude parameters follow the trends of the surface Rq value (see also Figure 6b) and are therefore not considered in the diagram.

Fig. 8, using the spectral analysis, characterizes the profile undulation of the gears produced. The curves indicate an undulation wavelength (λa) in the range of 0.25 to 0.3 mm—these numbers refer to the location of the highest peak of the curves along the x-axis. The solid line represents the surface produced by grain size 180 at a running speed of 140 rpm. The dashed line analyzes the surface 120/560 (the lowest right one in Figure 5). A reduction of the undulation amplitude ($f$wa) and a shortening of wavelength (λa) was observed. The main reason for the reduction of ($f$wa) was the increasing tool speed. For the sake of clarity, only two curves are plotted. Spectral curves for the other surfaces are not included since their wavelength content and magnitude are within the two curves presented.

Discussions

The reason this article discusses the undulations is that they negatively influence the functional properties of the gear. The undulations increase the noise activity of the gear and influence the noise quality, the way the noise is perceived by the human ear. Harmonics of the mesh frequency increase significantly when undulations like those shown in Figure 2 were present on the surfaces (Ref. 2). The undulations on the surface shown in Figure 2 was two times higher and wider than those made by the power honing. It is known that the harmonics of a frequency influence the way it sounds. Therefore undulations are of great importance for the functional performance of the gear.

The results presented in this paper, surfaces obtained by power honing, are consistently in agreement with the results reported for other gear finishing operations, i.e. the results presented for spheric honing and threaded grinding operations (Ref. 1, 3). The three most important results are:

• That a rise in the tool speed reduces the amplitude parameters of the surface produced;

• That while tool grain size is of minor significance due to gear surface topography, it does have an indirect influence. The grain size can shorten the wavelength of the surface undulations and this, in turn, can offer a better condition for accomplishing lower amplitude levels. In other words, the problem is that in order to produce lower $f$wa, shorter λa are required:

• That undulations are unavoidable on gear surfaces and that they have different wavelengths and amplitudes for different operations.

Figure 7 bears strong evidence of the serious problems connected with evaluation of gear surface topography based only on a minor part of the surface. This is because gear surfaces are not uniform. For example, if the evaluation range of the flank were based on the area close to the root, the surface would be classed as a ground surface although it was honed. And, if the evaluation range were based on the near-tip area, the measurement would not show the existence of the undulations. In both cases a 40% error would occur. Furthermore, 2D measurements would also lead to a wrong assessment of the surfaces. None of the measurements would show the real surface features.

Conclusions

• The power honing process stands between conventional gear honing and threaded gear grinding operations. Since the wavelength and the amplitude level of the undulations on these surfaces is less than a half of that for undulations occurring in gear grinding operations, it is expected that this kind of surface reduces noise in the gearbox.

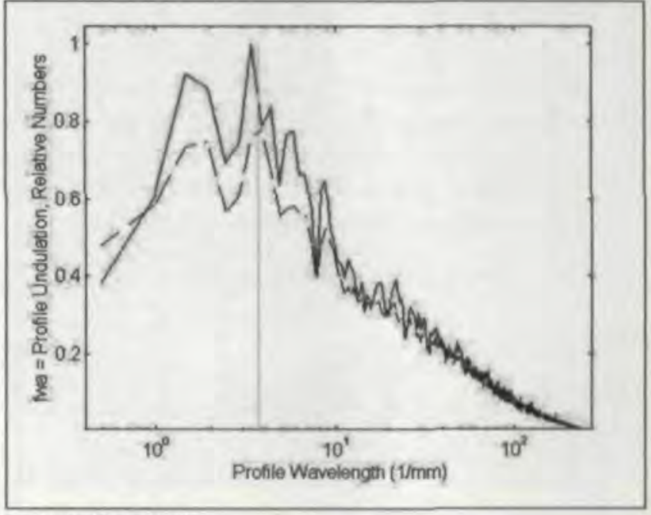


Fig. 8—Profile undulation.

• Increasing tool speed reduces the level of amplitude parameters on the surface.

• Grain size of the tool is of minor significance for the surface topography.

• Surfaces are not uniform from the root through the tip, and surface amplitude values may differ by as much as 40%. Evaluation of surfaces of this kind must be cautiously performed.

• Undulations with a wavelength of 0.3 mm occurred on surfaces, although it was expected that gear honing operations create a favorable surface lay with no grinding scratches on the surface. These parameters could not be significantly affected by running conditions; however they were slightly affected by the grain size of the tool.

• The surface lay was the same as that found in conventional gear honing processes. ○

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ISO 6336-5: Strength and Quality of Materials

Comparison of AGMA 2001 and ISO 6336 ratings for four gear sets.

Don McVittie

This is the fourth and final article in a series exploring the new ISO 6336 gear rating standard and its methods of calculation. The opinions expressed herein are those of the author as an individual. They do not represent the opinions of any organization of which he is a member.

Gear rating standards are intended to provide a reliable method of comparing gear set capacities, when the same standard is used to calculate each example. It should not surprise us that the same gear set has a different rated capacity when calculated by the ISO and AGMA standards. We should expect, however, that the ratio between ISO rated capacity and AGMA rated capacity be approximately the same for different gear sets. This article examines the calculated ratings of four gear sets and explores some possible causes for differences. Some differences are due to allowable material stress numbers and some are due to other influence factors. Tables provide specifics of the four gear sets and the influence factors according to each standard.

Classification of Materials

ISO 6336-5 contains data for a wide variety of cast and wrought ferrous gear materials with different heat treatment conditions. The material types are shown in Fig. 1, with the abbreviations assigned to each type.

St = Steel (σ_B < 800 N/mm^2)*
V = Through-hardening steel, through-hardened ($\sigma_B \geq$ 800 N/mm^2)*
GG = Grey cast iron
GGG (perl., bai., ferr.) = Nodular cast iron (perlitic, bainitic, ferritic structure)
GTS (perl.) = Black malleable cast iron (perlitic structure)
Eh = Case-hardening steel, case hardened
IF = Steel and GGG, flame or induction hardened
NT (nitr.) = Nitriding steel, nitrided
NV (nitr.) = Through-hardening and case-hardening steel, nitrided
NV (nitrocar.) = Through-hardening and case-hardening steel, nitrocarburized
*σ_B is ultimate tensile strength, approximately 3.4 • BHN, N/mm^2

Fig. 1 — Material Types in ISO 6336-5.

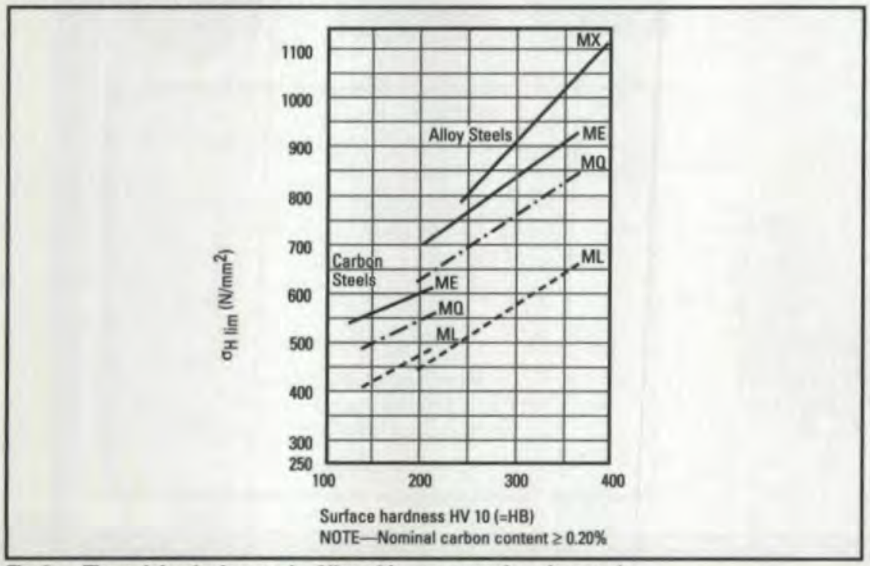

Fig. 2 — Through hardening steels: Allowable stress numbers (contact).

Note that through-hardening steels softer than approximately 235 BHN are classified as carbon steels (St) rather than as through-hardened alloy steels (V) with a reduction in allowable stress numbers. Carburizing steels are subdivided into three subclasses, depending on hardenability and minimum core hardness. Nitriding steels are also subdivided into several subclasses, depending on alloy content.

Each material type is subdivided into quality grades according to the cleanliness and processing criteria established in section 6 of the standard.

• Grade ML stands for the minimum requirement, similar to AGMA grade 1.

• Grade MQ represents requirements which can be met by experienced manufacturers at moderate cost, similar to AGMA grade 2. MQ is also the default material grade for industrial gears.

• Grade ME represents requirements which must be realized when higher allowable stresses are desirable, similar to AGMA grade 3.

• Grade MX is a special grade of through-hardened steel, with hardenability selected for the critical section size.

Although ML, MQ and ME requirements are listed for all material types, not all of these combinations are readily available in the market. An effort is being made to reduce the number of grades for the next edition of ISO 6336-5.

Allowable Stress Numbers

The ISO 6336-5 standard describes the methods used to derive allowable stress numbers from full scale gear tests (method A), reference test gears or test specimens. The stress numbers represent a survival rate of 99%, as in the AGMA standards. At present, ISO 6336 does not offer a specific way to calculate ratings for other survival rates.

Allowable stress numbers for recognized gear materials are presented in graphical form. Figures 2 and 3 are examples of those graphs.

The allowable stress numbers for pitting and bending are plotted against surface hardness, which is expressed in either Brinell or Vickers units. HB is used for softer materials, HV 10 (10 kg load) is used for most through-hardened materials and HV 1 (1 kg load) is used where appropriate for surface hardened materials. The allowable stress numbers for grade MQ are comparable to those for AGMA grade 2, except for the pitting strength of through-hardened alloy steels. Many experienced manufacturers of through-hardened gears will find that their products can meet the requirements of grade MX, which has allowable contact stress numbers comparable to AGMA grade 2. Figure 2 shows the higher allowable contact stress numbers permitted for the MX grade of through-hardened alloy steels, compared to ML, MQ and ME.

Requirements for Material Quality and Heat Treatment

A series of tables defines the metallurgical requirements for each grade of each material class. There is good general agreement between the ISO and AGMA requirements for similar materials and allowable stress numbers, but ISO metallurgical quality standards rather than ASTM are the reference documents for ISO standards. Your steel supplier and heat treaters will need to know the ISO standards to be sure that their work complies with the detailed requirements.

There are a few places where the details of the measurement methods and specifications differ. For example, the specified point to measure core hardness in a finished tooth per ISO 6336 is one module below the surface on a line perpendicular to the 30° tangent to the root fillet, rather than on the center of the tooth on the root diameter as in AGMA (Fig. 4). These differences don't affect the engineer making rating calculations, but they could be of concern in heat treatment control and certification.

The ISO standard recognizes *process control test bars*, which may be any size, to monitor the consistency of the heat treatment process and *representative test bars*, which are large enough to represent the quench rate of the finished part. The microstructure of the *representative test bars* may be considered equivalent to that of the finished part for quality assurance. Several informative annexes are provided, including a conversion table between ultimate tensile strength, Vickers, Brinell and Rockwell hardness values.

The following calculated examples represent actual gear sets for which performance is known from either back-to-back testing or field experience. In each case, a few geometrical values have been changed to make the example generic.

ISO does not directly calculate an allowable power for a gear set, nor does AGMA calculate a safety factor. In order to make the comparison tables, the "ISO allowable power" was calculated from the safety factor. The calculation was made with the values of $K_{H\beta}$ and K_v obtained at nominal load, disregarding the change in those factors due to load dependence. The "AGMA safety factors" were calculated by comparing allowable stress numbers to calculated stress numbers, as in ISO.

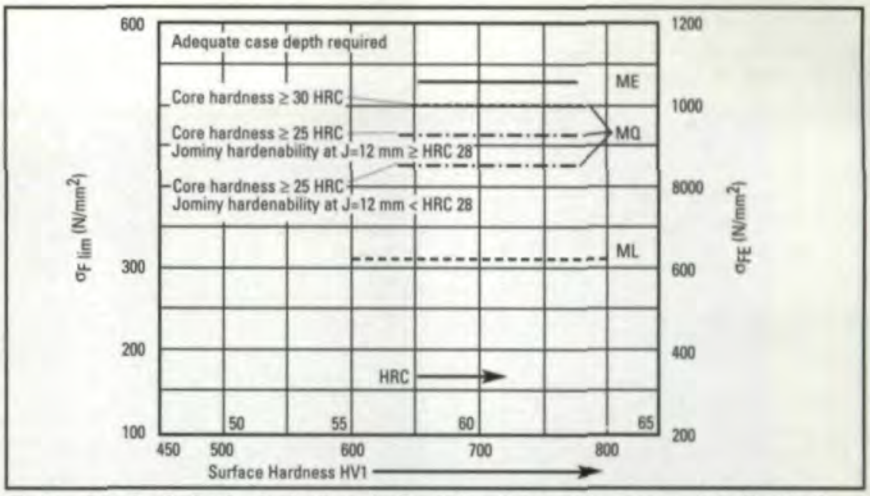

Fig. 3 — Case hardening (carburized) steels: Nominal and allowable stress numbers (bending).

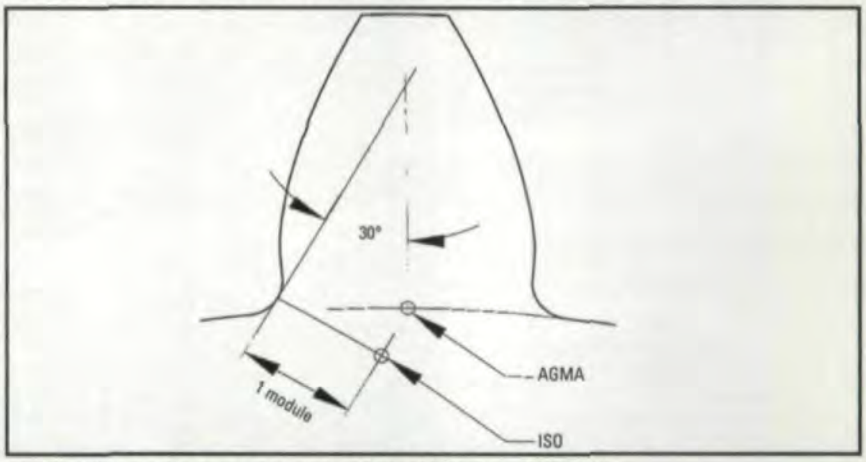

Fig. 4 — Core hardness measurement point in ISO 6336 vs. AGMA 2001.

