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The Journal of Gear Manufacturing

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January/February 1998

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POSITIVE TRENDS, HOT PRODUCTS, MINOR QUIBBLES AND OTHER NOTES FROM GEAR EXPO 97

Notes from Detroit . . . Overall, Gear Expo 97, the AGMA biennial trade show, was a success. While attendance may not have been what some people had hoped for, the *quality* of the attendees was high. Serious buyers came and brought their checkbooks.

Foreign attendance was up. We saw a lot more customers from Australia, South America, Mexico and Europe. Their positive reactions suggest that they will return home to spread the word about Gear Expo, which should net even more overseas visitors in 1999.

We also sensed a bigger number of visitors from the automotive and heavy industry sectors, implying that the "big guys" too seem to be developing an awareness of the advantages of this trade show as an opportunity to comparison shop and to get to know more about their potential suppliers—their CEOs, sales people, technical staff—and to nurture these relationships all in one place.

This growing awareness of the positive aspects of the Gear Expo experience is based, I think, on the fact that the Expo is growing up. The word is getting out that this is a worthwhile stop to make.

New products and technology helped to generate excitement at the Gear Expo. Both Gleason and Oerlikon demonstrated machines offering dry carbide face hobbing of spiral bevel gears. The new machines, first introduced at EMO, claim an up to 60% reduction in manufacturing time from their previously available machines. These machines are not only fast and eliminate the need for coolant, but leave the parts cool enough to handle as soon as the cycle is complete. We'll be looking for more of this technology in the future.

Mitsubishi introduced its new ST25CNC gear shaper, which has no helical guides. Instead, reciprocating and oscillating motion are synchronously controlled by the CNC. This seems like a great innovation for prototypes and short runs.

M & M Precision exhibited a new checker which used a laser rather than a probe to analyze parts. Right now, the technology is being applied to splines or cams, but it also may provide a "sneak preview" of the future.

The problems associated with resharpening carbides and recoating tools after every sharpening and the trend toward manufacturers narrowing their focus on their core competencies may have been addressed by Pfauter Maag Cutting Tools. The company has introduced a service to regularly pick up, resharpen, recoat, inventory and deliver cutting tools right to its customers' factories. Right now this service is limited to the Midwest, but it could be the beginning of a larger trend.

Amid all this innovation—four important developments announced at one show is not a bad record—I did notice one strange phenomenon: Two of the leading providers of hobbing machines, Gleason and Pfauter, didn't exhibit any of their hobbers, while two companies we don't associate with these machines, National Broach and Reishauer, did. Is this the start of another trend, or just one of those anomalies that make one go, "H-m-m-m"?

On a personal note, I was pleased by the very positive response to our demonstrations of ***powertransmission.com***™, our electronic buyers guide for the power transmission industry (you, our readers), and ***The Gear Industry Home Page***™, which provides information about machinery and services for the gear manufacturing industry. There is a growing awareness of how important it is to have a site on the Internet and of the usefulness of an electronic buyers guide like ours to help direct users to a company's own Web site. Our six-months-free offer had a lot of takers. Many companies at the show expressed a desire to create their own Web sites, but were afraid they'd never be found and were visibly enthusiastic that our buyers guide concept solved that problem. We were also pleased to note the number of show visitors who told us they were regular users of our sites. Both are becoming important resource tools for gear and power transmission engineers.

The feel-good mood of the show extended beyond the walls of Cobo Hall. Even the much-maligned city of Detroit seems to be turning a corner. The city has a long way to go, but the downtown area seems as though it will be undergoing a rebirth in the coming years.

Of course, at least some of the success of the show has to be laid at the doorstep of our strong economy. A rising tide raises all boats, and people are in a mood to buy right now. Companies need the capacity now; they need to make the investments now; they feel confident about upgrading their machinery and systems now. Furthermore, for once the perennial mess in Washington is working to the advantage of business and the economy. Both parties are so busy playing "gotcha" politics that they have left the economy alone to work with minimal interference—a fate we can all enjoy and take advantage of. Those things all go toward contributing to the "era of good feeling" that seemed to permeate the show.

The one nagging question that continues to be raised about the Gear Expo is whether or not the expense and effort of exhibiting is worth it. This show attracted just 4000+ people (including 1250 exhibitors and staff). And that's in good times.

Behind the smiles and happy talk about the show is the nagging feeling on the part of some major exhibitors that Gear Expo still costs way too much in terms of money, time and effort compared to the number of attendees and the amount of productive exhibit time. One exhibitor told me that he calculated the price of each lead he generated at the show at $1000!

AGMA needs to change its focus to attracting more visitors, not just more exhibitors. The show's success cannot be judged just by the number of booths sold. Key to Gear Expo's continuing success is for exhibitors to have a commercially successful show—one with lots of customers. Better, more aggressive publicity and year-round-promotion, even small things like clear, identifiable signage outside the show hall (one of the major exhibitors commented that he wasn't sure that the taxi brought him to the right place since the only sign on the outside of the building was for another show!), all can make for a better show.

AGMA also needs to look at the demographics of both its visitors and exhibitors. True, the Detroit location attracted an increasing number of automotive and heavy industry people, but visitors from small and medium-sized shops are critical to a show's success. More work needs to be done to attract them to the show. Perhaps Detroit's location at the edge, rather than in the heart of "gear country," works against attracting enough of these visitors.

That same fact may also cast a shadow on the possibilities for Nashville in '99. Like Detroit, Nashville is on the edge, rather than in the center of "gear country," and its location could work against it. If the economy is strong, '99 in Nashville will probably be another success; however, a weakening economy could mean a different scenario. A grimmer business picture just might provide the excuse people need not to travel the extra distance and for the exhibitors to decide to cut back on the "iron" they bring.

Granted, Gear Expo attendance numbers have shown small, incremental growth over the years, so perhaps these can be seen as minor quibbles. But is the increase enough? Are the additional visitors the kind of customers the exhibitors are looking for? Will exhibitors be willing to hang in long enough to allow customer attendance to grow at less than 10% every two years, (and this is in good times)? Are there other ways to get the numbers higher or the costs lower, and finally, will the increasingly popular Gear Pavilion at IMTS prove to be more cost effective for exhibitors—especially when the economy cools?

The planners at AGMA deserve full marks for growing the show as well as they have over the last decade, but they also cannot rest on their laurels. Gear Expo is a good idea that still needs work to ensure its long term success.

Michael Goldstein,
Publisher & Editor-in-Chief

Influence of Gear Design on Gearbox Radiated Noise

Fred B. Oswald, Dennis P. Townsend, Mark J. Valco
Robert H. Spencer, Raymond J. Drago & Joseph W. Lenski, Jr.

Introduction

A major source of helicopter cabin noise (which has been measured at over 100 decibels sound pressure level) is the gearbox. Reduction of this noise is a NASA and U.S. Army goal. A requirement for the Army/NASA Advanced Rotorcraft Transmission project was a 10 dB noise reduction compared to current designs.

The main exciting forces which produce gear noise are the meshing forces of the gear teeth in the transmission. While many factors influence transmission noise, the simple fact remains that if the basic exciting forces are reduced and no amplifying factors are present, the overall noise level of the system will be reduced.

Among the several ways in which the gear tooth meshing forces may be reduced, two of the most directly applicable to helicopter transmissions are the form of the teeth and the overall contact ratio. Both approaches are attractive for an aerospace application since, unlike sound absorbing treatments, these approaches have the potential for reducing noise without reducing performance or increasing overall system weight. Both approaches also offer the possibility of improving gear performance in terms of longer life, higher load capacity, greater reliability and reduced weight, while simultaneously reducing noise levels.

Helical gears, as compared to spur gears, typically produce lower noise levels. Winter (Ref. 1) provides a concise summary on the variation of excitation levels with face contact ratio. There is little other definitive data which defines the noise advantage of helical gears for accurate, ground gears. Similarly, anecdotal information indicates that higher contact ratios, both face and profile, also tend to reduce noise levels but, again, hard data is not readily available.

While helical gears provide some noise reduction, their use also generates a thrust load which must be dealt with in the design of the overall system, especially the support bearings, gear blank design and housing structure. Double helical gears, which cancel the thrust loads from each helix within the gear blank, provide relief from net thrust problems. However, the noise properties of double helical gears have not been reported.

Noninvolute tooth forms have been investigated for possible use in helicopter transmissions in recent years. Testing of high profile contact ratio, noninvolute tooth form gears (HCR-NIF) has shown that the load capacity can be substantially higher than that of conventional involute gears, and the bending load capacity (at high loads) was at least equal to that of the involute gears (Ref. 2). These investigations, however, have centered almost universally on the load capacity and not on noise generation.

This program was conducted as part of the Advanced Rotorcraft Transmission Project (Ref.

Table 1 — Test Gear Configurations

Configuration	Tooth Form	Type	Transverse Pressure Angle	Contact Ratio Profile	Contact Ratio Face	Contact Ratio Total
1. Spur Baseline	Involute	Spur	25	1.3	0.0	1.3
2. HCR Spur	Involute	Spur	20	2.1	0.0	2.1
3. Helical Baseline	Involute	21.5° Helical	25	1.3	1.25	2.6
4. Double Helical	Involute	38.2° Helical	25	1.3	2.50	3.8
5. Helical	Involute	28.9° Helical	25	1.3	1.76	3.1
6. HCR Helical	Involute	35.3° Helical	20	2.1	2.25	4.4
7. NIF Spur Baseline	Noninvolute	Spur	25	1.3	0.0	1.3
8. NIF-HCR Spur	Noninvolute	Spur	20	2.1	0.0	2.1

3). Its objective was to define, by controlled testing, the effect on noise levels due to changes in the profile and face contact ratios and the gear tooth form. These factors were varied both separately and in combination.

The test gear configurations were selected to be representative of those used in helicopter transmissions. The test gear designs include four different types of spur gears (low and high contact-ratio in both involute and noninvolute profiles), as well as five different helical (single and double) gear designs with various profile and face contact ratios. The gears were designed to be as nearly identical as possible, except for deliberate differences in tooth geometry and contact ratio.

Testing was conducted under controlled conditions (torque, speed, oil flow, temperatures, etc.). Acoustic intensity measurements were taken with the aid of a robot to insure repeatability of measurements between gear sets and to minimize the influence of operator technique. Results presented here include trends of the sound power at mesh frequency and narrow-band spectra of sound power. Preliminary results from this program were earlier presented by Drago (Ref. 4).

Test Gears

Eight sets of test gears were designed. Four of these are spur gears. Two sets have an involute tooth form, and two utilize a noninvolute, constant radius of curvature profile. All gears were designed in accordance with standard aerospace practice so that, except for size, they are representative of typical helicopter gears. The eight gear designs are summarized in Table 1 and are shown in Fig. 1. Additional test parameters are shown in Table 2.

Fig. 1 also shows a gear set which is not listed in Table 1. This was not one of the planned test variants. During the manufacture of the test gears, the double helical gear drawings went out with a drafting error such that both helices were manufactured with the same hand. The resultant gear set (known officially as "spread single helical gears" and unofficially as "OOPS" gears), are shown in the upper right corner of Fig. 1. Although these gears probably would not be used in a production environment, we decided to test one pair of them anyway.