Comparison ISO v. AGMA ratings for four example gear sets:

Example Number	1	2	3	4
Application	Gear Motor, HS	Catalog reducer, LS	Wind turbine, LS	Rolling mill final red.
Center Distance, mm (in)	39.32 (1.548)	266.7 (10.500)	630 (24.803)	2378.03 (93.623)
Pinion speed, rpm	1750	340	180	175
Input power, KW (HP)	0.373 (0.50)	224 (300)	300 (402)	1475 (1975)
Application factor	1.00	1.00	1.75	2.50
ISO Rated Power, KW	0.31	256	421	1538
AGMA Rated Power, KW	0.78	260	305	1680
ISO pitting safety factor	0.91	1.07	1.23	1.02
AGMA pitting safety factor	1.97	1.08	1.09	1.07
ISO bending safety factor	2.41	1.71	1.40	2.01
AGMA bending safety factor	2.09	1.25	1.02	1.23
Pinion material	Induct. hard.	Carburized	Carburized	
Through hardened				
Gear Material	Induct. hard.	Carburized	Carburized	Through hardened
Tooth form	28 DP helical	6 Mod. helical	7 Mod. helical	1.5 DP Herringbone
Notes	Catalog rating >10000 units in field	Catalog rating Lab test confirmed	Miner's rule equivalent application factor	25 year service life

Example 1: Small gear motor speed reducer. Thousands of these induction hardened gear sets are in service, driven by 1/2 horsepower (0.373 KW) 1750 rpm AC induction motors. Since this is a catalog rating, the application factor is set to 1.0. The ISO 6336 pitting safety factor is less than 1.0, indicating a high risk of pitting failure at this power. The AGMA pitting safety factor is almost 2. The principal difference is in the face load distribution factor $K_{H\beta}$, which is 2.083 according to ISO method C and 1.16 according to AGMA 2001. This is probably a good place to use method A (full scale, full load testing) or method B (measurement of misalignment under load) to determine the appropriate value. There is a significant difference between the ISO and AGMA allowable stress numbers for spin induction

Don McVittie

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GEAR ENGINEERS, INC.
Comparison ISO v. AGMA ratings for four example gear sets: 14–Oct–1998

Example Number	1 Gear Motor		2 Catalog reducer		3 Wind Turbine		4 Rolling Mill	
Standard	ISO	AGMA	ISO	AGMA	ISO	AGMA	ISO	AGMA
INPUT DATA:								
Center distance	39.324	1.5482	266.7	10.5	630.001	24.8032	2378.03	93.6232
Pinion No. Teeth	13	13	17	17	25	25	24	24
Gear No. Teeth	68	68	69	69	151	151	210	210
Module/Dia. Pitch	*0.9071*	*28.00*	*6*	*4.23*	*7*	*3.63*	*17.602*	*1.44*
Pinion face width	16.00	0.6299	120.65	4.75	204.00	8.0315	914.40	36
Gear face width	12.70	0.5	120.65	4.75	204.00	8.0315	914.40	36
Double helical	No	No	No	No	No	No	Yes	Yes
Gap between helices	0	0	0	0	0	0	15.875	0.63
X pinion	0.4697	0.4697	0.5187	0.5187	0.25	0.25	0.462	0.462
X gear	0.5987	0.5987	0.4614	0.4614	-0.2159	-0.2159	-0.462	-0.462
Normal Ref. pressure angle	20	20	20	20	25	25	17.495	17.495
Ref. helix angle	17	17	9	9	12	12	30	30
Pinion tip dia	14.94	0.588	121.03	4.765	196.41	7.7327	536.44	21.1197
Gear tip dia.	67.34	2.651	436.35	17.179	1091.59	42.976	4283.46	168.64
Pinion constr: Solid (1), Rim (2)	1		1		1		1	
Pinion web thickness			0			0	0	0
Pinion rim ID	0	0		0		0		
Pinion no. of webs	0		0		0	0		
Gear constr: Solid (1), Rim (2)	1		1		2		2	
Gear web thickness					65		50	
Gear rim ID					1011.6		4064	
Gear no. of webs	0		0		1		2	
Accuracy grade, pinion	6	11	6	11	6	11	8	9
Accuracy grade, gear	7	10	6	11	7	10	8	9
Flank roughness, pinion, mu-m	1.6		*0.406*		*0.4*		3.175	
Flank roughness, gear, mu-m	1.6		0.406		0.4		3.175	
Root fillet roughness, pinion, mu-m	2.28		3		2		6.2	
Root fillet roughness, gear, mu-m	2.28		3		2		6.175	
Crowning configuration	2		2		2		0	
Bearing arrangement	3		5		3		1	
Location of contact	7		7		7		7	
Initial misalignment	0		0		0		0	
Input face load distr. factor	0		0		0		0	
Finish stock allow. pinion	0	0	0.178	0.0297	0.224	0.032	0	0
Finish stock allow. gear	0	0	0.178	0.0297	0.224	0.032	0	0
Design tip relief	0		0		0.035		0	
Pinion tool addendum factor	1.25	1.25	1.40	1.40	1.30	1.30	1.15	1.15
Gear tool addendum factor	1.25	1.25	1.40	1.40	1.30	1.30	1.15	1.15
Pinion tool protuberance	0	0	0.2977	0.0496	0.294	0.042	0	0
Gear tool protuberance	0	0	0.2977	0.0496	0.294	0.042	0	0
Pinion tool tip radius	0.30	0.30	0.40	0.40	0.25	0.25	0.20	0.20
Gear tool tip radius	0.30	0.30	0.40	0.40	0.25	0.25	0.20	0.20
Pinion material yield strength							690	
Gear material yield strength							690	
Hardness scale, pinion	HRC	HB	HRC	HRC	HRC	HRC	HB	HB
Hardness scale, gear	*HRC*	*HB*	*HRC*	*HRC*	*HRC*	*HRC*	*HB*	*HB*
Pinion surface hardness	56	578	58	58	58	58	284	284
Gear surface hardness	54	548	58	58	58	58	266	266
Pinion material	IF	Ind (B)	Eh	Carb.	Eh	Carb.	V	TH
Pinion material subclass	1		2		1		1	
Gear material	IF	Ind (B)	Eh	Carb.	Eh	Carb.	V	TH
Gear material subclass	1		2		1		1	
Pinion material grade	MQ	2	MQ	2	MQ	2	MX	2
Gear materilal grade	MQ	2	MQ	2	MQ	2	MX	2
Bearing span	220.78	8.692	288.54	11.36	640.00	25.197	1317.60	51.874
Pinion offset	39.85	1.569	51.82	2.04	60.00	2.362	0.00	0
Pinion shaft outside diameter	20.64	0.8125	88.90	3.5	150.00	5.906	330.00	12.992
Pinion shaft inside diameter	0	0	0	0	0	0	0	0
Pinion idler?	No	No	No	No	No	No	No	No
Gear idler?	No	No	No	No	No	No	No	No
Application factor	1	1	1	1	1.75	1.75	2.5	2.5
Pinion Torque, Nm	2.0353		6274		15950		80493	
Pinion speed	1750	1750	340.48	340.48	180	180	175	175
Input power, KW	0.373	0.373	224	224	300.628	300.638	1475	1475
Minimum safety factor, durability	1		1		1		1	
Minimum safety factor, bending	1.50		1.00		1.20		1.20	
Pitting life required, hours	10000	10000	10000	10000	100000	100000	100000	100000
Bending life required, hours	10000	10000	10000	10000	100000	100000	100000	100000
Pitting permitted, pinion?	No		No		No		No	
Pitting permitted, gear?	No		No		No		No	
Input pitting life factor, pinion	0		0		0		0	
Input pitting life factor, gear	0		0		0		0	
Input bending life factor, pinion	0		0		0		0	
Input bending life factor, gear	0		0		0		0	
Input pitting life factor for 10^10, pinion	1.00		1.00		0.85		0.85	
Input pitting life factor for 10^10, gear	1.00		1.00		0.85		0.85	
Input bendng life factor for 10^10, pinion	*1.00*		*1.00*		*0.85*		*0.85*	
Input bendng life factor for 10^10, gear	1.00		1.00		0.85		0.85	
Kinematic oil viscosity at 40 C	320		220		320		560	
CALCULATED RESULTS, SI UNITS:								
Pitting safety factor, pinion	0.92	1.97	1.07	1.08	1.23	1.09	1.02	1.07
Pitting safety factor, gear	0.91	2.04	1.07	1.11	1.30	1.14	1.04	1.07
Bending safety factor, pinion	2.97	2.09	1.71	1.25	1.40	1.02	2.15	1.32
Bending safety factor, gear	2.41	2.20	1.75	1.27	1.42	1.07	2.01	1.23
Allowable power, KW	0.31	0.78	256.11	259.83	421.48	305.44	1538	1680
Pinion allowable power, pitting	0.32	1.45	256.11	259.83	456.30	359.11	1538	1686
Gear allowable power, pitting	0.31	1.56	256.11	277.12	509.63	390.08	1605	1680
Pinion allowable power, bending	1.11	0.78	383.19	279.13	421.48	305.44	3176	1944
Gear allowable power, bending	0.90	0.82	391.24	284.12	425.69	321.80	2968	1810
Face load distribution factor	2.083	1.16	1.266	1.2209	1.084	1.273	1.684	1.84
Dynamic factor	1.036	1.068	1.005	1.049	1.005	1.081	1.025	1.185
Pitting stress at input power	1149	614	1419	1344	1173	1275	738	756
Allowable pitting stress, pinion	1062	1209	1518	1448	1445	1393	753	808
Allowable pitting stress, gear	1043	1255	1518	1496	1527	1452	769	806
Pinion bending stress at input power	244	68	512	374	618	445	243	223
Allowable bending stress, pinion	482	142	877	*465*	722	452	436	294
Gear bending stress at input power	302	67	503	376	636	436	264	239
Allowable bending stress, gear	485	146	877	477	751	467	443	293
Life factor, pinion pitting	1	0.899	1	0.933	0.91	0.898	0.911	0.899
Life factor, gear pitting	1	0.933	1	0.964	0.962	0.936	0.974	0.944
Life factor, pinion bending	1	0.937	1	0.964	0.889	0.936	0.889	0.937
Life factor, gear bending	1	0.965	1	0.989	0.921	0.967	0.929	0.974

hardened materials, which also affects the rated capacity of this gear set.

Example 2: Standard catalog speed reducer. This is the low speed mesh of a carburized and ground double reduction catalog reducer similar to that manufactured by several large companies in the international market. Gears of this type rate almost identically under AGMA and ISO standards. Many full scale laboratory tests have confirmed these ratings. Since this is a catalog rating, the application factor is set to 1.0.

Example 3: Wind turbine speed increaser. The wind turbine example is a carburized and ground speed increasing drive subject to extremely variable loading with high overloads from wind gusts and the nature of the driven generator. An application factor was chosen for this drive based on a Miner's rule analysis of the effects of the load spectrum and applied to compare the ISO and AGMA ratings of this gear mesh. The ISO method calculates about a 14% higher pitting stress safety factor (30% higher power rating) than AGMA, primarily due to the difference in $K_{H\beta}$. The AGMA rated capacity of this drive has been confirmed by testing and field experience. It should be noted that the calculation of capacity by Miner's rule is more complicated under the ISO standard, since the values of load distribution and dynamic factors are load dependent, requiring a recalculation of all factors for each step of the load spectrum.

Example 4: Large through hardened rolling mill drive. The mill drive example is from a double helical (herringbone) rolling mill stand which survived 15 years at 85% of the rated power, followed by ten years at full rated power. It was replaced due to wear and pitting of the tooth profiles. The ISO pitting safety factor is slightly lower than the AGMA value due to differences in the allowable stress number. In this example the ISO load distribution factor is lower than AGMA, which partially offsets the difference in allowable stress numbers.

Figure 5 compares the minimum calculated pitting and bending stress safety factors for the four examples. The examples are characterized by center distance in the figure, but it should not be implied that center distance alone explains the differences between the ISO and AGMA safety factors for these four very different gear sets.

What Causes the Differences in Calculated Capacity in These Examples?

The tabulated results show that the calculated pitting capacities are very similar, with differences being mostly dependent on the evaluation of $K_{H\beta}$, the face load distribution factor. The difference in the dynamic factor also has an effect, particularly in very large gears.

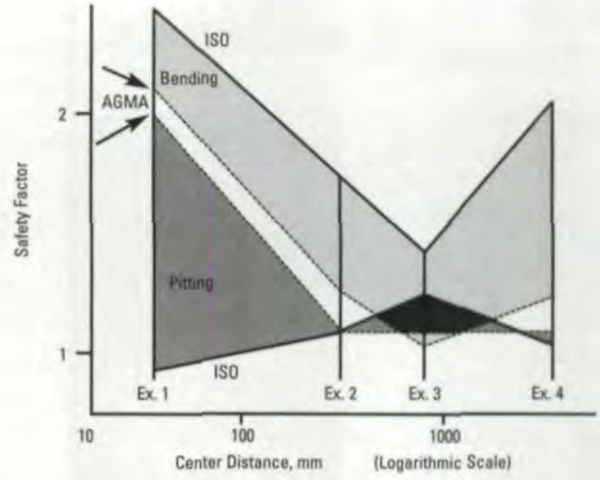

Fig. 5 — Pitting and bending stress safety factors for four examples.

In comparing ISO to AGMA, remember that the calculated ISO bending stress numbers include a stress concentration factor Y_S, which ranges from approximately 1.4 to 2.2 depending on tooth form and fillet roughness. It has a value of $Y_{ST} = 2.0$ for the test gears used to develop the allowable stress numbers for the materials. In short, both the ISO calculated root stress numbers and the ISO allowable stress numbers are about twice the AGMA numbers.

The calculated bending capacities according to ISO are generally much higher than the capacitiesaccording to AGMA. It appears from these examples that a minimum ISO bending safety factor of 1.3 would be required to have the same conservatism as the AGMA rating practice. It should also be clear from the examples that there is not a simple relationship between the ISO and AGMA rating results. In order to understand how your gears will rate under ISO 6336 you will have to go through the calculations case by case and compare the results.

You Can Have a Voice in Future Revisions of the ISO Gear Standards.

If you find errors or disagree with the ISO standard's calculation of the capacity of a specific class of gears, you can work through the ANSI Technical Advisory Group (TAG) to ISO Technical Committee (TC) 60, sponsored by AGMA, to suggest changes to the standard. Those suggestions should be well supported by calculations and test results to demonstrate the need for the changes proposed. The ANSI TAG meets regularly to establish the U.S. position on ISO standards. If there is a U.S. consensus for your proposal, it will become a U.S. proposal to ISO TC60, which is responsible for changes and updates to the standard. TC60 is already working on the next revision of ISO 6336, which is due to be completed in 2001.

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TECHNICAL CALENDAR

January 19–21. Orlando Advanced Productivity Exposition. Orange County Convention Center, Orlando, FL. Florida's largest machine tool and metalworking convention will feature more than 130 exhibitors, including machine tool builders, regional distributors and others. Sponsored by the Society of Manufacturing Engineers. Call (313) 271-1500, fax (313) 271-2861 or send e-mail to *lipndav@sme.org* for more information.

January 25–28. Gleason Pfauter Hurth Basic Fundamentals. Loves Park, IL. This four-day program is designed for those new to gear making who are seeking a basic understanding of gear geometry, nomenclature, manufacturing and inspection. Also runs February 15-18. For more information call (815) 877-8900 or visit *www.pfauter.com.*

February 19. Call for Papers. Deadline for submissions to the upcoming System Solutions with Mechanical Components conference to be held Sept. 21-29, 1999 in Baden-Baden, Germany. The conference focuses on developing innovative products and processes that improve efficiency and/or reduce costs or development cycles in the fields of mechanical, plant and vehicle engineering. For more information, contact VDI-EKV at ++(49) 211-6214-239 or *ennulat@vdi.de.*

March 2–4. Nashville Advanced Productivity Expo. Nashville Convention Center, Nashville, TN. The largest machine tool and manufacturing expo in the mid-South will have more than 250 machine tool builders and regional distributors. Sponsored by the Society of Manufacturing Engineers. Call (313) 271-1500, fax (313) 271-2861 or send e-mail to *lipndav@sme.org* for more information.

March 4. AGMA Annual Meeting. Westin Mission Hills Resort, Rancho Mirage, CA. Opportunity for networking and learning about industry trends and ways to stay competitive in today's gear industry. For more information contact AGMA at (703) 684-0211 or visit *www.agma.org.*

March 16–18. 4th World Congress on Gearing and Power Transmission. CNIT Paris La Defense, France. Learn about the current trends in design, materials, heat treatment, manufacturing and applications of mechanical transmissions. Nearly 200 presentations on cylindrical gears, worm gears, bevel gears, plastic gears, sintered gears, bearings, chains, belts and other power transmission components and systems. Contact Maryse Deleris, congress director at MCI, 19 Rue d'Athenes, 75009 Paris, France or *unitram@iway.fr.*

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While we have made every effort to ensure that company names and addresses are correct, we cannot be held responsible for errors or fact or omission.

If your company is not listed and you would like to be included in next year's directory, e-mail *people@geartechnology.com*, call 847-437-6604 or fax 847-437-6618, and we will add you to our mailing list.

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Memphis MI 48041-4680
810-392-2586
Fax 810-392-2586
flintrrc@klondyke.net
Titles: *Spur Involute Engineering, Serration Engineering, Helical Involute Engineering, Milling Cutter Selection, Lead Gear Calculations*

ABA-PGT, Inc.
1395 Tolland Turnpike
P.O. Box 8270
Manchester CT 06040
860-649-4591
Fax 860-643-7619
dellis@abapgt.com
Titles: *Plastics Gearing*

AGMA
1500 King Street #201
Alexandria, VA 22314
703-684-0211
Fax 703-684-0242
software@agma.org
www.agma.org
Titles: *ISO 6336 Software*

Algor, Inc.
150 Beta Drive
Pittsburgh PA 15238
412-967-2700
Fax 412-967-2781
info@algor.com
www.algor.com
Titles: Algor, Accupak/VE

Alliance Mfg. Software
P.O. Box 2009
Santa Barbara CA 93120
805-965-3000
Fax 805-957-4569
www.alliancemfg.com
Titles: *Alliance MFG® for Windows*

American Stress Technologies, Inc.
267 Kappa Drive
Pittsburgh PA 15238
412-963-0676
Fax 412-963-7552
ast@sgi.net
Titles: *AST Plotter*

Ash Gear & Supply Co.
21380 Bridge Street
Southfield MI 48127
248-357-5980
Fax 248-357-4324
Titles: *Gear Calculation Program*

B

Bizsoft Corporation
P.O. Box 129
Wind Gap PA 18091
888-BIZ-SOFT
Fax 610-863-7206
daull@prolog.net
Titles: *iSO-Pro*

Bourn & Koch Machine Tool Co.
2500 Kishwaukee St.
Rockford IL 61104
815-965-4013
Fax 815-965-0019
bournkoch@worldnet.att.net
www.bourn-koch.com
Titles: *Gear Manufacturing, Production Estimating, Gear Measurements*

C

Camnetics Inc.
926 Autumn Woods Ln.
Oregon WI 53575
608-835-2378
Fax 608-835-8702
info@camnetics.com
www.camnetics.com

C-Dot Engineering
14900 Robinwood
Plymouth MI 48170
313-420-2075
Fax 313-420-1279

CETIM
52, Avenue Felix Louat
BP 80067
60304 Senlis Cedex
France
++ (33) 3-44-67-31-07
Fax: (33) 3-44-67-34-25
Pascal.Marcheix@cetim.fr
Titles: Cador Exter-Inter-Rouvis, Carol

CIATEQ, A.C.
Retablo 150
Queretaro, Qro. 76150
Mexico
++ (52) 42-163808
Fax ++ (52) 42-169963
rodlop@ciateq.mx
www.ciateq.mx
Titles: *Diseng Gear Design Software*

Cimlogic, Inc.
402 Amherst St. #203
Nashua NH 03063
603-881-9918
Fax 603-595-0381
info@cimlogic.com
www.cimlogic.com
Titles: *Cimlogic Toolbox/2D, Toolbox Pro, PowerTransmission, NC Link*

Computer Resources
388 Swallow Lane
Wray GA 31798
912-423-8586
Fax 912-423-0404
info@comprsc.com
www.comprsc.com
Titles: *Gearbox Calculator, Machine Train Calculator, Bearing Frequency Calculator*

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University of Georgia
382 East Broad Street
Athens GA 30602
706-542-3265
Fax 706-542-4807
service@cosmic.uga.edu
www.cosmic.uga.edu
Titles: *NASA-GRA, DANST, DANST-PC, TLIFE, SBG-TAPER*

D

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24567 Northwestern Hwy #430
Southfield MI 48075
248-357-2200
Fax 248-357-4933
dgs@winspc.com
www.winspc.com
Titles: *WinSPC Analyst, RealTime Plus, Network Monitor, LaunchPad, C/S, C/S Enterprise, C/S Plant Monitor*

Dataworks Corporation
Vista & Vantage Div.
600 S. Highway 169, Suite 2000
Minneapolis MN 55426
800-457-3015
Fax 612-544-8253
info@dataworksmpls.com
www.dataworks.com
Titles: *Vista, Vantage*

Diamond Solutions, Inc.
13152 Bavarian Drive
San Diego, CA 92129
619-538-2287
Fax 619-484-4802

Drive Systems Technology, Inc.
24 Marlborough Lane
Glen Mills, PA 19342
610-358-0785
Fax 610-358-2776
geardoc@worldnet.att.net

Dynacomp, Inc.
4560 East Lake Road
Livonia NY 14487
716-346-9788
Fax 716-346-9788
Titles: *Gear Design, Planar Mechanisms, FreeGear, Resonance*

E

Echoscan Inc.
P.O. Box 163
Tonawanda NY 14151
905-371-1645
Fax 905-371-1647
www.npiec.on.ca/~echoscan
Titles: *Gear Design, CAM Design, Resonance, Rotary Shaft, First Gear*

ESDU International
27 Corsham Street
London N1 6UA
England
++ (44) 171-490-5151
Fax (44) 171-490-2701
sales@esdu.com
www.esdu.com
Titles: *ESDU Mechanisms & Subseries, ESDU Tribology & Subseries*

Euro-Tech Corp.
14665 W. Lisbon Road
Brookfield WI 53005
414-781-6777
Fax 414-781-2822
eurotech@execpc.com
Titles: *Spline Calculation Software*

F

Fairfield Manufacturing
P.O. 7940
Lafayette IN 47903
765-474-3474
Fax 765-474-7342
Titles: *Fairfield Gear Design Software*

G

GB Gear Shop Tools
2688 Sweet Springs
Deltona FL 32738
904-532-9787
geneb@bigfoot.com
Titles: *Book, Differs, Hobcycle, HS-Calc, Sizes, SZ-More*

GearSoft Design
8126 Huxtable Avenue
Lane Cove, NSW 2066
Australia
++ (61) 2-9411-1282
Fax (61) 2-9411-1282
winches@ozemail.com.au
Titles: *GearCAD*

Geartech Software, Inc.
100 Bushbuck Road
Townsend MT 59644
406-266-4620
Fax 406-266-4625
Titles: *AGMA218, Scoring+, Gearcalc*

The Gleason Works
1000 University Ave.
Rochester NY 14692
716-461-8061
Fax 716-256-6812
www.gleasoncorp.com
Titles: *Phoenix PC, G-Age, Cage, UMC, Cyclocut PC*

Great Solutions Inc.
P.O. Box 661
Duvall WA 98019
gr8solv@rossnet.com
www.rossnet.com/gr8solv

H

Hexagon Software
Stiegelstrasse 8
D-73230
Kirchheim/Tech
Germany
++ (49) 7021-59578
Fax (49) 7021-59986
fritz.ruoss@hexagon.de
www.hexagon.de
Titles: *ZAR1+, ZAR2, ZAR3, WL1+, LG1, WN1, WN2, WN3*

I

Involute Simulation Softwares
2491 des Hospitalieres
Sillery, QC G1T 1V6
Canada
418-656-6428
Fax 418-656-0687
involute@microtec.net
www.microtec.net/~involute
Titles: *HyGears 2.0*

J

JobBoss Software
7701 York Avenue S.
Minneapolis MN 55435
612-831-7182
Fax 612-831-2811

answers@jobboss.com
www.jobboss.com

L

Liebherr Gear Technology
1465 Woodland Drive
Saline MI 48176
313-429-7225
Fax 313-429-2294

Lilly Software Assoc.
500 Lafayette Road
Hampton, NH 03842
603-926-9696
Fax 603-929-3975
www.visualmfg.com
Titles: *Visual Manufacturing*

M

Mahr Corporation
11435 Williamson Road
Cincinnati OH 45241
800-969-1331
Fax 513-489-2020
www.mahr.com
Titles: *WinGear*

Manufacturers Technologies, Inc.
59 Interstate Drive
W. Springfield MA 01089
413-733-4972
Fax 413-739-9250
info@costimator.com
www.costimator.com
Titles: *Costimator*

Mechanical & Structural Design & Software
4275-29 Rosewood Dr.
Suite #180
Pleasanton CA 94588
510-455-3210
Fax 510-734-6701
lkeves@juno.com
www.rest.com/msds

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New Berlin WI 53151
414-860-0560
Fax 414-860-0561
www.microest.com
Titles: *Machine Shop Estimating*

Moore Products
Sumneytown Pike M/S 535
Spring House, PA 19477
212-646-7400
Fax: 215-653-0347
padinwr@mooreproducts.com
www.mooreproducts.com

N

NASA Lewis Research Ctr.
Mechanical Components
21000 Brookpark Road
(MS 77-10)
Cleveland OH 44135
216-433-3915
Fax 216-433-3954

Normac, Inc.
720 E. Baseline Road
Northville MI 48167
248-349-2644
Fax 248-349-1440
manny@normac.com
www.normac.com

O

Ohio State Univertsity Gear Dynamics & Gear Noise Research Lab
206 W. 18th Ave.
Columbus, OH 43210
614-292-5860
Fax: 614-292-3163
houser.4@osu.edu
Titles: *LDP-Load Distribution Program, DYTEM–Dynamic Transmission Modeling, RGDO– Robust Gear Design Optimization* (All titles available to corporate sponsors of the gear lab)

P

PC Enterprises
115 Yonder Lane
Sedona AZ 86336
800-437-2368
Fax 520-282-3001
pcent@sedona.net
Titles: *GearShop for Windows*

Power Engineering & Mfg. Ltd.
2635 WCP&N Drive
P.O. Box 4055
Waterloo IA 50704
319-232-2311
Fax 319-232-6100
dlichty@pemltd.com
www.pemltd.com
Titles: *PEMS*

Precision Gage Co.
6939 W. 59th Street
Chicago IL 60638
773-586-2121
Fax 773-586-2159

R

R.H. Software
Four Reddick Road
Asheville NC 28805
704-298-1008
Fax 704-298-6030
frtq76a@aol.com

Redei Enterprises
1424 Brett Pl. #359
San Pedro CA 90732
310-832-6984
Fax 310-832-6984
redei@aol.com
Titles: *GearXprt 2.0*

Roberts Eng. & Design
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Albertville AL 35950
205-840-9128
Fax 205-840-9128
RKunkel651@aol.com

Romax Technology Ltd.
Potterdike House
Lombard Street
Newark, Notts NG24 1XG
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937-859-8503
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rotomktg@rototech.com
www.rototech.com
Titles: *GEMS*

S

Smart Software
1162 Bowen Drive W.
N. Tonawanda NY 14120
mikecpu@msn.com
Titles: *ChangeGear Solver*

Software Eng. Service
2801 Ridge Avenue
Rockford IL 61103
815-963-1760
sesrvice@aol.com

Solid Dynamics
53 Rue Albert Thomas
42300 Roanne
France
++ (33) 4-7770-2111
Fax (33) 4-7770-8700
info@solid-dynamics.fr
www.solid-dynamics.fr
Titles: *SDS*

T

Trogetec Inc.
605 E. Washington
Riverton WY 82501
307-856-0579
Fax 307-856-0579
info@trogetec.com
www.trogetec.com
Titles: *EZgearplot, Invogear, PPOWD2, Quasi-Cycloidal*

U

UNIK Associates
12020D W. Feerick Rd.
Wauwatosa WI 53222
414-462-3201
Fax 414-462-3205
unikuma@aol.com
www.unik.com
Titles: *Engineering Tool Box, Hydro Pack, Unit Conversion System*

Universal Technical Systems, Inc.
1220 Rock Street
Rockford IL 61101
815-963-2220
Fax 815-963-8884
sales@uts.com
www.uts.com
Titles: *Gear Design & Mfg. Software*

User Solutions, Inc.
11009 Tillson Drive
South Lyon, MI 48178
248-486-1934
Fax 248-486-6376
sales@usersol.com
www.aboutus.net
Titles: *Resource Manager* for Excel Spreadsheet QC

V

Van Gerpen-Reece Engineering Co.
1502 Grand Blvd.
Cedar Falls IA 50613
319-277-7673
Fax 319-277-4236

W

Worrall Grinding Co.
1639 South Street
Anderson CA 96007
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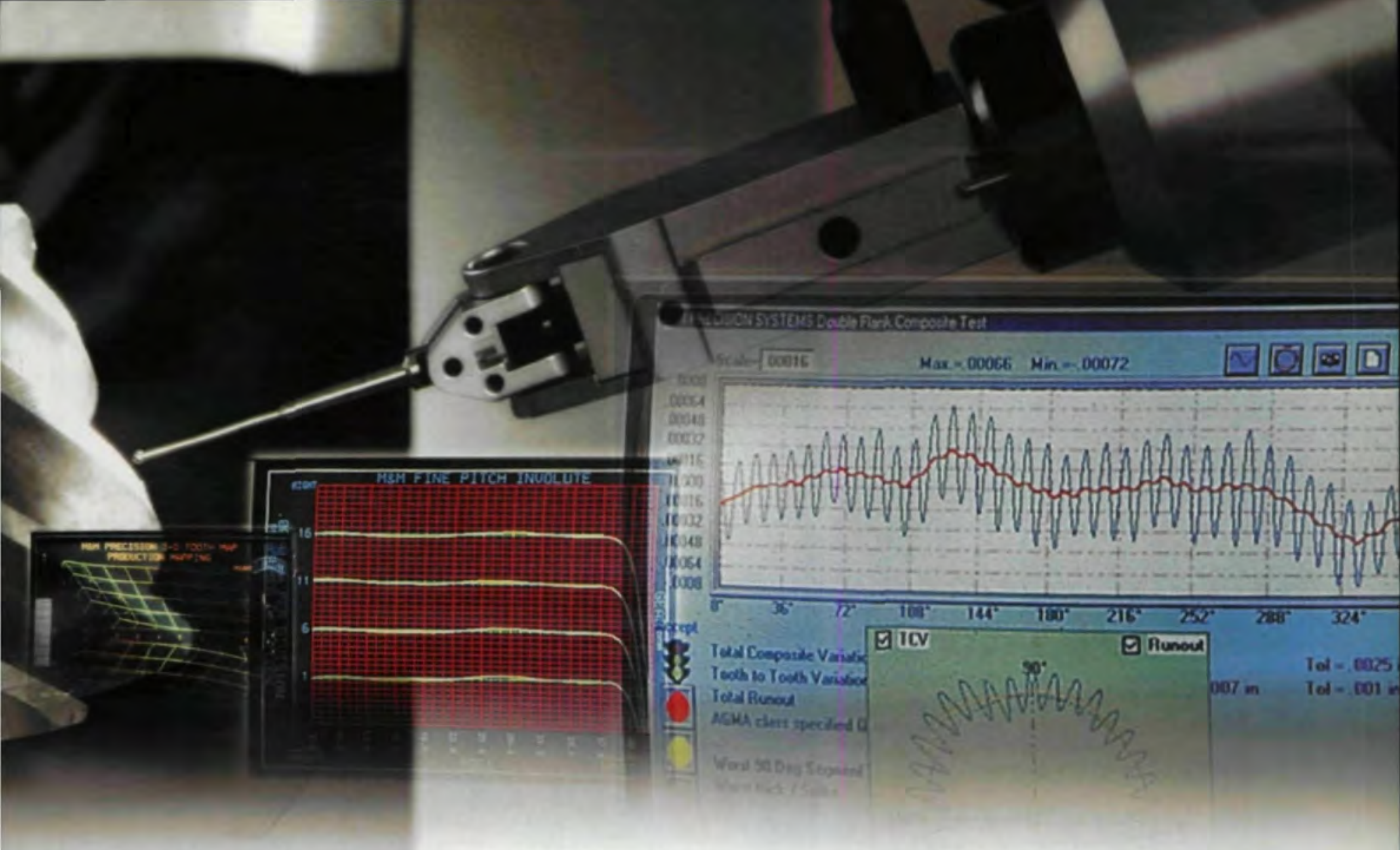
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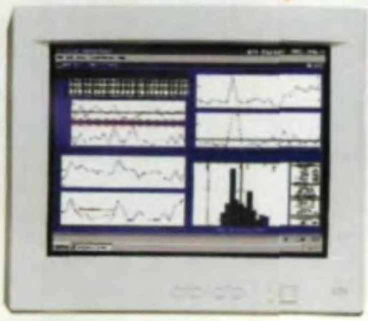
Total Runout



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Welcome to the 1999 *Gear Technology* Software Products Index. Use this index to locate the names of companies according to the software packages they provide. The complete mailing address, phone and fax numbers and e-mail and Web sites of each company are listed in the Company Index on p. 26. *Gear Technology* advertisers are shown in boldface type. To find the pages on which their ads appear, see the Advertisers Index on p 25.