Apparatus & Procedure

Test Facility. The NASA Lewis gear noise rig (Fig. 2) was used for these tests. This rig features a single-mesh gearbox powered by a 150 kW (200 hp) variable speed electric motor. An eddy current dynamometer loads the output shaft. The gearbox can be operated at speeds up to 6000 rpm. The rig was built to carry out fundamental studies of gear noise and the dynamic behavior of gear systems. It is designed to allow testing of various configurations of gears, bearings, dampers and supports. To reduce unwanted reflection of noise, acoustical baffles covered test cell walls, floor and other nonmoving surfaces. The material attenuates reflected sound by 20 dB or more for frequencies of 500 Hz and above.

Instrumentation and Test Procedure. Experimental modal test results from a previous testing program (Ref. 5) provided the first five natural frequencies and modes of vibration of the gearbox top. The natural frequencies were checked to assure that gear mesh frequencies did not coincide with important modes of the gearbox. Also, from previous analytical work, we know that torsional modes of the gear system are well above the 6000 rpm speed limit of the rig.

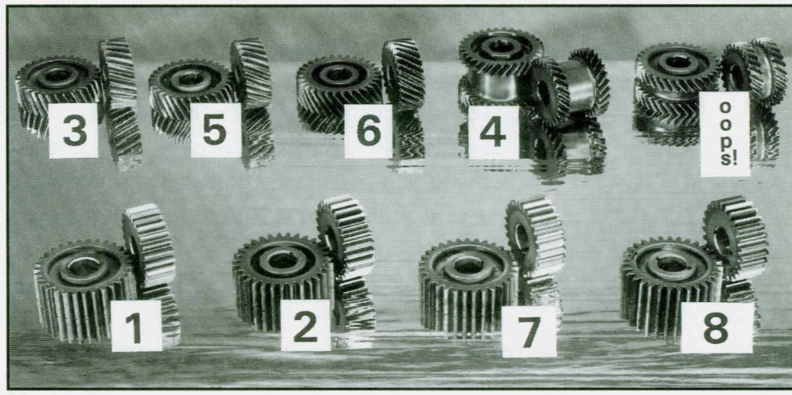

Fig. 1 — Test gears.

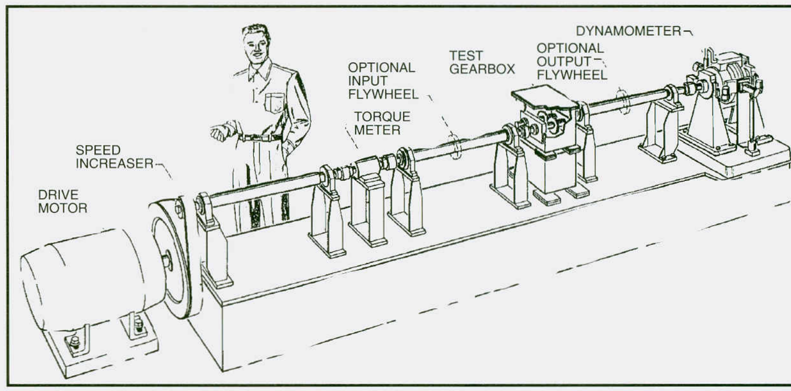

Fig. 2 — Gear noise rig.

Table 2 — Test Gear Parameters	
No. Teeth	25 and 31
Transverse Module, mm (diametral ptich, in^{-1})	3.175 (8)
Face Width, mm (in)	31.8 (1.25)
100% Input Speed, rpm	5000
100% Input Torque, N-m, (in-lb)	256 (2269)
100% Power, kW (hp)	134 (180)

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Acoustic intensity measurements were performed, under stable, steady-state operating conditions, with the aid of a computer-controlled robot designated RAIMS (Robotic Acoustic Intensity Measurement System). The RAIMS software (1) commanded the robot to move an intensity probe over a prescribed measurement grid; (2) recorded acoustic intensity spectra in the analyzer for each node of the grid; and (3) transmitted the spectra to the computer for storage on disk. The gearbox, robot and intensity probe are illustrated in Fig. 3. RAIMS is more completely described in Refs. 6 and 7.

The acoustic intensity probe consists of a pair of phase-matched 6 mm microphones mounted face-to-face with a 6 mm spacer. The probe has a frequency range (±1 dB) of 300-10,000 Hz. Measurements were made at a distance of 60 mm between the acoustic center of the microphones and the gearbox top.

At each operating condition, the intensity spectra collected from the twenty nodes of the grid were averaged, then multiplied by the area to compute an 801-line sound power spectrum. The area was assumed to be the area of the grid, plus one-half additional row and column of elements, or 0.0910 m^2. The actual area of the top is 0.1034 m^2. We did not extend the measurement grid completely to the edges of the gearbox top because the edge of the top was bolted to a stiff mounting flange which would not allow much movement, and measurements taken close to the edge of the top would be affected by noise radiated from the sides of the box.

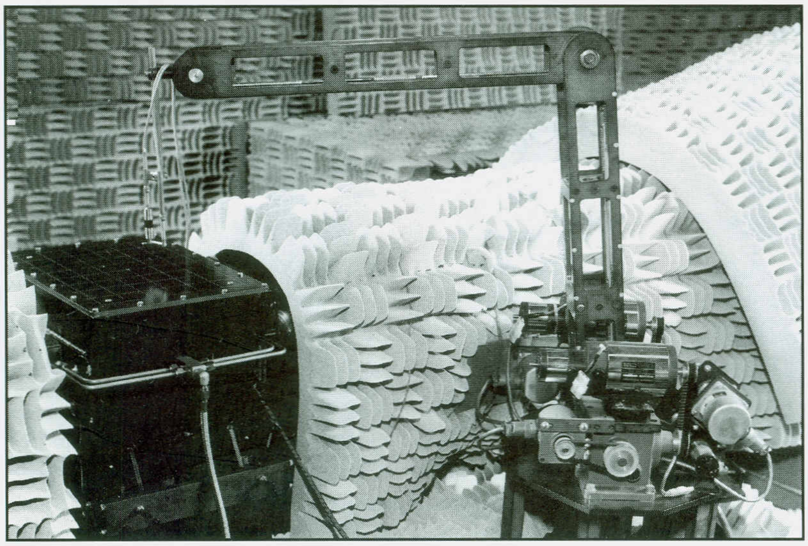

Fig. 3 — Test gearbox and RAIMS robot.

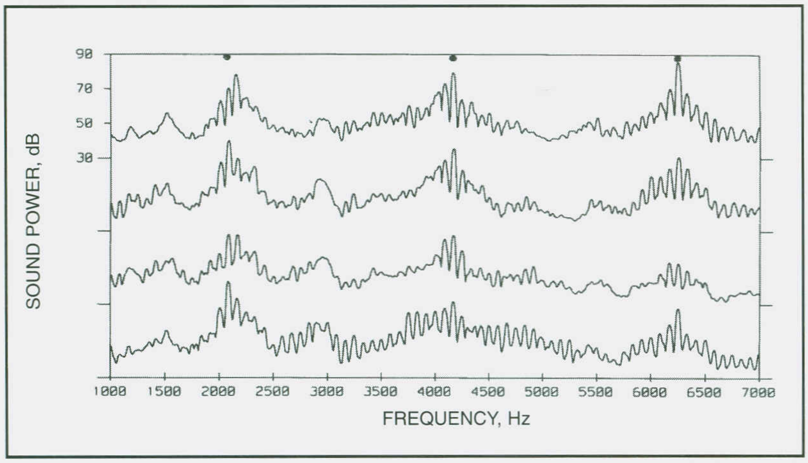

Fig. 4 — Spectra for spur gears (from bottom, Configurations 1, 2, 7, 8) at 100% speed, 100% torque.

Noise measurements from the gearbox sides were not attempted for the following reasons: (1) the top is not as stiff as the sides; thus, noise radiation from the top dominates at most frequencies; (2) the number of measurement locations were reduced; and (3) shafting and other projections made such measurements difficult.

Sound power measurements were made over a matrix of nine test conditions: 3 speeds (60, 80 and 100% of 5000 rpm) and at 3 torque levels (60, 80 and 100% of the reference torque 256 N-m (2269 in-lb)). During each intensity scan, the speed was held to within ±5 rpm and torque to ±2 N-m. At least five complete sets of scans were performed on each gear set.

Acoustic intensity data were recorded over the bandwidth 896-7296 Hz. On the 801-line analyzer, this produced a line spacing of 8 Hz. We chose this frequency range because it includes the first three harmonics of gear meshing frequency for the speed range (3000–5000 rpm).

Processing Sound Power Data. The sound power data captured by the method outlined above consists of many data files of sound power spectra. Sample spectra for the four spur gear configurations are shown in Fig. 4, and spectra for the five helical gear configurations in Fig. 5. Each spectrum includes the first three harmonics of gear mesh frequency. The harmonic frequencies are marked with a "•" on the top border. Each harmonic is surrounded by several sidebands. The most prominent sidebands were related to the pinion shaft frequency. Gear shaft sidebands were not prominent.

To characterize the measurements, we decided to reduce each 801-line sound power spectrum to a few numbers that would represent the gear mesh noise. We call these numbers the harmonic sound power levels.

We considered five methods for determining the sound power level.

(1) Record only the value at the mesh frequency harmonic. This means to ignore sidebands even though they were often significant.

(2) Check the harmonic frequency and several sidebands and record the highest value.

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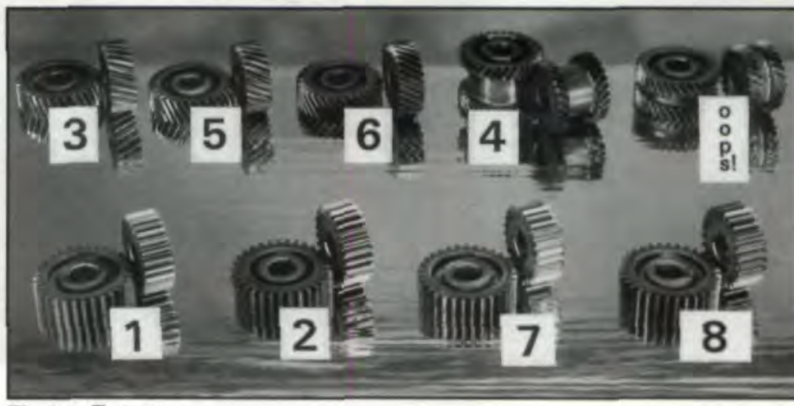
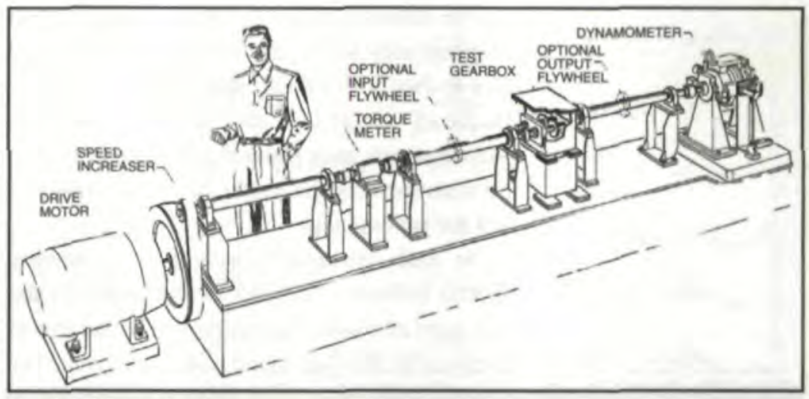


Fig. 1 — Test gears.