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Abacus Computer Services—*Gage Design, Helical Involute Engineering, Back Taper Calculation, Database Design, Quotation Programs, Steel Ordering Programs, Involute Spline Plot*

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C-Dot Engineering—*Involute Gears & Splines*

CETIM—*Gear Design Software*

Cimlogic—*Gear Profile Drafting*

Drive Systems Technology, Inc.—*Software provided as part of gear design courses taught at University of Wisconsin*

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PC Enterprises—*Gear/Bearing Design/Digital Simulations*

Romax Technology

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HYDRODYNAMIC BEARINGS
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ESDU International
NASA

ROLLING ELEMENT BEARINGS
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COSMIC
ESDU International
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Hexagon Software
Mech. & Struct. Design
NASA
Romax Technology

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Mech. & Struct. Design
Romax Technology
UNIK Associates

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Romax Technology

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Romax Technology
Universal Technical Systems

SHRINK FIT CALCULATIONS
Solid Dynamics
Romax Technologies
Universal Technical Systems

SPRING RATE CALCULATIONS
Echoscan
Mech. & Struct. Design
Ohio Sate University
Solid Dynamics
Trogetec
Universal Technical Systems

OTHER REFERENCE
Cimlogic—*AGMA Standard Profile Generation*

Solid Dynamics—*Gear Design Calculations*

Trogetec—*Modnpt 4.8 Software for DC Motor Motion Servos*

GEAR DESIGN

ARRANGEMENT OPTIMIZATION
CETIM
COSMIC
Dynacomp
Fairfield Mfg.
Hexagon
NASA
Romax Technology
Solid Dynamics
Universal Technical Systems

CUTTING TOOL DESIGN
Abacus Computer Services
Ash Gear & Supply
Ciateq, A.C.
Hexagon Software
Involute Simulation Softwares
PC Enterprises
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Romax Technology
Software Engineering Service
Trogetec
Universal Technical Systems
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PC Enterprises
Romax Technology
Solid Dynamics
Universal Technical Systems
Van Gerpen-Reece

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ESDU International
Involute Simulation Softwares
NASA
Universal Technical Systems

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Dynacomp
Echoscan
Hexagon Software
NASA
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Ciateq, A.C.
COSMIC
Dynacomp
Echoscan
ESDU International
Fairfield Mfg.
Gearsoft Design
Geartech Software
Hexagon Software
Involute Simulation Softwares
Mech. & Struct. Design
NASA
Ohio Sate University
Roberts Engineering
Romax Technology
Solid Dynamics
Software Engineering Service
UNIK Associates
Universal Technical Systems
Van Gerpen-Reece Engineering

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C-Dot Engineering
CETIM
Ciateq, A.C.
Hexagon Software
Mech. & Struct. Design
PC Enterprises
Roberts Engineering
Software Engineering Service
Solid Dynamics
UNIK Associates
Universal Technical Systems
Van Gerpen-Reece Engineering

LEAD MISMATCH CALCULATIONS
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Involute Simulation Softwares
Romax Technology
Universal Technical Systems

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Dynacomp
ESDU International
Geartech Software
Hexagon Software
Involute Simulation Softwares
Mech. & Struct. Design
Universal Technical Systems

OPTIMUM INVOLUTE PROFILE MODIFICATION
CETIM
Ciateq, A.C.
COSMIC
Gearsoft Design
Hexagon Software
Involute Simulation Softwares
NASA
Ohio Sate University
PC Enterprises

Roberts Engineering
Romax Technology
Software Engineering Service
Trogetec
Universal Technical Systems

OPTIMUM LEAD/CROWNING MODIFICATION
Involute Simulation Softwares
Ohio Sate University
PC Enterprises
Romax Technology
Universal Technical Systems

PLASTIC GEARS
ABA-PGT
CETIM
Cimlogic
Dynacomp
PC Enterprises
Roberts Engineering
Universal Technical Systems
Van Gerpen-Reece Engineering

PRELIMINARY DESIGN SIZING
Ash Gear & Supply
CETIM
Ciateq, A.C.
Drive Systems Technology
Dynacomp
Echoscan
ESDU International
Fairfield Mfg.
Gearsoft Design
Geartech Software
Hexagon Software
Involute Simulation Softwares
Mech. & Struct. Design
Ohio Sate University
Roberts Engineering
Romax Technology
Universal Technical Systems
Van Gerpen-Reece Engineering

TOOTH MESH EVALUATION/PLOTS
CETIM
Ciateq, A.C.
COSMIC
Dynacomp
Echoscan
Gearsoft Design
Hexagon Software
Involute Simulation Softwares
NASA
PC Enterprises
Romax Technology
Software Engineering Service
Trogetec
Universal Technical Systems
Van Gerpen-Reece Engineering

WORM GEAR ANALYSIS
Ash Gear & Supply
CETIM
Echoscan
Hexagon Software
Ohio Sate University
Romax Technology
Solid Dynamics
UNIK Associates
Universal Technical Systems
Van Gerpen-Reece Engineering

YIELD STRESS CALCULATIONS
C-Dot Engineering
CETIM
Dynacomp
Hexagon Software
Involute Simulation Softwares
Solid Dynamics
Universal Technical Systems

OTHER GEAR DESIGN SOFTWARE
Algor, Inc.—*Physics-Based Simulation, Mechanical Event Simulation for Vitual Prototyping, Finite Element Analysis*

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Camnetics, Inc.—*Creating Solid Models of Gears in Solidworks*

CETIM—*Powder Metal Gear Design*

Ciateq, A.C.—*Optimizing Cylindrical Gear Design*

Gleason Corp.—*Proprietary Software*

Hexagon Software—*Bevel Gear, Toothed Shaft*

Involute Simulation Softwares—*Bearing Pattern Development*

Moore Products—*Master Gears*

Roberts Engineering—*Powder Metal Gear Design*

Solid Dynamics—*Dynamic Gear Simulation*

Trogetec—*Cycloidal and Quasi-Cycloidal Systems, Power Ratings vs. Housing Size*

GEAR INSPECTION

CMM SOFTWARE
Involute Simulation Softwares
Liebherr Gear Technology
Ohio State University
Roberts Engineering
Roto-Technology
Trogetec

CUTTING TOOL INSPECTION SOFTWARE
Liebherr Gear Technology
Roto-Technology
Software Engineering Service
Trogetec

OVER PINS/BALLS MEASUREMENT
Abacus Computer Services
ABA-PGT
Ash Gear & Supply
Bourn & Koch
C-Dot Engineering
Ciateq, A.C.
Fairfield Mfg.
GB Gear Shop Tools
Involute Simulation Softwares
Mahr Corporation
Mech. & Struct. Design
Moore Products
PC Enterprises
Roberts Engineering
Software Engineering Service
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OTHER GEAR INSPECTION
Ash Gear & Supply—*Span Measurement & Reverse Engineering*

Ciateq, A.C.—*Span Measurement*

Involute Simulation Softwares—*Corrective Machine Settings*

Mahr Corp.—*Double-Flank Gear Roll Testing*

Moore Products—*Tight Mesh Gear Inspection Roll Stands*

Precision Gage—*Tight Mesh Composite Analysis*

Roto-Technology—*Dedicated CNC Gear Inspection Systems*

GEAR RATING

BENDING STRESS/LIFE (BENDING STRENGTH)
AGMA
C-Dot Engineering
CETIM
Ciateq, A.C.
COSMIC
Drive Systems Technology
Dynacomp
ESDU International
Fairfield Mfg.
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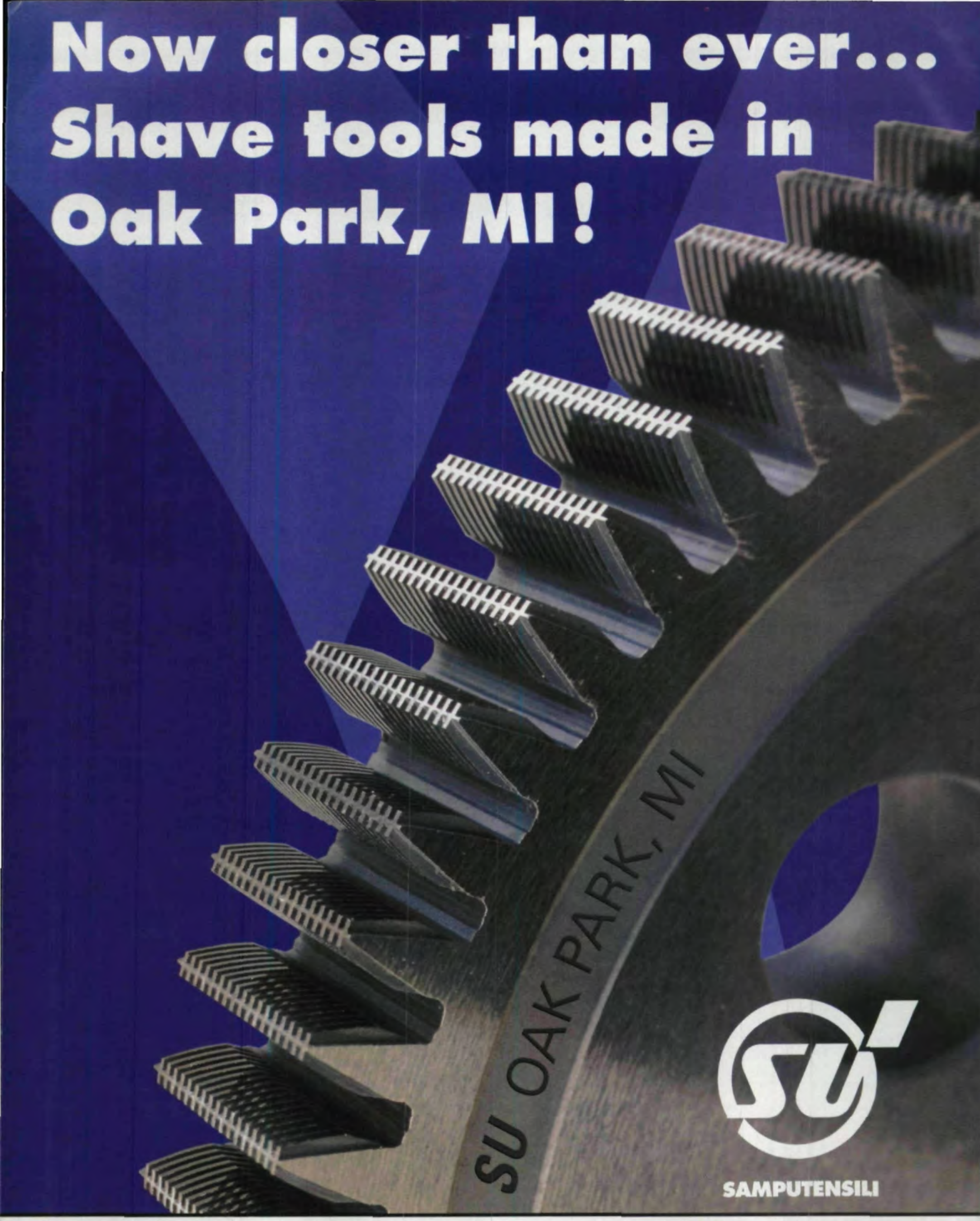
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Selection of the Optimal Parameters of the Rack-Tool to Ensure the Maximum Gear Tooth Profile Accuracy

Dr. Evgueni Podzharov

Introduction

An analysis of possibilities for the selection of tool geometry parameters was made in order to reduce tooth profile errors during the grinding of gears by different methaods. The selection of parameters was based on the analysis of the grid diagram of a gear and a rack. Some formulas and graphs are presented for the selection of the pressure angle, module and addendum of the rack-tool. The results from grinding experimental gears confirm the theoretical analysis.

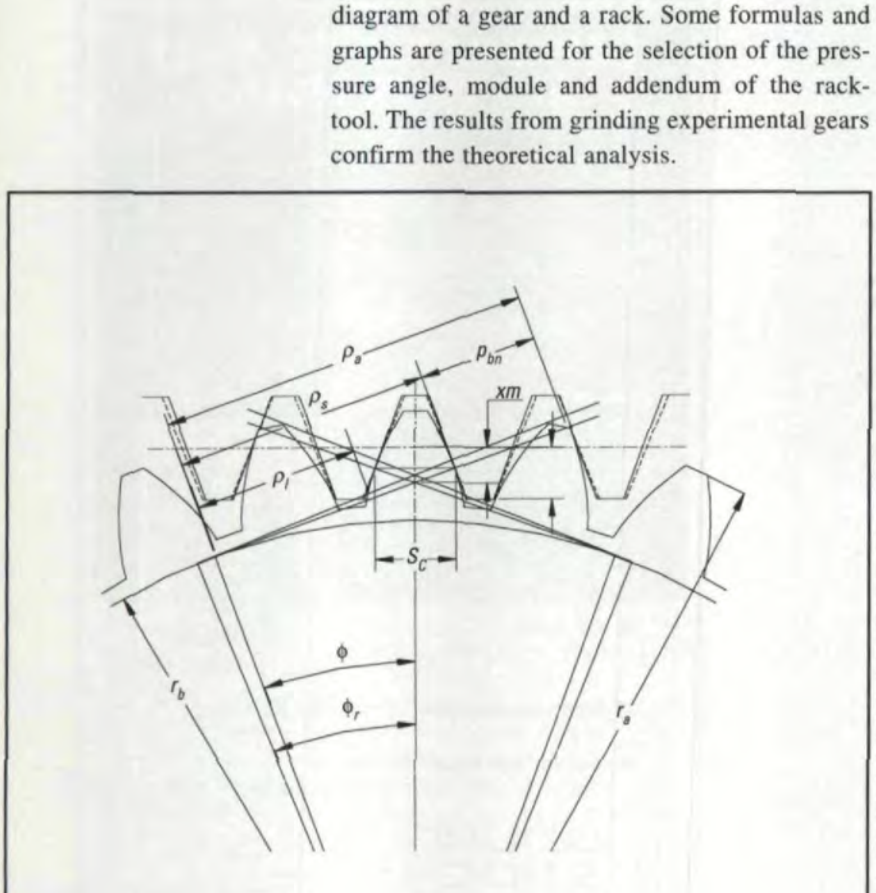

Fig. 1 — Geometry of a gear-rack engagement.

Profile generation methods are mostly used to grind precision gears at a suitable cost. But because of discontinuous contacts between the gear teeth and the tool, the resultant cutting forces periodically change their magnitude and direction. That causes tooth profile errors in some types of gears.

In a U.S. patent for gear tooth finishing (Schlichthorlein, 1965), the general principle was expressed for even numbers of contacts between the teeth of a gear and a tool to to prevent such profile errors, but a concrete method was implemented only for gear shaving. Later, this principle was applied to gear grinding with worm wheels (Podzharov, 1975, 1976) and then dish wheels (Podzharov and Fradkin, 1991).

In this paper, an analysis has been made of the ability of each gear grinding method to realize the condition of an even number of contacts during the gear tooth profile generation.

Analysis of Engagement of a Gear and a Rack

The profiles of gear grinding wheels have the form of a rack (worm wheels in Reishauer type machines) or a part of a rack (double tapered wheels in Niles type machines or dish wheels in Maag type machines). Consider the general case of the engagement of a gear and a rack-tool. The rack has a profile angle ϕ_r that may not coincide with the pressure angle ϕ of the gear (Fig. 1). The gear has a profile shift xm, where x is the gear addendum modification coefficient and m = the module of the gear. Therefore the profile angle ϕ_r and the pitch p_r of the rack must be selected so that the base pitches of the gear and the rack are equal.

$$p_b = \pi m \cos\phi = \pi m_r \cos\phi_r \qquad (1)$$

where m_r and ϕ_r are the module and the profile angle of the rack. The profile angle of the rack can, in general, be changed from 0° to the magnitude that permits the necessary height of the tooth root to exclude the interference with a conjugated tooth in a gear pair.

Now consider the geometry of the engagement of a gear and a rack (Fig. 1). For the analysis of the process of tooth generation by a tool-rack, use a grid diagram of this engagement (Fig. 2), which was first proposed in the work of Kalashnikov (Ref. 5).

In the grid diagram, the inclined lines represent the movement of the points of contact between the gear and the rack. The grid diagram is constructed in the following manner: On the horizontal axis is the longitude S of the arc of the base circle corresponding to the angle φ of rotation of the gear. On the vertical axis is the radius of curvature ρ of a tooth profile in a point of contact. The lines inclined at 45° to the horizontal axis represent the movement of the points of double flank contacts of the gear teeth with the tool teeth. Therefore the distance between two adjacent lines measured on the horizontal axis is equal to the arc of the base circle corresponding to the angular pitch of the gear teeth. The distance between two adjacent lines measured on the vertical axis is equal to the base pitch.

In the grid diagram ρ_a = radius of curvature of the tooth profile in the outside diameter, ρ_s = radius of curvature in the points which determine the permanent chord S_c

$$\rho_s = 0.5\left(d_b \tan\phi_t + \frac{\cos\psi_b}{\cos\phi}\right) \qquad (2)$$

$$S_c = \left(\frac{\pi}{2}\cos^2\phi + x\sin(2\phi)\right)m \qquad (3)$$

where ϕ_t = transverse pressure angle, ψ_b = base helix angle and x = addendum modification coefficient.

$$\rho_l = 0.5mN\sin\phi_t - \frac{a_r - xm}{\sin\phi_t} \qquad (4)$$

where ρ_l = radius of curvature in the limit point of the involute profile, a_r = rack addendum and N = gear teeth number.

Conserving the standard proportions of the teeth (addendum $a = 1.00\ m$ and dedendum $b = 1.25\ m$),

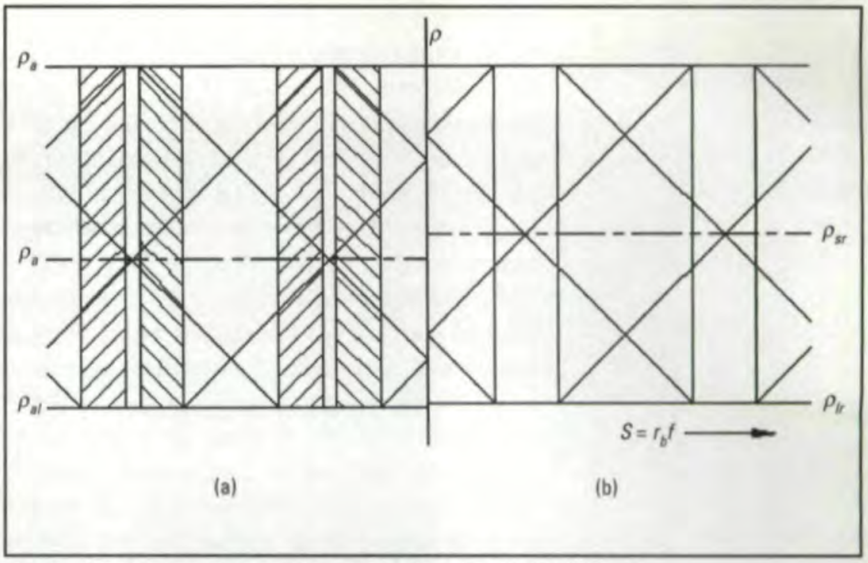

Fig. 2 — Grid diagrams for the profile angles of the rack: (a) 20°, (b) 21°47'.

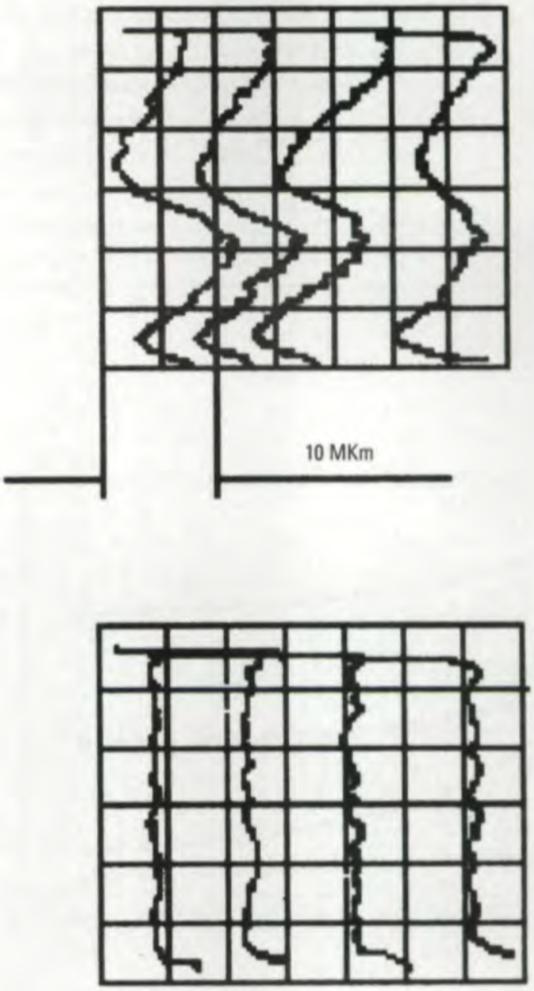

Fig. 3 — Involute diagrams measured after the grinding by worm wheels with profile angles: (a) 20°, (b) 21°47'.

we find that the variable parameters can be a_r, m_r, ϕ_r. The tooth height of the tool can only be changed in a small range. One reason for this is to conserve the necessary magnitude of the active tooth profile, and another is to allow the use of a standard tool for preliminary tooth cutting. The diagram in Fig. 2b was constructed for a gear with the following parameters: $m = 3.5$ mm, $N = 30$, $x = 0.857$, $\phi = 20°$.

By drawing a vertical line on the diagram, one can find the number of contacts between the gear and the tool as the number of inclined lines intersected by the vertical line. When the number of contacts on the right and on the left profiles of the gear are not equal, the total number of contacts is an odd number (this corresponds to the hatched areas on part (a) of the diagram). In this case the cutting forces on the left and right profiles are not equal and a profile error appears on the profiles with the lesser number of contacts. In the Reishauer type gear grinding machines, this occurs during the last pass when the gear is "free cutting." As a result, the teeth can obtain an undulated form of the profile (see the profile diagram in Fig. 3a), which provokes vibrations and gear noise.

Selection of Optimal Parameters of the Rack

From an analysis of the grid diagram one can conclude that when the grid diagram is symmetric in respect to any horizontal line that passes through the points of intersection of the inclined lines, the profile error will be reduced. This symmetry of the grid diagram can be arranged by changing the geometric parameters of the gear and the tool.

The condition of symmetry of the grid diagram for a general case of a helical gear has the following form

$$\rho_a + \rho_{lr} = 2\rho_{sr} + kp_{bn}\cos\psi_b \tag{5}$$

From hereon, the parameters which depend on the profile angle and the module of the rack will have a subindex r. In the equation (5) we have

$$k = 0, \pm 1, \pm 2, \pm 3, ...$$

$$\rho_{sr} = 0.5\left(d_b \tan\phi_{tr} + S_{Cr}\,\frac{\cos\psi_b}{\cos\phi_r}\right) \tag{6}$$

$$S_{Cr} = \left(\frac{\pi}{2}\cos^2\phi_r + x_r\sin(2\phi_r)\right) m_r \tag{7}$$

$$\rho_{lr} = 0.5 m_r N \sin\phi_{tr} - \frac{h_l - a - x_r m_r}{\sin\phi_{tr}} \tag{8}$$

We can find the rack profile shift x_r from Fig. 1:

$$x_r = x\,\frac{\cos\phi_r}{\cos\phi} - \frac{N}{2}\left(1 - \frac{\cos\phi_r}{\cos\phi}\right) \tag{9}$$

Solving the combined equations (5) – (9) one can find a series of values of ϕ_r which satisfy the equation (5). We have to select from these values the one closest to ϕ.

This technique was proved when grinding gears with the parameters mentioned above in a Reishauer NZA gear grinding machine. The optimal profile angle of the rack calculated by the equations (5) – (9) was $\phi_r = 21°47'$. The corresponding module of the rack from the equation (1) was 3.5418 mm.

The grid diagram for the gear with this rack is shown in Fig. 2b. In this diagram there are already no zones with odd numbers of contacts. The corresponding diagram of involute profile errors received after grinding a gear of the same type in the same grinding machine as it was before is shown in Fig. 3b. In this diagram there is no profile error of undulated form. The total profile error was considerably reduced.

The selection of an optimal pressure angle of the rack-tool can also be made from the graphs of Fig. 4 for gears with pressure angles of 20°-s (short addendum) and 20°, 22.5° and 25° (full height tooth) when $k = -1$.

For the method of gear grinding with a double tapered wheel (Niles type grinding machines) that represents one tooth of the rack, we can only select the rack pressure angle with $k = -1$.

Fig. 4 — Optimal pressure angles of the rack for gears without addendum modification.

In the 20° method of gear grinding with dish wheels (Maag type machines) we have $k = -1$ when the wheels grind the flanks of adjacent teeth in the same space between teeth. But when the profiles of adjacent spaces between teeth are ground, $k = -2$. The last value of k is more probable for gears with negative addendum modification coefficients.

It follows from Fig. 4 that when $k = -1$ and the number of teeth of the gear is greater than 20, an even number of contacts during the grinding can be obtained by adjusting the addendum of the rack a_r to get the transverse contact ratio to equal an integer number. For a standard full depth gear with a 20° pressure angle, this value must correspond to the contact ratio $m_c = 2$ between the gear and the rack. From Fig. 1a we find

$$m_c = \frac{2(a_r - x)}{\pi \sin(2\phi)} + \frac{N}{2\pi}(\tan\varphi_a - \tan\phi) \qquad (10)$$

where φ_a is the pressure angle at the outside circle of the gear. From this equation we find

$$a_r = x + \frac{\pi}{2}\sin(2\phi)\left[m_c - \frac{N}{2\pi}\ (\tan\varphi - \tan\phi)\right] (11)$$

In the following table are presented the values of a_r calculated by the formula (10) when the addendum modification coefficient of the gear $x = 0$ and $m_c = 2$ for the standard gears with pressure angle 20°.

N	20	30	40	50	60	70	80	90
$\frac{a_r}{m}$	1.23	1.18	1.15	1.13	1.12	1.11	1.10	1.09

We see from the table that the addendum of the rack corresponding to the contact ratio $m_c = 2$ is in the admissible limits for a wide range of gears. Therefore, in the gear grinding of standard full tooth height gears with pressure angle equal to 20°, there is no need to change the tool pressure angle.

The selection of an optimal tool pressure angle is necessary in the grinding of short addendum gears, gears with addendum modification coefficients and gears with pressure angles higher than 20° (22.5° and 25°), which are also AGMA standard. O

Conclusions

1. During gear grinding, when the contact ratio between the ground gear and the wheel is less than 2, a profile error of undulated form may occur. This is related to the odd number of contacts in the engagement of the ground gear and the wheel.

2. Errors of this type can be avoided by selecting the pressure angle of the tool in such a manner that the grid diagram of the engagement of the gear and the tool are symmetric.

3. Formulas and graphs have been presented for the selection of optimal pressure angles of a rack-type tool.

4. In the grinding of standard, full tooth height, 20° pressure angle gears, profile errors of undulated form can be excluded by adjusting the tool addendum. O

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is a professor of engineering mechanics at Panamerican University in Guadalajara, Mexico. After graduating in 1972 with a Ph.D. from the Moscow Peoples Friendship P. Lumumba University, he began his gear manufacturing career as senior research engineer in the machine tool building factory "Krasnyi Proletarii" in Moscow, where he was responsible for reducing the gear noise of the machine tools. He continued his work in gear noise as associate professor at the Moscow Textile Institute, where he worked from 1975-1995 and where he earned a Doctor of Science degree in 1995. He has published more than 40 articles related to gear manufacture, gear noise and vibration. Dr. Podzharov also works as a consulting engineer with Molinos y Maquinaria, S.A. de C.V., helping them to design and manufacture gear transmissions for agave mills for the tequila industry.

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Issues of Gear Design Using 3D Solid Modeling Systems

Charles Cooper

More and more gear shops are wrestling with the issue of whether or not solid modeling is right for their gear design work. The Q & A Page of* The Gear Industry Home Page™ *has had numerous questions asking how to model gears in solid modeling applications such as AutoCAD, Solidworks and Pro/Engineer. Given the problems people have been having, we are presenting the step-by-step process for modeling gears in Pro/Engineer, but first we thought it would be a good idea to explore the question of whether or not you should even try to design gears using Pro/Engineer or any other 3D solid modeling program.

"From a design point of view, we've gotten along for hundreds of years without solid modeling—we don't need it!" These are the words of Gulliver Silvagi, a product design engineer with Ford Motor Co., but they reflect the general opinion among gear designers as to the application of 3-D solid modeling programs like Pro/Engineer, Solidworks and Autocad to their work: Such programs have their uses in both design and manufacturing processes, but initial gear design is not one of them. The issue really comes down to the way gear design programs work versus the way 3D solid modeling programs work, and how they each model gears.

Helical Gear Model. Courtesy of Performance Gear Systems

Gear Design Software. Dedicated gear design software is mathematical in nature. It has to be in order to properly model the involute curve and the tooth profile generated from that curve. Dedicated gear design programs do the calculations necessary to create the true geometry of the gear tooth. This used to be a tedious and time-consuming operation, often taking the gear designer 50 hours or more to perform the calculations. These programs do the same calculations in seconds and so produce a true involute tooth profile quickly and easily.

However, due to their graphical nature, CAD/CAM systems can not do this. "They are graphical modeling tools and there is a finite number of calculations they can perform, a finite number of points they can plot along the involute curve," said Universal Technical Systems President Jack Marathe. "Because of this, the best they can do on their own is approximate the involute tooth profile."

Pat O'Donnell, President of Performance Gear Systems and a consultant who works extensively with Pro/Engineer said, "Pro/Engineer is a great CAD/CAM system, but it was not written to design gears. That's not what it does."

CAD systems approximate shapes such as the involute tooth profile by defining points along a curve and then simply connecting those points with straight lines. The more points you can plot, the smaller the lines are that draw the curve. While they can plot many of the points along the curve, coming close to the involute profile, there is always an error due to the need for the software to approximate using points and lines.

Another area where the mathematical model used by gear design software is preferable is in the design of the gear itself. Taking a helical gear and designing it in Pro/Engineer as an example, one sees that the method of constructing the three dimensional solid model provides a good approximation, but not a precise duplication, of the true geometry of the gear being designed.

Frank DeSimone, the Product Line Manager for Geometry at Parametric Technology Corporation, the makers of Pro/Engineer, explains that "a helical gear is nothing more than a constant cross-section [of a spur gear] rotated by a helix angle as the profile is swept across the gear width. Since a profile (sketch) is changing in rotary position as it is being swept, it naturally translates into a Pro/Engineer feature, the Variable Section Sweep." According to O'Donnell, this means that there is a cut at the center of the gear's face width and that the two resulting halves are rotated in accordance with the helix angle, slanting the teeth into the characteristic helical shape, transforming the spur gear into a helical. Because the spur gear design was based on the involute tooth design which was, itself, only an approximation of the true involute geometry (see sidebar), this model of a helical gear can only be as good and as accurate as the original approximation.

Gear ratings. Dedicated gear design programs allow you to make a gear that is within the AGMA or ISO quality rating you are designing for. In fact, the standards are already incorporated into many gear design programs. According to Robert Errichello, President of GearTech, a gear design consulting firm, "For rating gears, for bending fatigue and pitting, you want software that will allow you to stick to industrial quality codes. That way you can compare the gear you just designed to the accepted industry standards." Solid modeling programs can't do

MODELING GEARS IN PRO/ENGINEER

On the Q & A Page of **The Gear Industry Home Page™**, we have had several questions about modeling gears in Pro/Engineer. These questions describe problems with modeling the gear geometry, especially involute profiles, helicals, spurs and other forms. For example: "I have an application that calls for a molded sector gear. I will need to create part geometry for this design. I need help in generating an involute tooth profile. Can someone help me with suggestions how to model this in Pro/Engineer?" and "I am trying to model gears using Pro/E and am having a hard time with it..."