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convert back to watts.) The confidence limit was calculated from

$$C_1 = t(\delta/\sqrt{n})$$

where

C_1 = confidence limit, dB
t = probability distribution ("Student t" distribution)
δ = standard deviation of data, dB
n = number of samples (typically 5)

Values for the "t" distribution can be found in any standard statistics text. We chose a 95% con-

standards. The overall accuracy of the gears was consistent with production helicopter gears of similar size and configuration. The variation between the sets of gears is reasonably typical of normal production for gears in the same manufacturing lot. Lot-to-lot variations (not tested here) may be higher, but the overall trend of the effect should be about the same.

A large difference in noise level is sometimes observed on production gearboxes simply as a

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Noise measurements from the gearbox sides

result of rebuilding them after disassembly for inspection, even though no parts were changed. Considering this effect, in addition to the manufacturing variability checks, we also checked for variability due to disassembly and reassembly.

We checked for variability by testing three "builds" of the first gear set. Each build used exactly the same parts, and each was accomplished by the same technician using the same tools and parts.

Results

A very large amount of data was collected during this test program. An overview is presented in the composite noise level bar charts of Figs. 7–8.

Spur Gears. We tested gears with both involute and noninvolute tooth forms and with both standard and high profile contact ratios. Though the noise levels (Fig. 7) generally increased with speed, in general, the high contact ratio spur gears (Configs. 2, 8) were 2 dB quieter than the standard contact ratio gears (Configs. 1,7) regardless of the tooth form. Similarly, the involute tooth form gears (Configs. 1, 2) were quieter (by 3–4 dB) than their noninvolute counterparts (Configs. 7, 8).

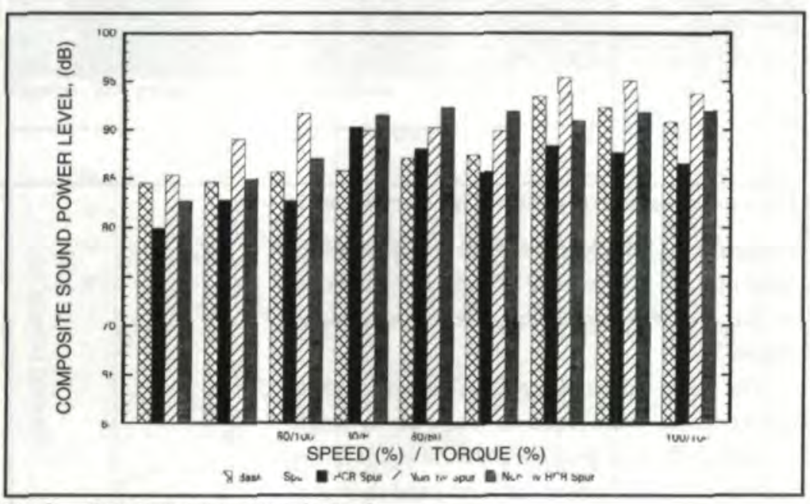

Fig. 7 — Spur gear composite noise levels.

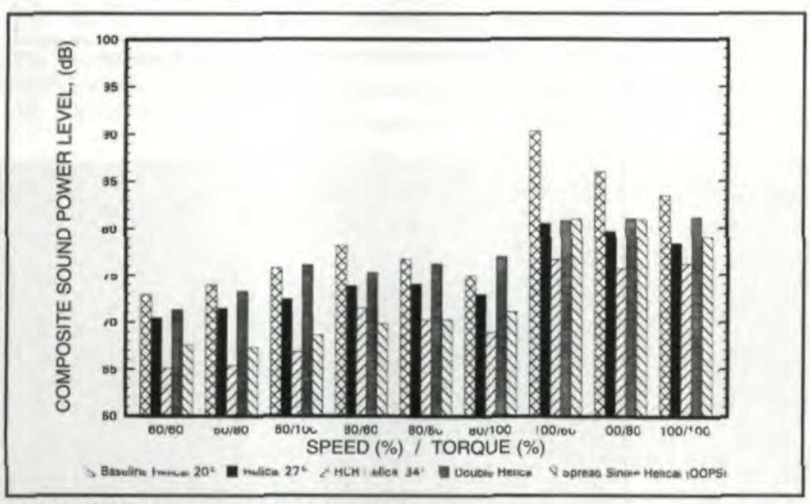

Fig. 8 — Helical gear composite noise levels.

Helical Gears. The single helical gears include three different helix angles and both standard and high profile contact ratios. As in the spur gears, an increase in the contact ratio correlates with a decrease in the noise level. Increasing the face contact ratio from about 1.15 (Config. 3) to 1.6 (Config. 5) decreases the noise level substantially in every case, though the results at higher speeds are more dramatic than at lower speeds. Also, at every operating condition, the composite noise level of a helical gear (Fig. 8) is less than the level for a spur gear with similar profile contact ratio.

The combination of high profile and high face contact ratio further decreases gear noise. Indeed, the high profile and high face contact ratio design (Config. 6) with profile and face contact ratios of 2.1 and 2.1 respectively was the lowest noise generator at almost every operating condition.

Helical gears used in helicopters tend to have relatively low face contact ratios (helix angles are kept low to minimize thrust loading and the extra weight associated with reacting to the thrust); thus, this result is especially interesting, since it suggests that it may be possible to trade off helix angle against increasing profile contact ratio to improve the noise level without the weight penalty associated with accomplishing the same reduction with helix angle alone.

A surprising result, the double helical gear set was noisier (by 4 dB on average) than its single helical (OOPS gear) counterpart. The OOPS gear set is essentially a single helical set with a gap in the middle of the tooth face. Its effective face contact ratio is similar to that of the high contact ratio helical gears (Config. 6).

The double helical phenomenon appears to be related to axial shuttling, which occurs as the double helical pinion moves to balance out the net thrust loading. The shuttling is due to the presence of small mismatches in the relative positions of the teeth on each helix. No matter how accurate the gear is, some mismatch will always be present; thus, this is an unavoidable phenomenon.

While the thrust balancing characteristic of a double helical gear is a valuable design feature, since it greatly simplifies the bearing system, a price is paid in terms of noise and vibration as the gear set shuttles back and forth.

Since the per helix face contact ratio, face width, profile contact ratio, etc. are identical for the OOPS and the double helical gear sets, the only operational difference is the lack of axial shuttling. The double helical set will be in a constant equilibrium-seeking state because of the theoretically zero net thrust load, while the OOPS gear set will run in a fixed axial position because of the net thrust load.

This test provides some insight into the magnitude of the noise penalty which is paid when double rather than equivalent single helical gears are used. Since these test gears are all very accurate (typical for helicopter gears), it should be obvious that a larger penalty would be paid if gears of lesser quality were to be used, because the lower the gear quality is, the more shuttling would be likely to occur.

Sample, Build & Specimen Variations. At least five sets of noise scans at each operating condition were taken. Our goal was to obtain confidence limits within 1 dB for each value of harmonic sound power level. This goal was met on about 60% of the test sets.

During other testing, the authors have noted significant variations in the measured (and perceived) noise level of the same gear system before and after disassembly. In some cases, this variation was of considerable magnitude. To investigate this phenomenon, the first set of baseline spur gears (Config. 1), was assembled, tested, disassembled, reassembled and then tested again. This process was repeated until the gears had been tested three times.

The largest minimum-to-maximum build variation was 7.8 dB (at the high speed, low torque condition), while the minimum build variation was 0.7 dB (at the medium speed condition). The average build variation was about 3 dB. While no real pattern is apparent, it appears that the variation decreased slightly with increasing load.

Since we tested two samples of each of the eight gear designs, we can compare the "build" variation to the variation between "identical" parts. For the eight gear designs, the average part-to-part variation in the composite noise levels was 2.8 dB. One would expect the variation between samples of the same part to equal or exceed the variation from rebuilding the same parts. The "build" test was performed at the beginning of the test program. Increased experience may have reduced the variation for later tests.

The factors considered above point out the difficulty in defining a noise reduction effort in that the variations due to unintended effects are often of the same order of magnitude as the changes which may be attributed to gear configuration or treatment. Such differences should exceed the variations due to sample and build effects and those observed among different specimens of the same part before they can be considered significant in themselves.

Conclusions

Nine different spur and helical gear designs were tested in the NASA gear-noise rig to compare the noise radiated from the gearbox top for the various gear designs. Sound power measurements were made under controlled conditions for a matrix of operating conditions. The following conclusions were made:

1. The most significant factor for noise reduction within a gear designer's control was the total contact ratio. Gear noise may be reduced by increasing either the profile or face contact ratio.

2. The noninvolute tooth form spur gears have a 3–4 dB noise penalty compared to their conventional involute counterparts.

3. The high contact ratio spur gears (with a 58% increase in profile contact ratio) showed an average noise reduction of about 2 dB over standard gears.

4. The noise level of double helical gears averaged about 4 dB higher than otherwise similar single helical gears.

5. In noise reduction tests, variation due to unintended effects, such as testing different part specimens or even reassembly with the same parts, may be of the same order of magnitude as the effect of deliberate design changes. ○

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CIRCLE 158

Automated Inspection Systems: The Whole Picture

Why The Sum of the Features Doesn't Always Add Up to the Whole Part.

Richard Jennings

No one (not even you and I) consistently makes parts with perfect form and dimensions, so we must be able to efficiently check size and shape at many stages in the manufacturing and assembly process to eliminate scrap and rework and improve processes and profits. Automated inspection systems, which are widely used in all kinds of manufacturing operations, provide great efficiencies in checking individual features, but may not be as effective when asked to evaluate an entire part. You need to know why this is true and what you can do to improve your part yields.

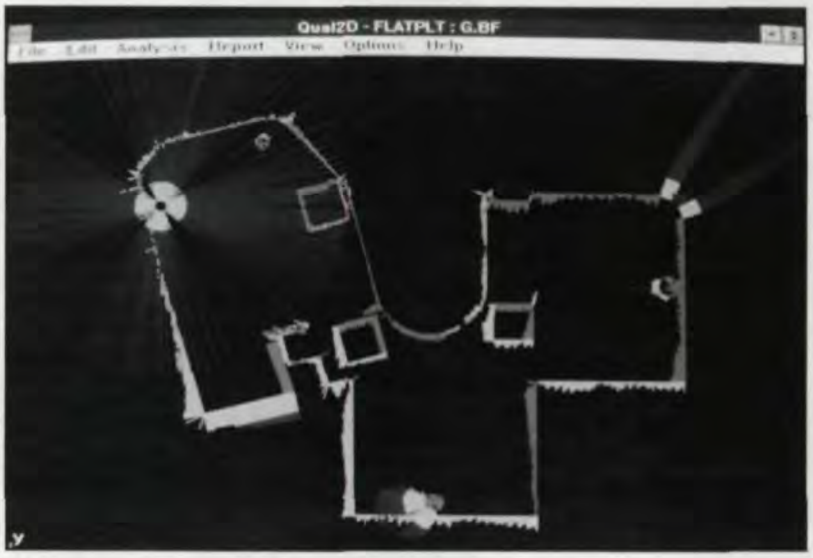
But, you ask, if all of the features are "good," doesn't that mean that the part passes? Not if you are measuring the size and shape of *individual part features,* expecting to learn whether or not the *entire part* passes or fails. Automated inspection systems measure individual features. But you don't make or buy features; you are interested, instead, in complete parts and assemblies.

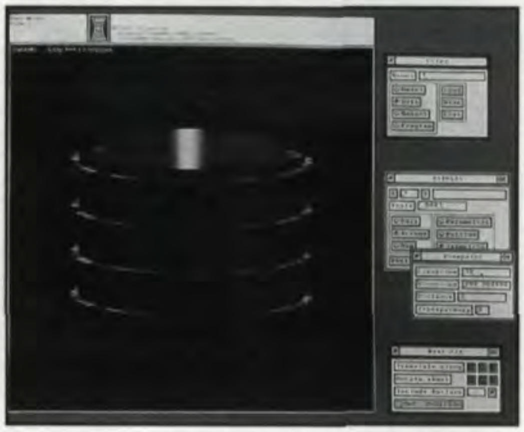
When you need to know if the part conforms to specified design criteria or whether it will fit in assembly, individual feature measurements are not sufficient.

You need a way to easily evaluate the entire part, all at one time. If you do 2-D inspection, your old reliable optical comparator will serve very nicely. You must put the proper profile chart on the comparator screen; then you put your part on the inspection stage, and you move and rotate ("wiggle and jiggle") the part until it fits between the "railroad" tracks on the comparator screen. You can see the results, and everyone lives happily ever after.

But the optical comparator has drawbacks too. It is relatively slow and labor intensive; results are subjective (two users may arrive at different conclusions for the same part); there is no way to quantify the dimensions of a single feature (diameter of a hole, width of a slot); and there is no permanent record (printed reports, computer files, etc.) for the inspection.

The automated inspection system (AIS) overcomes each of these shortcomings, but fails to duplicate the one capability which makes the comparator so powerful and easy to use—its ability to show at a glance if the complete part is within tolerance limits (contact probe systems fail this test as well). These systems can measure and report on individual part features (holes, slots, edges, etc.), but tell nothing about the acceptability of the complete part.





(Above) Fig. 1 — A part profile shown with an ICAMP template. 4500+ points were collected on this part, and each point is shown as a colored "whisker"; green (low) and yellow (high) whiskers show deviations from nominal. When whiskers turn to red, a user-set scale has been exceeded; the total length of each whisker is a multiple of the green/yellow segment. The scale can be set to the design tolerance for the part, so if red appears, the part fails. In this picture, the hole at the upper left was punched with an oversized tool. The hole at the bottom is oval-shaped (not circular) and shifted down and to the left. In both cases, the rays are in the red zone. The upper right section of the part does not match the model. Is it the wrong model or the wrong part?

(Left) Fig. 2 — A solid model of a shaft with data taken at four depths.

Measuring Perfect Features . . . Every Time

The problem is this: When measuring prismatic features (lines, arcs, circles, cylinders, cones, planes, etc.), automated inspection systems gather data on *real* features (geometry), but report on approximate or *substitute* geometry. If you remember your high school geometry and trigonometry, you know that the measurements (diameter, etc.) and computations (angle between

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two lines, etc.) you learned in those courses implicitly depend on *perfect* geometry—but no one ever made a perfect part to be measured.

And therein lies another problem.

When measuring prismatic features, the user first tells the inspection software what type of feature is being measured. Then he or she gathers data, and the software "constructs" the perfect (substitute) feature which most closely approximates the real feature in terms of dimensions and orientation. The software then compares the substitute feature to the ideal (nominal) feature and reports any differences between the two perfect features.

The inspection machine software measures perfect substitute features (or substitute geometry), **not** the real part, or even the real feature. If the actual feature is very close to the intended design, this approximation may provide acceptable measurements, but if the actual feature differs widely, then misleading results can be reported.

Once a substitute feature measurement (circle diameter, etc.) has been computed, the discrete point values that were collected on the real part are thrown away because there is no further use for them in the inspection system.

ALGORITHM TESTING & EVALUATION PROGRAM FOR COORDINATE MEASURING SYSTEMS (ATEP-CMS)

The National Institute of Standards and Technology (NIST) has established the ATEP-CMS Special Test Service to evaluate the performance of data analysis software embedded in coordinate measuring systems.

To do this, ATEP-CMS compares the output of the customer's software under test to predetermined corresponding reference values; the comparisons currently use orthogonal-distance, least-squares algorithms and support features such as circle, line, plane, sphere, cylinder, cone and taurus.

ATEP-CMS personnel work with customers to define the general guidelines for testing. NIST then provides to them a set of test data based on the guidelines. Then customers produce fit results for the data sets from their analysis software and sends them to NIST. ATEP-CMS processes the same data through reference alogorithms and compares the two sets of results and provides a comparison report to the customer.

The performance measures developed by ATEP-CMS quantify how well the software under test computes "substitute geometry" (see main article) over a range of inspection problems.

ATEP-CMS asserts that "there are no standards for testing and assessing the performance of dimensional metrology software" (NISTIR 5651), and this program is the first in the U.S. which provides traceability of data analysis results to an internationally recognized calibration body.

ATEP-CMS is addressing a portion of the problem described in the main body of this article; that is, it recognizes that CMMs measure perfect (single feature) substitute geometry, and their tests will determine how well the CMM software performs that role and helps the CMM user to understands what analysis algorithms are being used in the CMM. It is a first step in providing insight into analysis software behaviors and accuracy when compared to applicable standards.

Technical contacts at ATEP-CMS are Cathleen Diaz Pluguez at 301-975-2889 and Craig Shakarji at 301-975-3545.

MIMETEK is developing a complimentary rapid response system, 2nd Opinion™, for online periodic performance verification after the user, working with ATEP-CMS, understands algorithm behavior and output. For more information on MIMETEK's 2nd Opinion™, call 860-643-1711 or visit their Web site at *www.mimetek.com.*

Measuring, Sort Of, Against ASME Y14.5M-1994, The GD&T Standard

Most automated inspection systems generate at least some measurements that do **not** conform to ASME Y14.5M-1994, "Geometrical Dimensioning and Tolerancing Standard," and its predecessors. For years, users, if they thought about it at all, assumed that their inspection equipment complied with the measurement definitions in Y14.5M.

In August, 1988, a GIDEP (Government-Industry Data Exchange Program) Alert Message disclosed that large numbers of automated inspection systems were failing good parts and passing bad parts when the dimensioning and tolerancing standard was used as the measurement criterion. Hard gage advocates could say, "We told you so!"

Should You Worry?

So long as you are comfortable with the knowledge that:

1) Automated inspection systems measure *features, not parts*;

2) The features that are measured are *not* even the real features;

3) The reported feature measurements are not based on the Y14.5M; then you may not need to worry about how inspection data is being used in your company or in your customer's in-coming inspection areas. Bear in mind that virtually all inspection systems, with one or two very high-end exceptions, share these three characteristics.

If you are not comfortable with this situation, you will want to rethink your inspection functions, processes and architecture.

AIS Architecture

Let's look at the architecture of an automated inspection system. For our purposes, we can think of these systems as having three components:

a) A motion control subsystem that moves the sensor around the part,

b) A data acquisition subsystem that registers point readings from the part surfaces,

c) A *software subsystem which computes the* measurements, performs the analysis and creates the reports that users see.

The three problems that we have highlighted all fall under (c).

Motion control (a) and data acquisition (b) are so closely intertwined that they must share the same software operating platform, but discrete point values are passed from (b) to (c) for processing, and the measurement and reporting software can actually reside on a separate computer and even be at a distance from the inspection system. If the discrete data points can be transferred to another computer as they are taken, then third-party software can be used for measurement, analysis and reporting. This means that the AIS becomes an automated data acquisition system, and users can evaluate and analyze data *independently* of the vendor's software.

Moving Data Analysis Off the AIS

Of course, this is never as easy as it sounds. Not every vendor wants to lose control of the analysis, measurement and reporting of the status of the measured part, nor will he make it easy to extract point measurements from his systems. It may require sustained customer pressure to persuade vendors to add or reveal the procedures to support data transfer.

All inspection systems (touch trigger probe, electrostatic probe, laser, video), somewhere deep down inside, are acquiring point readings and using them in computations, and the software on the AIS can be modified to output those values.

Individual data points can be written to a file on the AIS hard disk or on a floppy disk, or individual points can be sent as they are taken through a serial port to another computer. While data files are most easily transferred and translated when in ASCII format, a variety of formats are supported.

Once We Have The Data, What Do We Do With It?

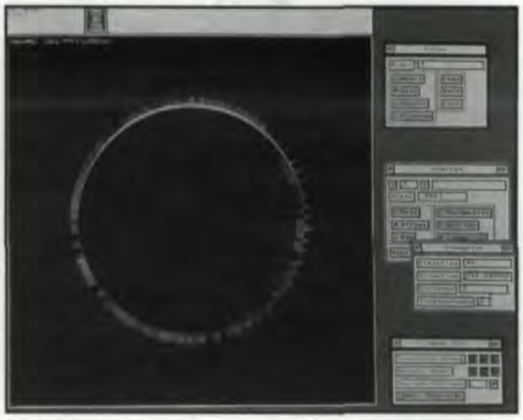
We started this article with the question, "Wouldn't it be nice if an automated inspection system could behave like an optical comparator?" Thanks to several inspection vendors who are adding more measurement and evaluation tools to their product lines, we are arriving at that point.

While their part programming software is more widely used, the following companies offer some analysis: Automation Software (PC-DMIS); Origin; and Technomatix (ROBCAD and Valisys). At least two inspection companies, Carl Zeiss and Leitz (Brown & Sharpe) have developed their own analytical capabilities for prismatic parts.

Ely Software for 2-D (through Metronics and OGP) offers dedicated contour software; Mitutoyo is reported ready to introduce a dedicated contour package; and ICAMP (2-D and 3-D) provides 3-D profile analysis such as Sheffield's DirectAnalysis and supports video systems such as Micro-Vu RAM Optical and View Engineering with its 2-D TEMPLATE analysis. ICAMP also supports "independent distributed analysis" with articulated arm digitizers from Faro and Romer, contract probe systems from Mitutoyo and Sheffield, laser and video systems and any device which can output point readings in ASCII format.

Benefits

There are some very real benefits which flow from the use of independent analysis software.



(Left) Fig. 3 — Looking down the long axis of the shaft, the data at the four levels is shown in one plane, and the deviations show that the shaft is tilted relative to its Z axis. Yellow whiskers turning to red (lower left) indicate that the shaft is larger than nominal on one side; on the opposite side of the shaft, (right in photo) blue whiskers indicate that the shaft is smaller than nominal at one depth, and yellow whiskers indicate that the shaft is larger than nominal at another height. This configuration is sometimes called the "banana" shape.

1) It can be performed anywhere—on the shop floor, at your desk or at your customer's facilities.

2) Moving analysis off-machine frees the inspection system to measure more parts faster.

3) Part programming can be reduced as more emphasis is placed on the part rather than on the feature measurement and analysis.

4) Single features, multiple features and/or the entire part can be simultaneously evaluated.

5) The actual features, not substitute features, can be measured and evaluated.

6) Measurements based on Y14.5M-1994, the GD&T standard, can be processed correctly.

7) Independent software can be easily verified by NIST and other certification agencies.

8) Independent, stand-alone analysis can work with machine tool probes as well as CMMs.

9) Finally, the inspection vendors, all relatively small operations compared to their customers, will be able to concentrate their software development efforts on better positioning accuracy, resolution and data acquisition rather than on measurement and analysis.