With the help of Frank DeSimone, Product Line Manager for Geometry at Parametric Technology Corporation, the authors of Pro/Engineer, and Daniel Gratten, a gear designer and technical specialist at Meritor Automotive, we will endeavor to answer some of these questions.

The Steps Involved. The first step in modeling a gear in Pro/Engineer is to define the involute curve. Once this is done, the gear itself, whether a spur or helical, is simply extruded from the tooth form. In Pro/Engineer, there are two ways to develop this involute tooth profile: You can do it mathematically or you can do it graphically.

The Mathematical Model. According to DeSimone, this is where most people get into trouble. However, he says that the following steps in Pro/Engineer will mathematically define an involute curve. The lines preceded by a /* are embedded notations to guide the designer. The Layout mentioned is Pro/Engineer's version of a template.

```
/*This first group of relations sets Feature Parameters to values in the Layout "gear_calc_sm.lay"
n = num_teeth            md = 1.25/Pd
Pd = diametral_pitch     cp = pi/Pd
a = pressure_angle       ts = cp-tt
Dr = root_diam           fr = fillet_rad
ad = addendum            rlf = relief_diam
tt = tooth_thick         D_o = Dp+2*(ad)
Dp = n/Pd                r_b = .5*Dp*cos(a)
/*This group of relations is composed of a start angle (alpha) and three simultaneous equations for r,
/*theta, and z, in cylindrical coordinates. /*(alpha) is calculated directly from the geometry defining the
/*involute curve.
alpha = t*sqrt(D_o^2/(4r_b^2)-1)
/*(r) is simply the changing length of a string that defines the involute.
r = r_b*sqrt(1+alpha^2)
/*(theta) is the angle created by the changing length of r, given that the line must always be held tan
/*gent to the base circle at (r_b).
theta = 180/pi*(alpha-pi/180*atan(alpha))
/*and we want the curve to stay in the same plane, so z = 0
```

According to DeSimone, this mathematical procedure creates a datum curve, the basis for the involute tooth profile, using an equation. It references the Layout for key parameters but, in the absence of geometry it has to explicitly calculate ***alpha*** to give the involute a starting point. The variable ***t*** varies from 0 to 1 over the length of the curve and is used as a time variable.

The Graphical Method. What follows is the step-by-step process to create a spur or helical gear ring graphically that was worked-out by Dan Gratten of Meritor Automotive.

The Gear Ring. This ring can be placed on any gear blank and work. Also this helical gear ring could be used on multiple gear blanks. The following describes the process used to create this helical gear ring:

1. Begin by creating datum curves that will define the attributes of the gear. Use Feature, Create, Datum, Curve. Create the four following circles as shown in Fig. 1.
   Base Circle Diameter (BASE_CIRCLE_DIA).
   Pitch Diameter (PITCH_DIA).
   Minor Diameter (MINOR_DIA).
   Major Diameter (MAJOR_DIA).
   Set all four of these diameters to the values on your gear spec sheet.

2. Select Modify, Dim Cosmetics, Symbol to name these circles as shown in Fig. 1.

3. Create the Parameters:
   NUMBER_OF_TEETH.
   PRESSURE_ANGLE.
   HELIX_ANGLE.
   FACE_WIDTH.

Using: SetUp, Parameters, Create, Number. (Enter in values from your gear summary or spec sheet.)

4. Define the gear tooth itself. Begin by creating a datum curve, and define it as shown in Fig. 2. Note that *it is not a true involute profile.* Using this simpler method, ***you will obtain about a 98% accurate representation of the tooth*** without creating an involute.

Tooth Definition: The tooth radius is defined by a radius that has its center lying on the base circle diameter (it is aligned to the base circle diameter). The tooth thickness is defined by two points that intersect the pitch diameter and the tooth radius. The outside of the tooth edge is used from the datum curve ***MAJOR_DIA*** and the root of the tooth edge is used from the datum curve ***MINOR_DIA***. The fillet radius at the bottom of the tooth to the root or minor diameter of the tooth is defined in Fig. 2 as ***sd14*** & ***sd15*** and is defined in our gear summaries as the tip radius on the hob. This is not the exact radius.

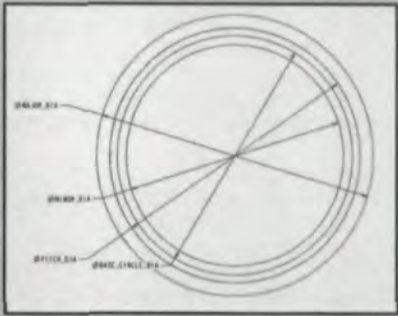


Fig. 1—Gear ring datum curves. Courtesy of Meritor Automotive.

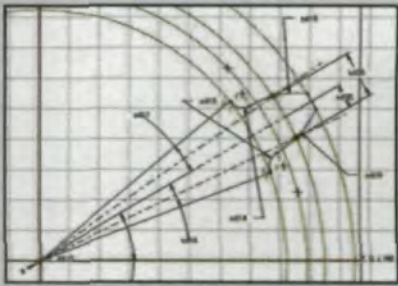


Fig. 2—Gear tooth definition. Courtesy of Meritor Automotive.

Fig. 3—Gear tooth copies. Courtesy of Meritor Automotive.

Fig. 4—Single helical gear tooth. Courtesy of Meritor Automotive.

The radius on the tooth will actually be greater than the tip radius on the hob, but once again we are about 98% accurate. Complete the curve by sketching lines to the center, forming a single tooth using a datum curve. Regenerate the curve and Select OK. Select Modify, Dim Cosmetics, Symbol and add names to the tooth thickness dimension (shown as ***sd36*** in Fig. 2) and one of the tooth radius dimensions (***sd18***) and the tip radius (***sd14***). Call the tooth thickness ***TOOTH_THICKNESS***, the tooth radius ***TOOTH_RADIUS*** and the tip radius ***TIP_RADIUS***.

5. Write the following relations into the part:
TOOTH_RADIUS=PITCH_DIA/2 * SIN(PRESSURE_ANGLE)
D35=TOOTH_THICKNESS/2
D19=TOOTH_RADIUS
D15=TIP_RADIUS
D17=180/NUMBER_OF_TEETH
D16=180/NUMBER_OF_TEETH

Make sure that you have a datum axis through the center of the diameters before you begin the next step. Then do a dependent copy of this curve and translate/rotate this curve. To do this use: Select, Feature, Copy, Move, Dependent, Done, then Select the Datum Curve, Done, Translate, Crv/Edg/Axis, and Select your center axis, Select OK, enter 1.00, Select Rotate, Crv/Edg/Axis, Select your center axis, Select OK, enter 10.0 for the angle, Select Done, Move, Done and OK.

It is best to create a relation driving these 2 Dimensions at this point. Simply Select Modify and then Select the copied Curve, Find the 10 Degree and the 1.00 Dimensions and then Select Relations and Note the system name for both dimensions. Select Add from the relations menu and type in the following:
DXX=FACE_WIDTH/3
D??=2* ASIN (DXX * TAN(HELIX_ANGLE)/BASE_CIRCLE_DIA)

where D?? is the system name for the angled Dim in the copy and DXX is the system name for the depth of the copy. Regenerate your part.

6. Create three copies by patterning the copied tooth using the two dimensions mentioned above as the driving dimensions for the pattern. This will give you a smooth translation to your helical gear. You will now have something that looks like Fig. 3. Then add relations to define the pattern which sets the patterned depth and angle = the DXX and the D?? mentioned above. Regenerate your part.

7. Create a datum curve that is aligned to the center axis of the four Diameters at a length of the face width of the gear (This dimension should now be driven by a relation ***D??=FACE_WIDTH***).

8. Create your protrusion using Advanced, Swept Blend, Select Sec, Normal to Spline. The trajectory is the straight line curve created above along the center line of the diameters. The sections are the four datum curves created and shown in Fig. 3. Simply Use Geom Tools. Use Edge, Sel Loop on all four datum curves to define your four sections.

Note: Make sure that your start points are the same on all four sections.

9. You have now created a single helical tooth for your helical gear ring. This tooth should look something like Fig. 4. Next create a copy of the first tooth using Feature, Copy, Move, Dependent, Done, Select the Protrusion, Done, Rotate, Crv/Edg/Axis and Select the center line axis as your rotating axis and then Select OK and enter your angle (use 360/Number of Teeth), then Done, Move, Done, and OK. Add the relation ***D??=360/NUMBER_OF_TEETH*** (where D?? = the system name of the dimension angle just entered above). Regenerate your part.

You can now pattern the copied tooth by using Feature Pattern and then Select the copied tooth and use the angle from the previous step to drive the pattern angle and the number of instances should be your Number of Teeth-1. Add the relations:
D??=360/NUMBER_OF_TEETH
P1=NUMBER_OF_TEETH-1

Where D?? and P1 are the system names that are given to the dimensions generated by the pattern creation. Regenerate your part. Once you are complete you should have something similar to Fig. 5.

10. Lastly, create a coaxial hole at a blind depth of the face width of the gear to turn it into a ring (Fig. 6). Set this blind depth dimension ***DXX= FACE_WIDTH*** using a relation and set the diameter of the hole ***D??=MINOR_DIA-.100*** using a relation. Regenerate your part. This we use so that this gear ring can be merged into any gear blank that you have developed. Add the relations to the gear part to drive all the geometry.

Automation. You can automate these steps for your users to simplify this process considerably. Create a Pro/Program out of this gear ring. Add to the gear ring program the information contained in Fig. 7. This can be done by selecting Program from the main menu and then Edit Design. From there simply add the information shown in Fig. 7 in between the input and end input lines. The user merely has to regenerate the gear ring. When he does, the system will prompt him to either use current values or to enter new ones. Simply select Enter, Select All, and then answer the questions that are asked. Once all the information is answered, the part regenerates and the gear is created.

It may be useful to create four such templates: A millimeter and inch version of both a right and left hand helical gear.

Once this gear ring is completed, you can then use the Advance Utilities Function to Merge it into your gear blank. The result is shown in Fig. 8. Also merged into the gear shown in Fig. 8 is an internal spline similar to the helical gear defined above. The helical gear can be converted into a spur gear simply by entering 0 for the helix angle.

Daniel Grattan is a Technical Specialist at Meritor Automotive. He can be reached at grattadv@meritorauto.com.

Fig. 5—Helical gear pattern. Courtesy of Meritor Automotive.

Fig. 6—Helical gear ring. Courtesy of Meritor Automotive.

INPUT PITCH_DIA NUMBER "WHAT IS THE GENERATING PITCH DIAMETER?"
NUMBER_OF_TEETH NUMBER "WHAT IS THE NUMBER OF TEETH?" MAJOR_DIA NUMBER "WHAT IS THE NOMINAL MAJOR DIAMETER?"
MINOR_DIA NUMBER "WHAT IS THE NOMINAL MINOR DIAMETER?" FACE_WIDTH NUMBER "WHAT IS THE FACE WIDTH?"
PRESSURE_ANGLE NUMBER "WHAT IS THE GENERATING TRANSV. PRESSURE ANGLE?"
HELIX_ANGLE NUMBER "WHAT IS THE GENERATING PITCH HELIX ANGLE?"
TIP_RADIUS NUMBER "WHAT IS THE TIP RADIUS ON HOB?"
BASE_CIRCLE_DIA NUMBER "WHAT IS THE BASE CIRCLE DIAMETER?" TOOTH_THICKNESS NUMBER "WHAT IS THE GENERATING TRANSVERSE CIRCULAR TOOTH THICKNESS?"
END INPUT

Fig. 7—Information for gear ring design automation. Courtesy of Meritor Automotive.

Fig. 8—Helical gear with internal spline. Courtesy of Meritor Automotive.

that for you and so force the designer to go back to the AGMA and/or ISO calculations to get the standards.

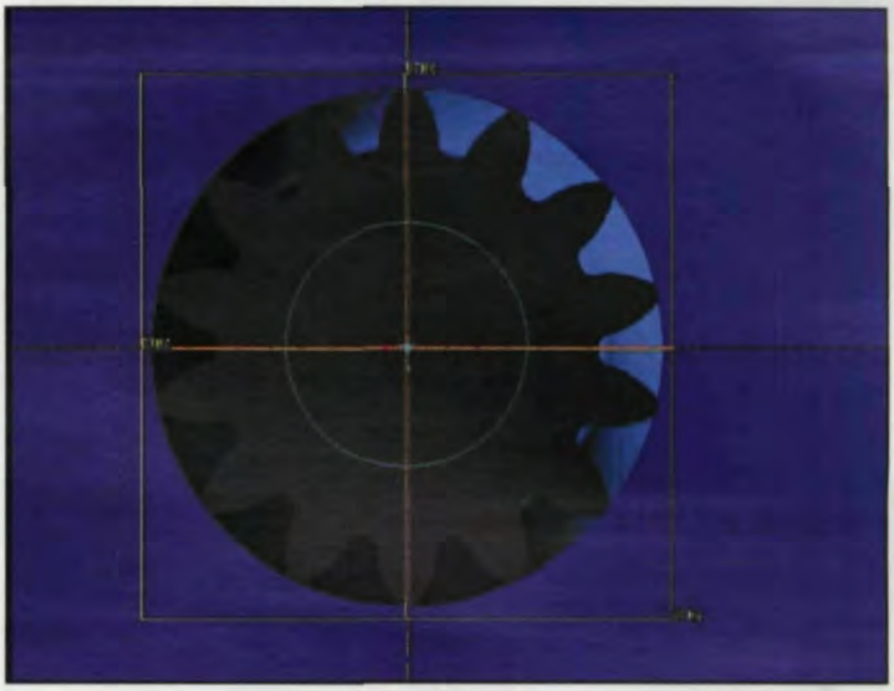
Strengths of 3-D Solid Modeling. One shouldn't believe that three dimensional solid modeling programs don't have a place in the gear industry. They clearly do, but not as gear design tools. According to Errichello, the place for solid modeling is in system design and analysis. "System dynamics analysis is helped by 3D solid modeling." This is especially true when trying to find the torsional natural frequencies of a particular system as well as in the aerospace industry, where gears are very thin and light-weight and have problems with resonance.

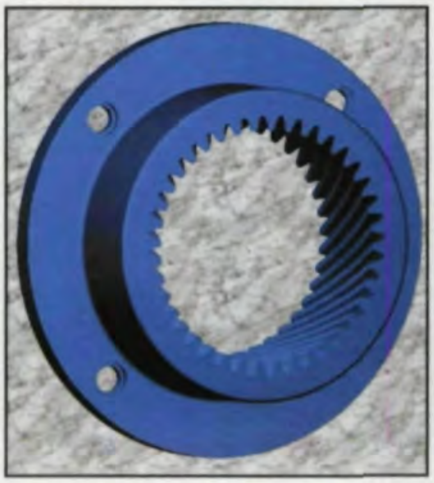
For applications like these, solid modeling programs are very useful. Silvagi adds that solid modeling is a good downstream tool, good for defining tool paths for EDMs, lasers and other systems that can draw data from a CAD system. Solid modeling is also the basis for stereolithography and other rapid prototyping systems.

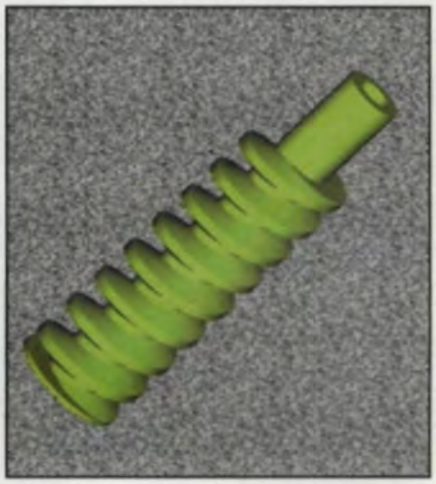
These abilities and applications make modern CAD/CAM systems such as Pro/Engineer powerfully versatile engineering design tools with a great deal to offer the designer. All of this flexibility is made possible by a process called parametric modeling.