For several years, inspection departments have successfully pushed for the development of off-line inspection programming tools. Now, as the customers (the rest of the corporation) better understand what inspection equipment can and cannot do, we expect to see increasing demand for independent measurement and analysis performed remotely from the inspection station.

This will lead to AISs being used as data acquisition devices which are linked through networks to design and manufacturing engineering workstations and manufacturing planning systems where sophisticated, but simpler profile analysis can be used to evaluate both part and process condition. This, in turn, will lead to simpler, cheaper, modular general purpose inspection devices and standardized analysis software and reporting formats. We will see more accurate, better understood measurements and, in turn, this will lead to better controlled processes and products.

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Production Increase When Hobbing with Carbide Hobs

LMT-Fette

STEERING PINION		
DP	**13.02556**	
No. of Teeth	8	
Helix Angle	13°	
Pressure Angle	20°	
Gear Width	1.039 inches	
Gear O.D.	.779 inches	
Tool	**HSS**	**Solid Carbide**
Dry/Wet	Coolant	Dry
O.D.	1.771 inches	1.771 inches
No. of Starts/No. of Gashes	1/11	1/11
LOC/Shift/Distance	4.606/4.015 inches	4.606/4.015 inches
Resharpenings/Tool Life	10/1686	10/2529
Technology		
Axial Travel	1.669 inches	1.669 inches
Surface Speed	85	320
Hob RPM	600	2260
Feed Rate	.035 inches	.035 inches
Time		
Main Time	.59 minutes	.16 minutes
Idle Time	.17 minutes	.17 minutes
Time/Piece	.76 minutes	.33 minutes
Costs		
New Hob	$987.65	$2,222.22
Per Regrind	61.72	216.04
Tool Costs/Piece	0.86	1.60
Machine/Hour	55.55	0.16
Machine Cost/Piece	0.70	0.31
Piece Part Cost	0.79	0.47
Hobs Produced/HR	63	145

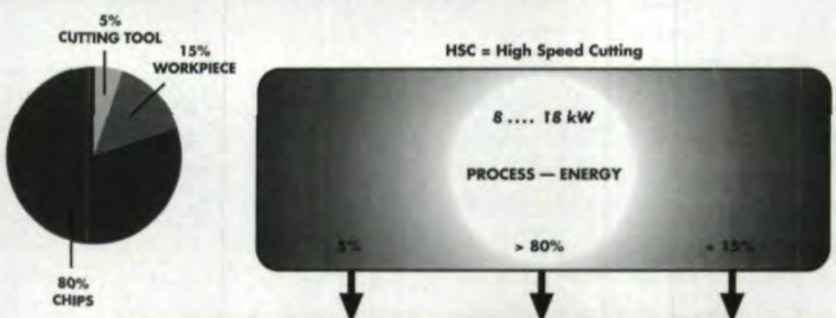
Table 1

We are all looking for ways to increase production without sacrificing quality. One of the most cost-effective ways is by improving the substrate material of your hob. Solid carbide hobs are widely used in many applications throughout the world. LMT-Fette was the first to demonstrate the use of solid carbide hobs in 1993 on modern high-speed carbide (HSC) hobbing machines. Since then the process of dry hobbing has been continuously improving through research and product testing. Dry hobbing is proving to be successful in the gear cutting industry as sales for dry hobbing machines have steadily been rising along with the dramatic increase in sales of solid carbide hobs.

Dry hobbing presents an advantage in itself as the oil does not have to be separated from the chips prior to disposal. Combining this advantage with the performance of solid carbide hobs will significantly increase surface speeds. The user will experience an increase in production, more available uptime for machining and a reduction in manufacturing costs. Examples for dry hobbing three separate gears are shown in Tables 1–3.

Solid carbide hobs are used primarily in machining gears and pinions in a range of 55–6.5 D.P. The design of the carbide hob consists of a solid carbide blank with bore and face drive slots.

HIGH SPEED — DRY HOBBING



	CUTTING TOOL	CHIPS	WORKPIECE
Temperature	approx. 140° to 212°F	approx. 932° to 1652°F	approx. 86° to 176°F
Effects	• Increased wear	• Chips too thin, red hot • Machine warms up	• Geometrical changes during hobbing
Measures	• Shift cycle • Coating is insulating factor	• Chip thickness according to hob design • Thermo-symm. Machine	• CNC corrections during hobbing

Fig. 1

LMT-Fette

LMT-Fette, Ohio, is a subsidiary of Wilhelm Fette GmbH. LMT-Fette offers an extensive line of custom design hobs manufactured to meet customer specifications.

Blanks can be produced up to 6" without any difficulty. A variety of smaller hobs can be manufactured with their shanks incorporated into a one-piece design. The configuration of the cutting tool depends mainly on the data of the gear to be machined and the desired chip thickness.

When dry hobbing first came into use, the majority of hobs were made from ISO 513 specified K grade carbide. This substrate has a tendency to cause chips to stick on the surface after the TiN coating has worn down. Since this substrate material cannot be used without a coated surface during dry machining, manufacturers have begun using the traditional P grades. P grades combine wear resistance characteristics with increased toughness, allowing higher surface speeds and increased tool life. New carbide grades and coatings are continually being developed which will provide longer tool life and an even more economic machining process (Chart 1, p. 22).

The cutting edges of a hob can reach temperatures up to 1700°F, causing scaling of the coated surface. In order to reduce scaling of the coated surface, leaving the substrate unprotected, four different coatings have been tested and proven acceptable (Chart 2, p. 22). According to ISO Standard 513, a good adhesion of the coating is of great importance, especially on the K grades. P grades however, require only one coating after the tool is produced. The tool can then remain in production even after it has been resharpened, and the coating on the flute face has been removed.

When all cutting parameters are specified correctly, 80% of the heat generated will be extracted directly into the chips (Fig. 1). During dry hobbing, tool wear occurs mainly on the relief side (flanks), unlike the case with high speed steel hobs, where the wear occurs primarily on the flute face. Special attention must be paid to possible *chipping on the cutting edge when the coating* surface is worn off. This is especially noticeable when using K grades. The abrasive wear on the substrate material is severe.

Without the protection of a coating, the edge wear increases as chips stick on the cutting edge. Edge wear needs to be monitored closely, as a rapid increase in wear occurs after approximately .009". As a general rule, carbide hobs should be resharpened prior to reaching an edge wear maximum of .006" (Fig. 2, p. 22).

The practice of dry hobbing has become common in many areas of the gear industry. Cost factors are greatly reduced by the elimination of the use of coolants and by eliminating the need to separate oil from chips. The primary savings gained from dry hobbing results from high

PLANET GEAR	
DP	**16.93**
No. of Teeth	15
Helix Angle	-23°
Pressure Angle	20°
Gear Width	.915 inches
Gear O.D.	1.1456 inches

Tool	**HSS**	**Solid Carbide**
Dry/Wet	Coolant	Dry
O.D.	2.362 inches	2.362 inches
No. of Starts/No. of Gashes	1/15	1/15
LOC/Shift/Distance	3.937/3.078 inches	3.937/3.078 inches
Resharpenings/Tool Life	10/1311	10/1966
Technology		
Axial Travel	1.740 inches	1.740 inches
Surface Speed	105	320
Hob RPM	560	1700
Feed Rate	.118 inches	.039 inches
Time		
Main Time	.35 minutes	.16 minutes
Idle Time	.07 minutes	.07 minutes
Time/Piece	.42 minutes	.25 minutes
Costs		
New Hob	$1,172.84	$2,962.96
Per Regrind	61.72	246.91
Tool Costs/Piece	0.12	0.25
Machine/Hour	55.55	55.55
Machine Cost/Piece	0.39	0.24
Piece Part Cost	0.52	0.48
Hobs Produced/HR	114	226

Table 2

SHIFT GEAR	
DP	**12.7**
No. of Teeth	31
Helix Angle	32°
Pressure Angle	16°
Gear Width	.71 inches
Gear O.D.	3.15 inches

Tool	**HSS**	**Solid Carbide**
Dry/Wet	Coolant	Dry
O.D.	3.54 inches	1.771 inches
No. of Starts/No. of Gashes	2/27	2/27
LOC/Shift/Distance	4.72/2.99 inches	4.72/2.99 inches
Resharpenings/Tool Life	8/994	10/1491
Technology		
Axial Travel	2.32 inches	2.32 inches
Surface Speed	95	320
Hob RPM	336	1131
Feed Rate	.160 inches	.140 inches
Time		
Main Time	.55 minutes	.21 seconds
Idle Time	.05 minutes	.05 seconds
Time/Piece	.60 minutes	.26 seconds
Costs		
New Hob	$1,481.48	$3,827.16
Per Regrind	61.73	246.91
Tool Costs/Piece	0.22	0.43
Machine/Hour	55.56	0.43
Machine Cost/Piece	0.55	0.24
Piece Part Cost	0.78	0.67
Hobs Produced/HR	80	200

Table 3

TOOL LIFE DURING DRY HOBBING

PIECE PART	HOB	CUTTING PARAMETERS
DP = 20 TEETH = 33 FACE WIDTH = .75 inches	SOLID CARBIDE GRADE P	VC = 300m/mm TOOL WEAR: max .004 inches

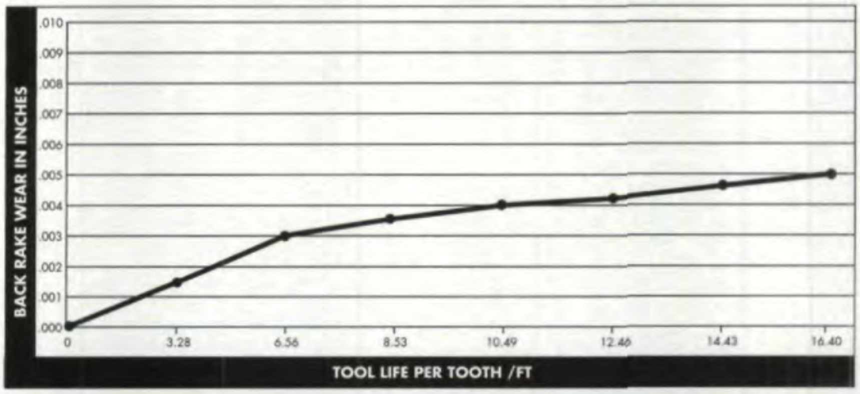


Fig. 2

Chart 1: Recommended Carbide Grades For Dry Hobbing

Carbide Grade	Chemistry of Carbide	Material to be Machined
P	WC TIC, Tac, NbC Co	• Long chip steel and cast steel components
K	WC Co	• Short chip cast iron and non-ferrous metals

Chart 2: Coatings

Coating	Microhardness by 20°	Advantages	Disadvantages
Ti (C,N)	3200HV	• Excellent wear resistance	• Increase of scaling above 752°F • Wear is noticable • Costly to recoat
(Ti, Al) N	2600HV	• High scaling resistance • Excellent wear resistance • Recoatable.	• Wear is noticeable • Reduced friction factor at the cutting surface with the risk of chip accumulation at the root
TiN	2200HV	• Moderate wear resistance • Recoatable • Wear is easliy recognizable due to coloring	• Increase of scaling above 932°F
LMT-Fette TiCN-Plus	N/A	• Excellent wear factor • Wear is easily recognizable due to coloring	• Increase of scaling above 932°F

Chart 3: Advantages & Disadvantages of Using Coolant

	Advantages	Disadvantages
Machine	• Chip transport	• Filtering units
	• Heat reduction	• Coolant pump
		• Coolant tank units
		• Additional use of electricity
Coolant		• Investment costs
		• Costs to separate oil from chips
		• Costs for stocking coolant
Environment		• Health risks
		• Dirty chips
		• Manufacturing and recycling problems
Machining Process		• Additional washing of piece parts

cutting speeds, which make the machining process much more economical than the traditional method of steel hobbing (Chart 3).