Parametric Modeling. Prior to the introduction of parametric modeling, most programs created engineering models via 2-D drawings, 3-D wireframes or 3-D surface models. In each case, full product descriptions, down to the proper dimensioning scheme and tolerances, were impossible. This changed with the introduction of parametric modeling.

Parametric modeling allows the design engineer to let the characteristic parameters of a product drive the design of that product. In the case of gear designers, key dimensions that would describe the gear being designed such as diametral pitch, pressure angle, root radius, web thickness, etc. could be used as the parameters to define the gear. But, the parameters do not have to be geometric. They can also capture key process information such as case hardening specifications, quality grades, metallurgical







Examples of Gears Rendered in Pro/Engineer. Courtesy of Performance Gear Systems

properties and even load classifications for the gear being designed.

Programs like Pro/Engineer use these parameters, in conjunction with the program's features, to generate the shape of the gear and to add in all the essential information needed to create a product model. In creating a tooth profile, for example, the parametric dimensional information drives the shape of the tooth and non-geometric parametric information specifies things like the required case hardening depth or the nondestructive test requirements.

Since many gears are similar in many respects, Pro/Engineer can capture the differences within a family of parts very easily. For instance, two gears may be identical except for the web thickness and material. With a single product model, both gears are completely described because Pro/Engineer models the baseline design ("generic") and iterations on that design ("instances") via a spreadsheet. Differentiating parameters are characterized in the spreadsheet.

While all of these features and abilities are very useful to the designer, they do not deal with the question of the complexity of the calculations needed to define a gear tooth, nor do they address the tendency toward approximation inherent in CAD/CAM programs. Clearly, something more is needed.

The Synthesis of Gear Design Software and CAD: One Solution.

Given the limitations imposed by most gear design software on visual rendering and by CAD systems on the accuracy of the models, what is the gear designer to do?

Link the Systems. Most gear design software on the market today will export DXF files or X-Y coordinates that can be used by mainstream CAD/CAM software to draw the part. There are also programs that act as bridges between the gear design application and the CAD/CAM system. One such product is DesignLink by UTS.

Developed in conjunction with Jerand Technical Services, DesignLink bridges the gap between UTS gear design and engineering programs that run on its TK Solver platform and PTC's Pro/Engineer. "The combination of the mathematical modeling power of TK Solver and 3D graphical modeling power of Pro/Engineer provides a whole new capability for Pro/Engineer users," said Jerand President Bob Monat. "It's a new paradigm, with a unique productivity-boosting capability."

The geometry of the gear is designed with TK Solver and UTS gear software. This includes optimizing the design to increase both the life of the gear and the horsepower rating, reduce noise and cost, and so on. For plastic or powdered metal gears, the UTS software also helps you design molds by adjusting for shrinkage (plastic gears) or growth (powdered metal gears) when the gears come out of the mold.

DesignLink transfers the numeric information from TK Solver to Pro/Engineer, which reads the data as parameters of the model. This includes the number of teeth, face width, outside diameter, helix angle, pitch, pressure angle and coordinates of the tooth profiles for all the teeth. Once the transfer is complete, the 3D model is easily rendered. Since they are changeable parameters in the solid model, users may control the size of the Pro/Engineer model according to the number of points on the tooth profiles. Fewer points may lower precision somewhat, but that will not be a problem unless you are designing tooling such as a mold cavity.

According to Marathe, this combination of gear design and solid modeling software is the only way to accurately create gears in a 3D solid modeling environment. "Gear design involves complex mathematical calculations to get the geometry correct. It is not as simple as drawing an involute and a fillet and joining a few curves together. Accurate cal culation of gear profile coordinates makes it easy to use CAD/CAM systems to make molds and other tooling for plastic and powdered metal gears. The whole job then becomes automated."

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A LIFETIME OF ACHIEVEMENT

The American Gear Manufacturers Association (AGMA) has recognized the contributions of member Donald R. McVittie, presenting him with the Association's newest honor, the Lifetime Achievement Award. The award was presented to Mr. McVittie before a crowd of 200 engineers at the Association's annual Fall Technical Meeting in Cincinnati, Ohio, October 26, 1998.

The Lifetime Achievement Award was established by the AGMA Board of Directors as the industry's highest honor, presented to individuals who have, through their life's work, raised the standards of the industry and helped in the growth of the AGMA. In selecting Mr. McVittie, the AGMA Board of Directors stated that "no one today more clearly exemplifies the spirit of this award than Don McVittie."

McVittie is a licensed mechanical engineer with considerable management experience who has been an active AGMA member since 1972. According to AGMA President Joe Franklin: "To say Don 'participated in AGMA' is like saying the New York Yankees 'played baseball!' Through the force of his intellect, his insight and his will, Don has made indelible marks within AGMA. He has received every award bestowed by AGMA, including the Technical Division Executive Committee Award, and the E.P. Connell award for service to AGMA. His slightest comment continues to carry great significance with the Association leadership and staff. It does so because of the person Don is—conscientious, involved, caring, demanding, perceptive and respected."

McVittie came to the gear industry in the late 1960s when he joined The Gear Works. As Executive Vice President, he was responsible for the company's operations until his retirement in 1989. Today, he is President of Gear Engineers, Inc., an engineering corporation specializing in gear design, gear application analysis and computerized gear studies. McVittie has been one of *Gear Technology*'s Technical Editors since 1991 (an example of his work appears on page 20).

ALBANY METAL TREATING APPOINTS NEW VICE PRESIDENT OF SALES AND MARKETING

Jack Richard, President of Albany Metal Treating, Inc., announced the appointment of Mark B. Auble to the position of Vice President of Sales and Marketing. Auble, a graduate of the University of Indianapolis, has over 18 years of experience in industrial sales and the heat treating industry, having served as Sales Manager for Acme National Heat Treating and as Director of Sales for Precision Heat Treating.

Richard states that "Mark, with his metal treating background, is a great addition to our management team. He will work with Chuck Fritz, senior Vice President, developing AMT's sales, client services and new business programs."


Mark B. Auble

SURFTRAN EXPANDS ITS FACILITIES

SurfTran of Madison Heights, Michigan, has expanded its main facility with additions to the machine building floor and office area. The overall expansion is 6,000 sq. ft., which allows SurfTran to increase floor space for its expanded lines of thermal energy deburring machines, electrolytic finishing machines, aqueous and solvent cleaning systems and push-pull ultrasonics.

LINDBERG HEAT TREATING TULSA DIVISION RECEIVES OKLAHOMA STATE QUALITY AWARD

Lindberg Heat Treating Company's Tulsa, Oklahoma division received the Oklahoma Quality Award for Achievement from Governor Frank Keating during ceremonies on November 5, 1998. The Oklahoma Quality Award recognizes those businesses and organizations with strong leadership, organization-wide commitment to customer satisfaction, and continuous improvement of their products and services. It is patterned after the prestigious Malcolm Baldrige National Quality Award.

The Tulsa division heat treats a variety of components for local and regional manufacturers as an integral part of the manufacturing cycle. Lindberg serves over 250 customers with major markets in the aerospace, oilfield and automotive industries. Lindberg's vision is to set the Benchmark of Quality so that the company will be the lowest total cost supplier and the preferred business partner of its associates, customers, suppliers and shareholders.

NEW AMT VICE PRESIDENT OF EXHIBITIONS APPOINTED

Peter R. Eelman has been appointed Vice President of Exhibitions by AMT, the Association for Manufacturing Technology. Eelman's primary responsibility is to market and present the biennial International Manufacturing Technology Show (IMTS). He will report to Don F. Carlson, AMT President. "Peter is well qualified for this position and has the experience in the industry to continue the tradition of excellence IMTS has established," said Carlson.

Eelman, 41, joined the AMT staff in 1996 as Exhibitions Director, reporting to the recently retired Elwood H. "Woody" Hasemann. Eelman has been associated with the U.S. machine tool industry since 1980 when he joined the Warner & Swasey Company in a marketing position with the Wiedemann Division. He spent several years at Toyoda Machinery USA Inc., where he became Vice President of Marketing and Service and senior executive in charge of all marketing activities in North America and the United Kingdom. Eelman also worked as an independent marketing consultant for a variety of industrial firms including major manufacturing technology companies.

CARL OVERTON DIES AT 81

The gear industry is mourning the loss of Carl E. Overton, engineer and Chairman of the Board of Overton Gear and Tool Corp., who died on November 20, 1998, of lung cancer in his Chicago-area home.

Overton began his career with the Illinois Gear and Machine Company in 1938. His contributions there during World War II led to advances in the production and machining of revolving turrets that are still in use today.

In the mid-1950s Overton launched the Overton Gear and Tool Corporation in Addison, Illinois. The firm has grown over the years under Overton's tireless care and leadership and now employs 130 people. Overton, who worked six days a week to ensure the success of the company, served as Chairman of the Board until two weeks before his death.

In addition to his business interests, Overton was also very active in the American Gear Manufacturers Association. He served as AGMA President from 1972-1973 and, over the years, received every award the Association bestows including the Board of Directors Award (1968), Technical Division Executive Committee Award (1969), Edward P. Connell Award (1978), and the Administrative Division Executive Committee Award (1979).

He is survived by his wife of 57 years, Lydia; his four daughters Katherine, Margaret, Mary Hitchner and Lydia Wachal; and eight grandchildren.

NEW BEGINING AND PROUD NAME FOR 114-YEAR-OLD MACHINE TOOL MAKER

Cincinnati's most famous machine tool maker celebrates a new beginning under a new name, Cincinnati Machine, that proudly echoes how it has been known for most of its history. Sale of the 114-year-old former machine tool group of Cincinnati Milacron to UNOVA, Inc. was finalized in October. The sale keeps intact the machine tool maker's workforce and product lines.

"UNOVA values us specifically for the unique strengths of our organization—the greatest product breadth and strongest heritage of any American machine tool maker," said Kyle Seymour, President of Cincinnati Machine. "We will function as a separate operating division within the Industrial Automation Systems group. UNOVA not only is maintaining the integrity of our organization, but even acted to preserve the Cincinnati name." Under terms of the sale, UNOVA acquired rights to the Cincinnati name, with Cincinnati Milacron dropping the Cincinnati from its corporate name, becoming simply Milacron, Inc.

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New Products

The latest in machine tools, cutting tools, and other products for gear manufacturing.

Toyoda Introduces its Smallest and Fastest Horizontal Machining Center

Toyoda Machinery USA's Cutting Machine Division has introduced its new FA400 horizontal spindle machining center. The FA400 is the smallest and fastest horizontal ever offered by Toyoda, providing a cost-effective alternative to lighter competitive machines without compromising any of the rugged construction and long-lived stability and accuracy that have become hallmarks of Toyodas.

Traverse rates of X, Y, and Z-axes are 1,969 ipm, with optional drives raising those rates to 2,835 ipm through a workcube defined by 17.72 inches (X), 17.72 inches (Y), and 23.62 inches (Z). The maximum cutting feedrate is 1,969 ipm, with acceleration to 0.34 G. The standard 20 HP spindle with its #40 Taper spindle nose provides speeds to 8,000 rpm with an exceptionally flat torque curve. Toyoda can also provide the FA400 with a 22 HP or a 30 HP spindle providing 20,000 rpm and 14,000 rpm respectively. The 15.75 x 15.75 pallets are capable of supporting 600 lbs each, are exchanged in 5 seconds, and are indexed on the table 90° in 1.5 seconds with an accuracy of +/- 3 seconds of arc. The standard magazine accommodates 40 tools and the high-speed servo-driven toolchanger provides 3-second tool changes, chip to chip. Machine control is via the Fanuc 16i CNC. For more information on the FA400, contact Toyoda's Cutting Machine Division at (847) 253-0340 or via fax at (847) 253-0540.

Circle 300

New Mitsubishi Gear Shaver with Moving Cutter Head

Mitsubishi Heavy Industries America has introduced the new Mitsubishi FC30CNC with a moving cutter head and fixed table. With the moving head generating work, more rapid cutting speeds and reduced cutting times are achieved, while the fixed table increases machining rigidity.

This economically priced gear production machine offers four user-selectable shaving processes—available at the touch of a button. Whether conventional, diagonal, plunge, or underpass cutting is required, the new FC30CNC integrates today's most popular gear cutting procedures with an extremely fast cutting tool changer. Just two or three minutes are required for a cutter change, one-third to one-fourth the time required by competitive machines. For more information on the FC30CNC Gear Shaver, contact MHI Machine Tool U.S.A., Inc., Marketing Division, 907 W. Irving Park Rd., Itasca, IL 60143-2023. (630) 860-4222, fax: (630) 860-4233.

Circle 301

Norton SG Fibre Discs

The Norton Company has introduced a new line of Norton SG Fibre Disks designed for grinding stainless steel, silicon bronze and aluminum. The products were showcased by the Norton Company at this year's IMTS, held in September at Chicago's McCormick Place.

The unique design of the F941 fibre discs combines Norton's patented SG "seeded gel" ceramic aluminum oxide abrasive with a supersize, reactive size coating, resulting in both chemical and mechanical cutting action. The proprietary resin system chemically prepares the metal in the grinding zone for removal, enabling the SG abrasive to easily abrade the metal. F941 fibre discs have demonstrated up to 72% increased performance on 304 stainless steel compared to competitive ceramic aluminum oxide discs. F941 fibre discs are available in four sizes: 4-1/2 in., 5 in., 7 in. and 9-1/8 in. with grit sizes ranging from 24–80 and a .030 fibre backing that meets stringent quality specifications for strength and performance. For more information contact Linda Lebel, Norton Company, (508) 795-2168 or by fax at (508) 795-4130.

Circle 302

New Inline CMMs from Mitutoyo

Mitutoyo has unveiled an all new family of shop floor CMMs to address the need for more efficient metal cutting operations. The MACH family of CMMs delivers the speed and durability of an ultra-high speed horizontal machining center with the accuracy of a stand-alone CMM. And, open communications links with machine tools and factory networks offer increased levels of machine tool utilization. MACH CMMs offer a complete package of measurement hardware and software in a seamless approach to long term, continuous quality control and higher spindle utilization.

All structural elements of MACH CMMs are steel, giving common coefficients of expansion. High stiffness allows three point mounting for easy installation and reconfiguration. Linear motion is accomplished using mechanical bearing guideways and precision ball screws driven by oversized AC motors with AC digital servo controllers. A fixed horizontal arm is guided in the same fashion to eliminate the droop found in other ram-type configurations. Even the linear scales are steel with a very fine resolution of .000004" (0.1 μm). The advanced Mitutoyo CNC features four Digital Signal Processors (DSPs) and a 250 microsecond position loop. This combination of mechanics and servo system yields 3D acceleration of 1.8 G (695"/s^2) and a velocity of 70"/sec. Extremely high probing speed of 1.15"/sec., almost four times the industry norm of .26"/sec. is possible using Mitutoyo's unique MTP 1000 probe. For more information contact MTI Corporation at (630) 820-9666 or by fax at (630) 820-7413.

Circle 303

Mori Seiki Announces New Dual-Spindle Turning Center

Mori Seiki has unveiled the new RL-250 Dual Spindle Turning Center, a machine tool configured to maximize productivity and to optimize operator efficiency. With the RL Series, Mori Seiki utilizes technology for simultaneous machining. The two-spindle configuration does the job of two machines in one. The spindles are located side-by-side and operate at the same time, effectively increasing productivity. In addition, the compact body layout allows downsizing, therefore permitting a saving of floorspace.

The standard drive for both spindles is a powerful 15/11 kW (20/15 HP) Direct Drive Spindle (DDS) motor with the option for a 22/15 kW (30/20 HP) high output type. With this increased power, the equipment minimizes vibrations and heat allowing for more stable, more efficient and more accurate production. Sufficient torque is ensured at low speeds, and full power is readily available across a wide range.

Twin turrets hold 12 tools each. A hydraulic positioning motor provides rotational drive power, thus allowing the turret indexing a rapid 0.6 sec/station. The rapid traverse rate for the X and Z axes is 24m/min (944.9 ipm). This provides users with superior speeds along the slideway and can reduce non-cutting time in the process. The leg and bed are cast as a single unit, ensuring high rigidity with no overhang and increased stability. For more information contact Mike Jouglard or Bill Jones at Mori Seiki at (972) 929-8321.

Circle 304

New 3D Laser Comparator from CAltech.