If the issue of chip separation from the oil is not a concern, then you can increase the tool life of a solid carbide hob by using oil as a coolant. The use of coolant will also have a significant influence on surface speed. Because of the high machining temperatures, the addition of coolant will create a thermal shock resulting in chipping of the cutting edges. When using a coolant in these conditions, surface speeds must be reduced to 800 to 850 sfm. Typical speeds for dry hobbing are in the 1100 sfm range.

Another new approach to optimizing tool life is using a minimum coolant supply of approximately one pint per hour. This procedure can still be considered "dry machining," as the piece parts and chips remain free of oil. Continued production increases utilizing the dry hobbing process can be obtained through improved carbide grades and new coating developments.

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Acknowledgment:

First presented at the International Gear Conference in Poznan, Poland, November 4–6, 1996.

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These courses are offered at ASM headquarters in Materials Park, OH. For more information, call 800-336-5152, x5613. Outside the U.S., call 440-338-5151, x5900. Fax 440-338-4634 or e-mail *mem-serv@po.asm-intl.org*. ASM's Web address is *www.asm-intl.org*.

PFAUTER-MAAG GEAR SCHOOLS

Pfauter-Maag Cutting Tools offers two gear courses, Basic Fundamentals and Advanced Gear Process Dynamics, at its facility in Loves Park, IL, several times throughout the year. The basic course, offered for those new to gear making, covers basic gear geometry, nomenclature, manufacturing and inspection. The advanced course is a three-day clinic on modern metal removal and measuring techniques for spur and helical gears.

Dates for the first half of the year are as follows:

Basic Course: **February 16–19, March 16–19, April 20–23, May 18–21, June 15–18.** Advanced Course: **April 28–30**.

For more information, contact Laurie Harshbarger at 815-282-3000, x313, fax 815-282-3075 or e-mail *sales@pfauter.com*.

April 26–May 1. Plastics Gearing Technology. The Product Design & Development Division of the Society of Plastics Engineers and the Plastics Steering Committee of the Emerging Technologies of AGMA is planning sessions on Plastics Gearing Technology to be held at **ANTEC '98** in Atlanta, GA. For more information, contact Andrea Knapp at SPE Headquarters, 203-740-5458 or fax 203-775-8490.

May 31–June 4. PM²TEC'98, The International Conference on Powder Metallurgy & Particulate Materials. Las Vegas, NV. Sponsored by the Metal Powder Industries Federation and APMI International. Technical sessions and poster presentations will report on new innovations in metal powders and advanced particulate materials, compaction technologies and processes, rapid prototyping, sintering, powder injection molding and more. For information, call MPIF at 609-452-7700, fax 609-987-8523 or log on to *www.mpif.org*.

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If you found this article of interest and/or useful, please circle **215**.

Beginning Gear Training

Gearing. An Industrial Training Course. The Salem Company, Woodstown, New Jersey, 1991.

Bob Moderow

Gearing is a self-training course for teaching the basic fundamentals of gears and gearing to those totally unfamiliar with the subject.

The study guide is broken down into eight sections, and each section has its own introduction, study material, self-study questions and answers and section summary. The framework of the book is quite good.

I especially liked the little historical introduction in each section, as it tends to make the subjects a bit more interesting and is a nice lead in to each topic. The summary at the end of each section is good, and the self-study questions and answers are very helpful, as they tend to make the student review and think more about what was covered.

However, the study material itself could use a little help. There are a number of errors, omissions and questionable definitions. For example, a pinion is defined this way: "A gear with a small number of teeth (under approximately 20 to 25 teeth) is called a *pinion*." Actually, a pinion is defined as being the smaller member of the two mating gears; therefore, a pinion can have any number of teeth. The correct definition is found on the next page of the book.

One self-study question includes the term "DP," but up to that point in the book, DP (Diametral Pitch) has not been defined.

When defining parts of gear teeth, such as addendum, whole depth, circular pitch, etc., the author should have included the abbreviations of the terms instead of adding them later in the book.

Two more serious errors: Pressure angle is not shown correctly in the drawings, and the author states that "circular pitch gears" are only used in old machinery, which is not the case. It also would have been helpful, in the course of the discussion, to point out why there are different PAs.

Whole depth (WD), is defined as whole depth = $\frac{2.157}{DP}$, but there are other proportions, such as WD = $\frac{2.25}{DP}$, WD = $\frac{2.35}{DP}$, etc., depending upon how the gear is manufactured.

Stub depth teeth are mentioned and covered nicely, but pointing out that stub teeth are stronger, but also noisier would have been helpful.

Fine pitch gears are defined as "smaller than 20 DP" This is correct, but the statement, "Those bigger than 16 DP can be called coarse pitch," is not. The dividing line between fine and coarse pitch gears is 20 DP.

The section on worm gearing is nicely done. It is difficult to explain linear and rotary motion on a two-dimensional drawing, and the author does it very well. In defining lead, the author states, "rhymes with reed." Very good!

However, the definition, "The angle of the [worm's] thread is called *lead angle* or *helix angle* is not correct. The helix angle is measured off the axis of the worm or gear, and the lead angle is measured off a line perpendicular to the axis. The helix angle is the complement of the lead angle. Helix angle = 90° minus the lead angle. The worm has a lead angle; the worm wheel has a helix angle.

In the "Helical Gears" section, it would have been better if the author had used TDP (Transverse Diametral Pitch) when calculating the pitch diameter of a helical gear, even if the TDP is an even number. This is common practice.

Other minor quibbles: When defining internal gears, only spur gears were mentioned: internal gears can also be helical. I also wish that when defining herringbone and double helical gears, the authors had explained why they are used.

A small "wish list" for the book would include a short explanation of compound gear ratios; an explanation of involute (the word was not found, which I found unimaginable when covering spur and helical parallel axis gears); and examples of typical gear drawings with gear data blocks included.

In spite of these shortcomings, I think *Gears* is an acceptable effort on a very complicated subject. The section on torque was done very well. The drawings throughout are clear, understandable and of good image quality. The material covered is very basic, but as the introduction states, it is a study guide for "beginners," "wanting to become familiar with industrial gearing."

I would recommend this book, (or sections of it) for initial training of people new to the gear industry. What is needed after *Gears* is a follow-up advanced study guide for specific types of gearing, where more necessary detail could be included. O

Bob Moderow
is a consultant and is in charge of gear training at Pfauter-Maag Cutting Tools, Loves Park, IL.

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For more information about Salem Publishing, please circle **214**.

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Dynacomp
ESDU International
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Hexagon
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Mech. & Struct. Design
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Thermal Capacity
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Web: *www .solid-dynamics.fr*
Titles: SDS

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U

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Titles: Engineering Tool Box, Hydro Pack, Unit Conversion System

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800-435-7887
Fax: 815-963-8884
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Web: *www.uts.com*
Titles: Gear Design & Mfg Software

V

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Fax: 319-277-4236

W

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CIRCLE 124
126-01S

Gear Teeth With Byte

Your guide to software for gear design, manufacturing and inspection.

William R. Stott

Computers are everywhere. It's gotten so that it's hard to find an employee who isn't using one in the course of his or her day—whether he be CEO or salesman, engineer or machinist. Everywhere you look, you find the familiar neutral-colored boxes and bright glowing screens. And despite the gear industry's traditional reluctance to embrace new technology, more and more of what you find on those screens are gears.

Most of you are probably aware of a few software programs out there which are designed for gears. Some of you may even have them. But the rest of you have probably scrambled and struggled and scratched out your own code to create routines that would enable you to perform the calculations required to design, manufacture and inspect gears.

You may be surprised to realize that there's a lot more gear-specific software out there than you knew about. It ranges in quality and ease of use, and it ranges in price. We've included as much information as possible in this article without making judgments about which is better. If any of you are interested, we hope you'll take the time to contact the companies directly and find out more about their products.

Who is Included?

The companies mentioned in this article all currently sell their software to the general public. A number of consultants, universities and others have gear design, analysis and manufacturing software which is available only to clients, customers or through other means.

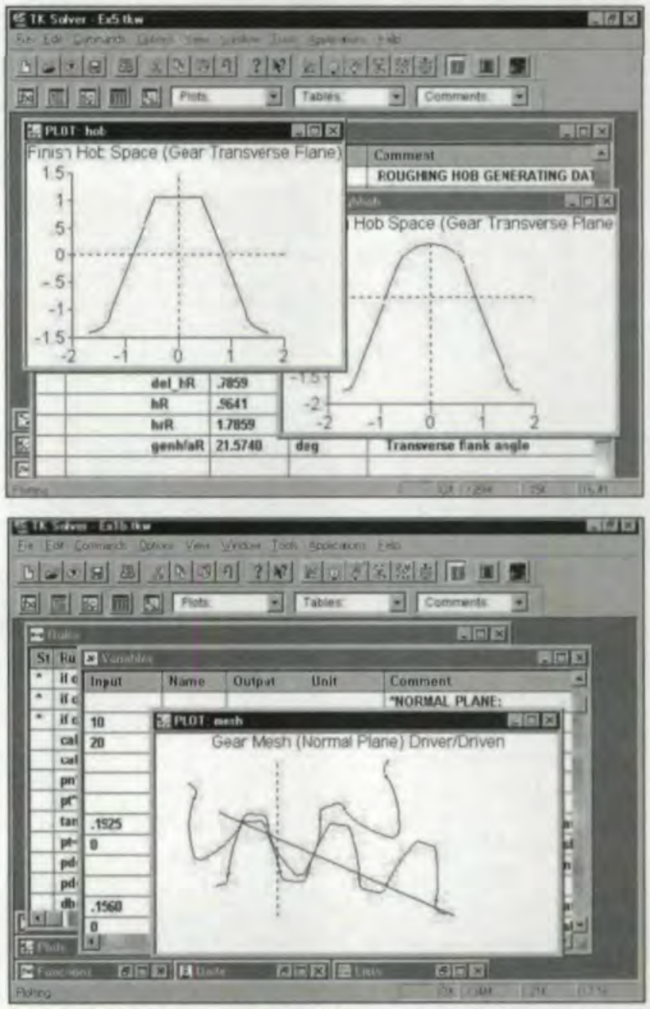
For example, the Gear Dynamics and Gear Noise Research Laboratory at Ohio State University has developed a *Load Distribution Program* and a variety of other computer programs. *LDP* computes the load distribution, root stresses and transmission error for helical and spur gears. However, the Ohio State software is available only to the companies that sponsor the gear lab.

Complete contact information for each company mentioned in this article is available in the 1998 Gear Industry Software Buyers Guide, which you can find on pgs. 26–31. In addition, this article can be found on ***The Gear Industry Home Page™*** at *www.geartechnology.com*. The online version will include hyperlinks to the Web sites of companies who have them.

Unless otherwise noted, all software mentioned in this article runs on DOS-based PC computers.

Manufacturing Software

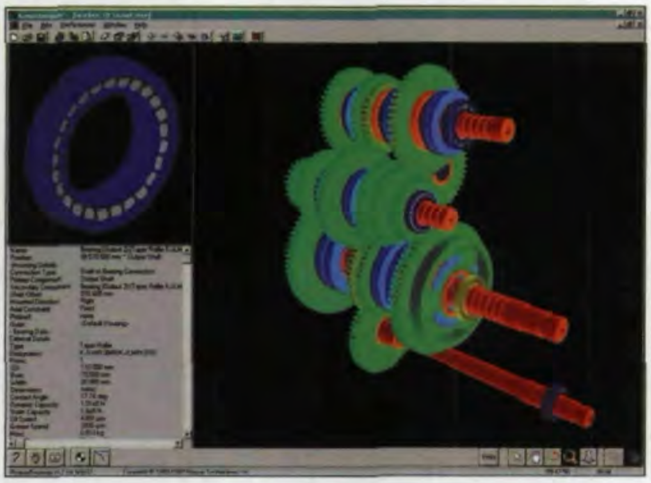
Software for gear manufacturing falls into two very broad categories: general shop management and gear-specific production and inspection software.



Universal Technical Systems now offers its programs for the Windows environment. Above: *Program 60-411, Hob Cutting Pattern for External Involute Gear* (top) and *Program 60-400, External Gear Line of Action Tooth Plot* (bottom).

General shop management software includes very comprehensive factory floor software that would be useful in any medium- to high-volume manufacturing environment. These systems can tie together the usually separate functions of accounting, administration, engineering and production. Some will hook right up to your machine tools or tie in to a jobbing bar code system so that the salesman or manager in the corner office knows exactly where a particular part is in the production cycle.

This type of software allows management to keep track of people, machines and materials to shorten production times, reduce inventory and cut costs. Some packages are geared toward statistical process control and



Romax Technologies offers its *RomaxDesigner* software for solid modelling of power transmission systems. Separate windows for the model and the design data allow the user to see instantly the changes made. *RomaxDesigner* includes modules for bearings, gears, power takeoffs, belt & chain drives and differentials.

will provide all the documentation required for compliance with ISO 9000 or other standards. Others are geared toward cost estimation and production cycle times. Some will combine these functions with billing, shipping, purchasing and other functions to provide a "manufacturing central," from which the entire operation can be run.

Examples of this type of software come from Alliance Manufacturing Software, BizSoft Corp., DataNet Quality Systems, Job-Boss Software, Micro Esti-mating Systems and many other manufacturers. Prices range from around $5,000 to $25,000 or more, depending on the complexity of the system and the number of connections or users.

There is also a great variety of shop floor software available that is tailored more specifically for the gear manufacturer. Most packages are available through machine tool suppliers, or they have been written by people at individual gear shops to calculate machine setups, figure out the correct measurement over pins or wires for a particular gear or to determine the appropriate hob or shaper cutter to use to cut a gear.

American Pfauter, L.P. offers its *Hobtime®* software for estimating hobbing cycle times based on material, hardness, hob and machine type. The user can enter specifications on the gear he wants to cut, and the program will suggest the best hob from his inventory or recommend suitable hobs available from Pfauter-Maag Cutting Tools, L.P. In addition, the program will recommend appropriate speeds and feeds for the parts in question. The "Gear Assistant" function will translate tolerance values and/or class levels among AGMA, DIN and ISO standards. Cost: $249.95.

Ash Gear & Supply is the exclusive distributor of *CPC-HOB*, a program for determining hobbing machine setup for spur and helical gears on differential and nondifferential hobbing machines. The program keeps information on all of your hobs. The user enters gear specs to determine appropriate change gears and other setup information. Useful for determining setup when cutting unusual gear angles or when you don't have the change gears called for by your usual setup. Cost: $600.00.

Bourn & Koch Machine Tool Co. offers its *Gear Manufacturing Program*, which calculates index and feed gears for spur and helical gears using nondifferential hobbing machines. It also estimates production cutting times and provides measurement over pins. Cost: $495.00 for each index constant and feed constant.

Bourn & Koch's *Four Gear Ratio Program* determines specific four gear ratios using change gears from 20 to 100 teeth. The program will calculate the gear ratios with allowable programmed error, and it will produce a hard copy. Cost: $100.00.

Bourn & Koch's *Gear Size Measurement Program* is used to obtain the span measurement for specific tooth thickness tolerances of spur and helical gears and splines. The user can also enter the span measurement to obtain the tooth thickness, which can then be used to determine the measurement over pins. Cost: $495.00.

Finally, Bourn & Koch's *Production Estimating Program* estimates the production cycles for hobbing spur, helical and worm gears or for shaping spur and helical gears. Cost: $200.00.

GB Gear Shop Tools sells a suite of programs designed for use on the shop floor. *BOOK* is a computerized collection of basic gear manufacturing information and formulas. The program will determine recommended backlash by pitch, amount of oversize allowance for preshaving and index gears for some of the popular index constants. Cost $40.00.

HOBCYCLE, also from GB Gear Shop Tools, calculates the hobbing cycle and length of cut for approach, rough and finish operations. It can also be used to determine gear grinding cycles. Cost: $35.00.

HS-CALC will determine complete manufacturing data for a gear set operating on a non-standard center distance. Cost: $40.00.

One of GB's most popular programs is *DIFFERS*, according to owner Eugene Beson. This program calculates the required ratios to hob helical gears on nondifferential machines. Cost: $45.00.

R.H. Software sells a program called *Gear Professor*, which is used to calculate index gears and feed rates for nondifferential hobbing machines and change gears for differential hobbing machines. The *Gear Professor* also calculates internal and external measurements over pins. Cost: $95.00.

R.H. Software also makes custom accounting packages for gear manufacturers. Designed to run on workstation-level systems (but currently being reformatted for the Windows 95 platform), this software tracks shop time for billing and places parts in inventory for future use. Parts can be looked up by customer or by gear specs. Cost: Varies.

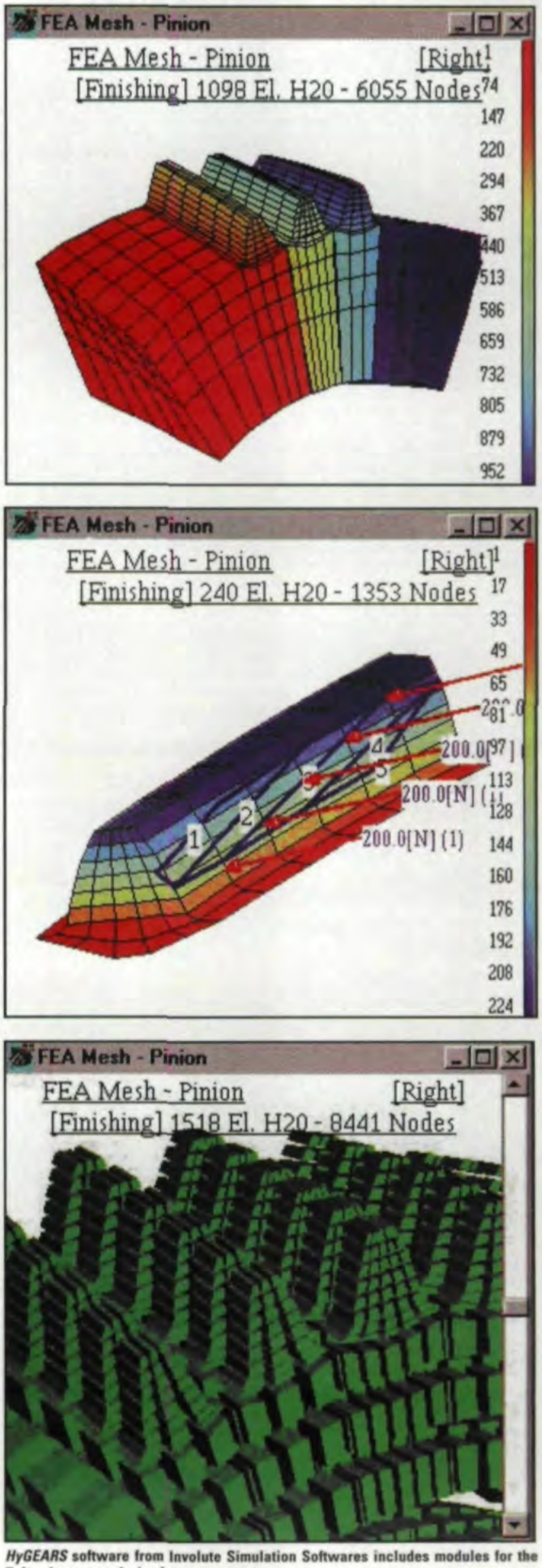
Software Engineering Service provides software that focuses on gear tool geometry, gear manufacturing and gear inspection. *HOBIT* software calculates change gear setups for hobbing machines or thread mills. It will find optimum helical setups for machines with or without differentials, and it comes with a library of popular machines. Cost: $250.00

Worrall Grinding Company's *WireSize version 1.2* calculates the size of wires for measurement of helical and spur gears with odd or even numbers of teeth. It uses the Zahorski long method so there is no need for tables, and it automatically calculates for backlash. Cost: $25.00.

Gear Geometry Software

Software for calculating gear geometry can be useful on many fronts. On the shop floor, it can provide important measurement data, such as the appropriate measurement over wires or pins. For the tool designer or engineer, the geometry can help determine the appropriate cutting tool for a particular part. Of course, the geometry of the gear is of obvious importance to the gear designer. Because many of the calculations are automated, this type of program saves time for any gear professional.

Ash Gear & Supply Co., a distributor of cutting tools, created the *GCP2 Gear Calculation Program* for its primary customer base of gear job shops. "If someone gives them a mystery gear, they can take some measurements and figure out all the specifications to make a new



HyGEARS **software from Involute Simulation Softwares includes modules for the finite element analysis of gears.**

one," says engineer Scott Atkinson.

GCP2 handles the geometry of external and internal spur and helical gears, worm gears, racks and straight-sided splines. It allows you to choose from six AGMA standard depth systems. Some of the calculations included are land at major diameter, base tooth thickness, apex of gear, operating pitch and pressure angles, long and short addendums and helix angle at any diameter.

GCP2 also has limited graphics capabilities. The user can press a key to view the space between two teeth to check for interference.

CIMLOGIC specializes in creating applications to be used within the popular AutoCAD system. *Power Transmission* streamlines the design and selection of cams, sprockets and gears within the AutoCAD environment. The user can specify gear requirements, including design diameter, surface speed, rpm, number of teeth and ratio, and the program will select and draw the gear based on AGMA standards.

Power Transmission can be used as a stand-alone or integrated with CIMLOGIC's *Toolbox* or *Toolbox Professional*, which are 2D and 3D geometry enhancement packages for AutoCAD. Cost: $495.00 for stand-alone; $1070 with *Toolbox*; $1340 with *Toolbox Professional*.

PC Enterprises offers its *GearShop for Windows* software, which will "design anything with an involute flank," says president Peter Conley. The program is a graphical gear design tool that animates gears in mesh to show whether there will be interference, backlash or undercut in the mesh.

GearShop for Windows will not calculate stresses or load factors for the gears, but it provides a complete geometry check of the gear train and creates DXF files for export to a CAD system.

The program is useful for fitting a gearbox in a particular space where shaft length and center distance are known, says Conley.