CAltech introduces a new generation of 3D part inspection equipment that is automatic, rapid, precise and cost effective. Priced under $20,000, the machine automatically verifies dozens of dimensions on a part to +/- 2 micron repeatability in 30 seconds. Three models handle different sized parts: 1"cube, 3" cube and 9" cube.

Unlike optical comparators that only image the 2D silhouette of a part, CAltech's 3D Laser Comparator measures the part's surfaces in 3D. Rugged and temperature compensated, it can be used on the shop floor next to production equipment. Dimensions on parts made on NC mills and lathes can be verified as they are produced, quickly identifying improper setup, tool wear or tool breakage. Molded parts can be checked for warp and short shots as they leave the injection machine. Bend angle and forming errors of stamped parts can be detected right at the press. The one-touch operation is simple enough for machine operators with little computer training. For more information contact CAltech at (408) 225-6377 or by fax at (408) 226-1950.

Circle 305

ONA EDM Introduces Techno 400 EDM

ONA EDM introduces its Techno 400 CNC EDM. The Techno 400 EDM is designed with intelligent engineering that reduces operator maintenance, slashes downtime and lowers repair costs. The Techno 400 features the new Techno high performance generator, linear glass scales on all axes and 1.5" diameter double nut, pre-loaded recirculating ball screws to maintain machine precision. It is available in both fixed and drop tank configurations. It also features the ONA 10,000 hour filtration system that eliminates the loss of production due to filter maintenance. Techno Series machines are also available in 300 and 600 models. For more information on the Techno 400 CNC EDM, call 1-888-ONA-EDMS.

Circle 306

New Multi-Stage Conveyor Wash System from Guyson

Guyson Corporation has introduced a series of conveyorized aqueous cleaning systems that incorporate a second washing or rinsing stage in addition to a heated air drying section. The upgraded Marr-Line through-belt power spray washers are offered in three standard sizes.

Designed for use with environmentally benign water-based cleaning solutions, the Marr-Line systems feature an overlapping circumferential spray pattern to ensure forceful impingement of the temperature-controlled aqueous solution on all aspects of the components as they move through the machine on a honeycomb mesh belt with variable speed control. High impact V-spray jets are fitted to a series of spray bars positioned on all four sides of the parts for complete coverage and thorough rinsing. The system's modular construction permits a combination of various wash, wash-rinse and wash-rinse-dry cycles to satisfy virtually any cleaning process requirement. For more information contact J.C. Carson at Guyson, (518) 587-7894.

Circle 307

Send your new product releases to:
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ZARXE, from Hexagon Industriesoftware, is used to calculate the addendum modification coefficient for an existing gear. The user enters values for pressure angle, helix angle, modulus and number of teeth. The addendum modification coefficient can be determined from dimension over balls, dimension over pins or span measurement for spur, helical or ring gears with involute teeth. For more information, visit *www.hexagon.de*.

Circle 260

Diamond Solutions Announces Gear Software Suite

Diamond Solutions, San Diego CA offers a suite of software tools for gear design and manufacture. The titles include *GearTools1*, which checks the usability of available shaper cutters and hobs for manufacturing external or internal spur gears, helical gears or splines; *MyMasterGear*, for master gear design and inventory management; *MySplineGages1*, for designing spline gages (plug and ring) and for managing gage inventory; and *MyExtGearGeo1* and *MyIntGearGeo1*, which are used for calculating gear geometry parameters, wire size for measurement and machine setup details.

Circle 261

AGMA's ISO 6336 Rating Calculation Software

ISO 6336 is the international rating standard for external spur and helical gears. AGMA, in conjunction with its work in developing the standard itself, has developed and tested software that addresses ISO 6336 "Method B," the most comprehensive, analytical calculation method the standard allows.

The AGMA/ISO 6336 software allows the user to determine gear capacity in accordance with the new standard, compare existing practices and designs with ISO 6336 results, and understand the ratings of competitors who use the standard.

The software comes with a manual that guides the user through the more than 80 input values the calculations require. Visit *www.agma.org* for more information.

Circle 262

DesignLink Bridges TK Solver and Pro/E

Gear shops around the world use TK Solver software and the related gear design modules from Universal Technical Systems. A new package from UTS provides a link between TK Solver and Parametric Technology Corporation's Pro/Engineer solid modeling program.

Numeric information is transferred from TK Solver to Pro/E: number of teeth, face width, outside diameter, helix angle, pitch, pressure angle and tooth profile coordinates. A single button click on the Pro/E side generates the solid model.

DesignLink also makes it feasible to transfer parametric data from a 3D model to TK solver for further engineering analysis or other calculations. After the analysis is complete the data can be transferred back to Pro/E and a new model generated.

Design rules like Roark's formulas for stress and strain or in-house design rules and procedures can be implemented in the solid modeling environment through DesignLink, says UTS spokesman Todd Piefer. For more information, visit *www.uts.com*.

Circle 263

FeatureWorks Recognizes Parametric Features

Solidworks Corp. has released FeatureWorks, a software application that recognizes parametric features from files produced by standard 3D translators for use in the company's SolidWorks solid modeling software.

FeatureWorks captures data and recognizes features imported from STEP, IGES, SAT, Parasolid and VDAFS files so that engineers can share 3D models with organizations that use different CAD systems.

FeatureWorks software is best suited for quadrangular, conical and cylindrical machined and sheet metal parts containing features such as extrusions, cuts, bosses, fillets and chamfers. For more information, visit *www.solidworks.com*.

Circle 264

New CAD-Based Gear Measuring Software

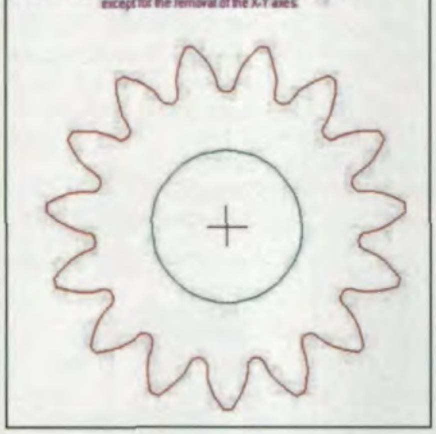
International Metrology Systems demonstrated a new gear module, VirtualDMIS, at IMTS 98. The application of CAD-based measurement to gears greatly simplifies gear measurement and reduces checking cycle times by more than 50% compared to conventional gear measuring software, company representatives say.

VirtualDMIS enables coordinate measuring machines to measure all geometric parameters for spur and helical gears, including lead, profile, pitch, runout and tooth thickness. The software extends the versatility of the CMM for gear manufacturers, possibly avoiding the need for specialized gear checking equipment.

The software uses the ANSI Dimensional Measurement Interface Standard DMIS 3.0, to enable CAD to CMM communication regardless of CMM brand.

Circle 265

FIGURE 2: This gear plot is the same as that in Figure 1 except for the removal of the X-Y axes.



New Release from Trogetec

EZgearplot v3.9-w is a menu-driven program for creating high-resolution drawings (300 X 300 dpi and higher), layouts, text, charts, diagrams, etc. The program is recommended for creating drawings of gears, roller chain sprockets, timing belt pulleys, harmonic gearing profiles, etc. The program is designed for Windows 95 and generates WMF files, which can be easily converted to AutoCAD format. For more information, visit *www.trogetec.com.*

Circle 266

Dr. DWG CADLite Library 5.0

CADLite Library 5.0 from Dr. DWG reads and writes AutoCAD R13 and R14 drawings saved in DWG, DXF and binary DXF formats, giving users the ability to extract and modify blocks, attributes or text data and to import and export AutoCAD drawings.

Developers say the CADLite Library 5.0 is the fastest AutoCAD library utility on the market. It operates on Windows 95, 98 or NT platforms. A fully functional 30-day trial version is available for download from *www.drdwg.com/download.htm.*

Circle 267

Send your new product releases to:
Gear Technology
1401 Lunt Avenue,
Elk Grove Village, IL 60007
Fax: 847-437-6618.

Tell Us What You Think...
If you found this article of interest and/or useful, please **circle 268.**

LITERATURE MART

INDUCTION FIXTURES

The LR-PAK data sheet describes induction lift rotate fixtures useful for heat treating parts such as transmission O.D. races, I.D. cams, hubs, spindles, C.V. joints and gears. LR-PAKs are completely assembled and interconnected.

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1745 Overland Avenue
Warren, OH 44482
800-547-1527
Fax: 330-372-8608

CIRCLE READER SERVICE #144

GLEASON PFAUTER HURTH INTRODUCES THE GP SERIES:

a new line of gear hobbers, shapers and grinders that share a "common platform" and use standard modules to greatly simplify the traditional processes of machine design, assembly and maintenance. They're designed to take advantage of the latest tool technologies available—wet or dry. Call us at (815) 877-8900 to request this brochure.

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Fax: 815-338-1549
E-Mail: ***sales@dura-bar.com***
Internet: ***http://www.dura-bar.com***

CIRCLE READER SERVICE #171

HYDRAULIC CHUCKS

Schunk Inc. has expanded its stock of hydraulic chucks to include more CAT taper chucks, HSK chucks, grinding chucks, new flange-mounted chucks, plus a greater selection of reduction sleeves. Schunk hydraulic chucks provide a Total Indicated Run-out (TIR) value less than .003mm and are guaranteed for one year. Custom designs are available.

Schunk Inc.
Morrisville, NC
(800)772-4865

CIRCLE READER SERVICE #173

BROACHING MACHINES & TOOLS

This sixteen-page brochure covers National Broach's complete line of Red Ring vertical, pot, blind spline and surface broach machines, along with CNC broach sharpening systems. National Broach also offers a comprehensive range of broach tools, accessories and services. For more information and a free brochure, contact the **National Broach & Machine Company** at (810) 263-0100.

CIRCLE READER SERVICE #133

G-SERIES GEAR HOBBER

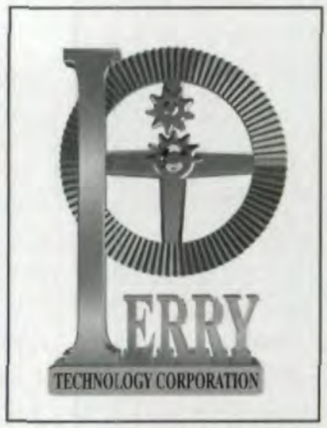
Twelve-page, color brochure describes nine high-performance models that provide unexcelled accuracy and productivity. Simple conversational programming greatly reduces set-up time. A hardened and ground gear set and special, feed-forward servo system optimize speed while maintaining precision. MHI Machine Tool USA, Inc. 907 W. Irving Park Road, Itasca, IL 60143-2023. Phone: (630) 860-4222, Fax: (630) 860-4233, Web site: www.mhi-mmt.com.

CIRCLE READER SERVICE #166

BOURN & KOCH

Bourn & Koch Machine Tool Co.'s new brochure outlines our wide variety of products and services including standard OEM products, specialty products, remanufacturing and retrofitting services, repair parts and more. Bourn & Koch Machine Tool Co., 2500 Kishwaukee Street, Rockford, IL 61104. Phone: (815) 965-4013, Fax: (815) 965-0019, E-mail: *bournkoch@worldnet.att.net*, Web site: *www.bourn-koch.com*.

CIRCLE READER SERVICE #163



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www.perrygear.com.

CIRCLE READER SERVICE #167

LITERATURE MART

GEAR MACHINES

This full color brochure shows 18 models of WOLF gear machines, including gear hobbers, shapers, honers, shavers, grinders, cutter grinders, bevel generators, rack shapers, worm millers, testers and more. WOLF offers new machines at extremely affordable prices.

Basic Incorporated Group
P.O. Box 36276
Los Angeles, CA 90036
Phone: (323) 933-7191
Fax: (323) 933-7487

CIRCLE READER SERVICE #159

CNC FORM GEAR GRINDERS

The SU RI 370 CNC machine allows you to grind a large variety of parallel axis gears and worms. It is good for frequent changeover environments as well as medium and high volume production runs. Thanks to the ability to dress the grinding wheel onboard, the tool cost is very low. For an application study, contact SU America, Inc./Samputensili
Ph: (248) 548-7177
E-mail: *usasu@concentric.net*

CIRCLE READER SERVICE #185

METROLOGY SYSTEMS

M&M metrology systems are designed for universal application and ease of operation-making them ideal for a wide range of inspection and process control tasks. This brochure describes how they employ **generative motion** via **linear interpolation** for lead and involute measurement. M&M software can be used on remote or networked PC's for SPC study or data entry. For a free copy, call 937-859-8273 or fax 937-859-4452.

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CIRCLE 125

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CIRCLE 169

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CIRCLE 156

HELP WANTED

Gleason Generating and Grinding

Aero Gear, a supplier of components to the aerospace industry, seeks an individual with experience grinding and generating spiral bevel gears. In-depth experience with Gleason machinery is required (116, 104, 463, Phoenix). Familiarity with Detroit, Red Ring, or Fellows machinery would be beneficial.

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DO YOU HAVE OUR NEXT COVER?

***Gear Technology* is looking for some HOT cover art for our March/April 1999 HEAT TREATING issue.**

Please send them to:
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Creative Drive

Gear Technology's bimonthly aberration — gear trivia, humor, weirdness and oddments for the edification and amusement of our readers. Contributions are welcome.

ALEXANDER DEEB COULD HAVE BEEN A GEAR ENGINEER.

"I have always had a fascination with movement and moving parts," Deeb says. "As a boy at Christmas time, I was much more interested in how and why my new toys worked than in what they actually did. That curiosity has never left me."

As it turns out, Deeb is not an engineer, but an artist.

"All my life, I have felt compelled to put things together, make them fit, make them move and then cover them with paint."

Deeb, a full-time student at Georgia State University, specializes in kinetic paintings and has created several works that feature gears not only for the functional elements that make his paintings move, but also for the deeper symbolism that the gears represent.

"I am intrigued by the single gear as a symbol for individuality. I could even go so far as to say that the individual teeth are the comprising factors of that individual entity," Deeb says.

Some of Deeb's work features rows of identically shaped gears, and at least part of the point of these works is that even when set among a field of exact replicas, the individuality of each component is not lost.

The gear also seems to be the perfect metaphor for humanity's dependence on industry and machines, Deeb says.

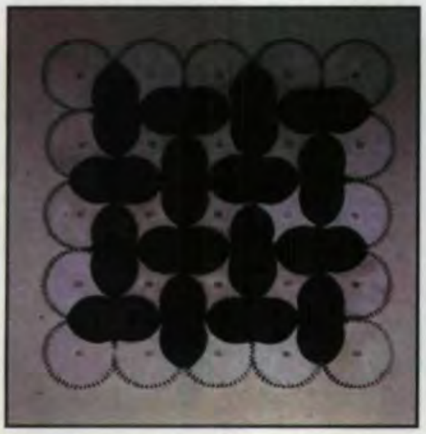
Nearly all of the gears in Deeb's paintings have been hand-crafted from wood, although he is searching for a source of factory-precise gears that he could use in his work. Prices for his work range from $200 to $1200, but he's willing to work out an exchange of artwork for gear sets with vendors who are interested. "It is more important to me now to develop my work in this area than it is to gain monetary reward," Deeb says.

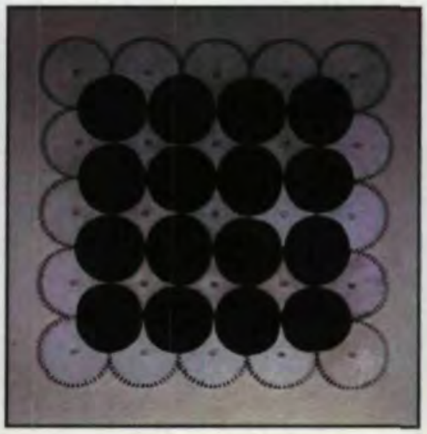
The Addendometer: If you've read this far on the page and enjoyed it, please **circle 225.**

If you'd like additional information about Alexander Deeb and his artwork, please **circle 226.**

Above: "Midnight Machinations"
19" X 19" wood, acrylic paint & motor

Below: "Gearfield With Dots"
20" X 20" wood, acrylic & oil paint



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