Software Engineering Service has two programs that calculate gear geometry. *GEARPACK* converts gear print information into manufacturing and inspection information—either for single gears or gear pairs. The program will calculate tooth thickness, over pins measurement, span measurement, general involute geometry, backlash, hob approach and overtravel. You can use this software to find the specs for replacement gears in old, worn or damaged machines when only the gear center distance and number of teeth are known. Cost: $265.00.

CONFORMS can be used to design your own hob or shaper cutter to generate any form, including spur, helical, worm, noninvolute forms, splines and ratchets. With *CONFORMS*, you can play back a generated form to get a direct comparison between the input form that you want and the generated form. You can also find potential interferences between mating gear teeth by comparing the theoretical form with the form actually generated. Cost: $500 for basic setup; $850 for a package that includes graphics, CAD transfer and other add-on modules.

Analysis Software

Several software providers have packages that are useful for determining the best gear for a given application. These packages analyze load distribution, bending strength, pitting resistance, thermal capacity, tribology or other factors affecting the potential life of individual gears or gear sets. Often, they are very specific and limited in scope.

COSMIC, the software technology transfer center for NASA, has been releasing computer software to the public for nearly 30 years. Hundreds of software packages developed and written at the NASA research centers around the country have been released over the years.

Most of the NASA software comes in source code format and is intended for a very specific purpose. "Much of it is research-oriented and often takes a large commitment in time on the part of the designer in order to be able to use it," says John J. Coy, chief of the mechanical components branch of the NASA Lewis Research Center. The Lewis Research Center is continually developing new codes for gear design and often uses industry experts for beta testing and development of the codes. Currently, the center is working on a helical gear dynamic analysis program, says Coy.

GRA—Geared Rotor Analyzer is designed to solve for the steady-state dynamic responses of multi-geared rotor systems. The algorithm includes an accurate gear-mesh model for spur and helical gears, a massless elastic shaft model and a linearly coupled fluid film bearing model. *GRA* is written in FORTRAN 77 to be machine independent, but has only been implemented on workstation or mainframe level machines. Cost: $500 within the U.S.; $1,000 outside the U.S.

DANST—Dynamic Analysis of Spur Gear Transmissions can be used for parametric studies to predict the effect on dynamic load and tooth bending stress for spur gears due to operating speed, torque, stiffness, damping, inertia and tooth profile.

DANST calculates the properties of system components and substitutes them into the governing equations to solve for dynamic tooth loads and tooth bending stresses. The model includes driving and driven gears, connecting shafts, motor and load. *DANST* allows users to choose from a variety of gear materials, basic gear geometries and operating conditions. Users can also choose from combinations of tooth profile variations and user-digitized profile modifications. It has been used only on workstation-level machines and requires additional commercially available graphics libraries. Cost: $500 within the U.S.; $1,000 outside the U.S. A PC version has been submitted to COSMIC and is currently undergoing testing and evaluation.

TLIFE—Spur, Helical and Spiral Bevel Transmission Life and Reliability Model estimates life, dynamic capacity and reliability of aircraft transmissions, enabling the optimization of transmissions during the design stage.

The analysis provided by the program is based on the two-parameter Weibull distribution lives of the component gears and bearings. Input and results can be formatted in either metric or English units. *TLIFE* has been successfully implemented on IBM-compatible PCs and UNIX workstations. Cost: $500 within the U.S.; $1,000 outside the U.S.

SBGTAPER—Tooth Contact Analysis of Face-Milled, Tapered Tooth Spiral Bevel Gears With Improved Geometry provides a new method for design and generation of spiral bevel gears of tapered teeth with localized bearing contact and low level of transmission errors. The program is an approach to detection and avoidance of vibration caused by misalignment and edge contact created by interference.

SBGTAPER is written for IBM PC-compatible computers and was released to COSMIC in 1997. Cost: $150 within the U.S. only.

Other NASA software related to gears, bearings and transmissions is available through COSMIC, and new titles will be released on an ongoing basis.

ESDU International produces "Data Items," which are comprehensive handbooks on a variety of engineering disciplines, compiled from the latest standards and field data. Most are presented as handbooks, but many are supplemented by computer programs. Data items are available on an annual subscription basis.

Dimensions, Deflections and Stresses for Hertzian Contacts under Combined Normal and Tangential Loading locates critical stress points on rolling bearings, cams and gears for failure prediction. Cost: $875 per volume per year, with a minimum order of $2675.

Solid Dynamics offers a software package for design, analysis, optimization and simulation of the motions and forces of 3D multibody mechanical systems. The *SDS/Gears* module analyzes spur and helical gears, pinions, racks and straight bevel gears.

The user can very quickly model normal backlash and positive or negative tooth shift. The program will calculate local shift on the tooth, specific sliding and relative sliding. Contact forces are calculated according to the Hertz theory. Cost: Contact Solid Dynamics.

Specialists

Much gear software has been written by experts in certain areas of gear design and manufacturing. Many of these experts have available software to perform very specialized tasks. While this software might not be useful to the average engineer who is creating traditional hobbed spur or helical gears, they can be of significant use to the right person.

ABA-PGT specializes in the manufacture of plastic injection molded gears. Their *Plastics Gearing* program enables the gear engineer to design spur or helical gears from any plastics material or any combination of plastics and metals. The software incorporates the "PGT" tooth form, which was developed specifically by ABA-PGT for plastic gears. Cost: $149.50 without manual; $179.50 with manual.

C-Dot Engineering is a consulting firm owned by Charles Dieterle, a former General Motors employee and spline design and manufacturing expert. Dieterle writes custom programs for splines and gears that determine design and durability based on the ANSI B92 spline standard. Cost: varies depending on customization.

Euro-Tech Corp. is the North American distributor of spline calculation software from Frenco. The Frenco software enables calculations of different parameters of spur & helical splines, including tooth thickness, space width, profile shift, dimension over pins, and radii at major and minor diameters. The software will calculate spline data according to ANSI 92.1 - 1970, DIN 5480 or ISO 4156. Demo versions are available at *www.frenco.de*.

Roberts Engineering & Design has software that has been in use since 1960. The software was originally developed to aid in the design and manufacturing of gear tools. The software will calculate all the geometry parameters for internal and external spur gears.

Roberts Engineering also specializes in software for designing, optimizing and manufacturing gear rotors. The software will generate DXF files for CAD systems or CNC output that can be used for wire EDM or CNC milling machines.

Trogetec Inc. specializes in trochoidal gear technologies. The Trogetec software emphasizes a quasi-cycloidal tooth form that allows highly precise positional accuracies for applications such as micro gearboxes or instrument gearing. Cost: Custom combinations quoted on request.

Trogetec also has some more traditional gear design and development packages. *INVOGEAR* includes 8 subprograms on involute gear design, specification and inspection. Cost: $195.00.

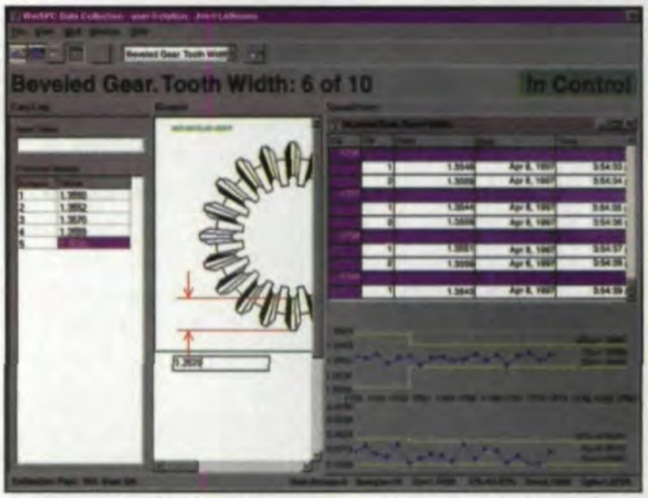
EZgearplot includes 5 subprograms on standard and special involute gears, non-involute gears, circles and polygons. Cost: $195.00.

Comprehensive Systems

Comprehensive gear design systems combine the functions of creating gear geometry with some or all of the analysis functions that help to optimize individual gears and gear sets. These systems create not only standard AGMA, DIN or ISO gears but also allow customization of tooth forms and provide the means to calculate load, life and wear characteristics based on materials, bending stress, contact stress, lubrication and more. These systems help not only design the gear, but design the best gear for the application.

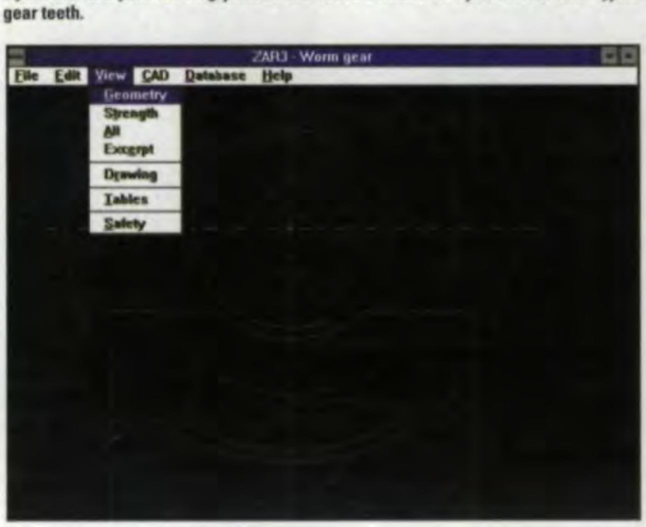
CIATEQ, A.C. produces the *diseng* gear design software as a tool for optimizing a gear or gearset for a particular application. Each gear parameter can be entered as a single explicit value or as a range of values, giving the user flexibility in defining a design problem. Along the way, the program offers extensive help for determining input values. For example, a subroutine assists the user in the initial sizing of the gears based on factors such as power, torque and speed.

Calculations are based on AGMA 2001-B88 and sup-



WinSPC **from DataNet Quality Systems allows tracking of parts for statistical process control.**

HyGEARS **analyzes bearing pattern and tooth contact for spiral bevel and hypoid gear teeth.**



ZAR3 Software for Worm Gear Calculation **calculates geometry and strength factors for worm gears.**

porting standards. The program automatically saves intermediate results so the user can compare between iterations made during the optimization process.

The data output by *diseng* gear design software includes all of the dimensional specifics for manufacture, along with a summary of loads, stresses, rated bending and surface fatigue lives and many other values.

The program runs under DOS, but an upgrade to Windows is in the works. A free demo demo disk is available, and a shareware version should be available soon via CIATEQ's Web site at *www.ciateq.mx*. Cost: $2,500 for commercial users; $1,500 for school and research users. Also, a fully-enabled demo is available for $500. This version stops working after five runs.

AGMA TO RELEASE ISO 6336 SOFTWARE

After years of work, the AGMA Computer Programming Committee is nearly ready to release a program for calculating gear ratings according to the recently approved ISO 6336 standard.

ISO 6336-Calculation of Load Capacity of Spur and Helical Gears was approved in 1996. The standard offers five methods, labeled A through E, for calculating the rating of a gear. The A method, based on actual measurements of the part, is the most reliable. The B method is based on theoretical values and the application of formulas to determine results (along with some measurement for certain factors). C, D and E are less exact methods for determining capacity.

Because of the large number of inputs and formulas and because of the choices in methodology, the new standard is definitely not for the beginning engineer, says AGMA's computer programming committee chairman Michael Antosiewicz of the Falk Corporation. In fact, without a computer to automate the calculation process, the standard is unwieldly for even the most experienced gear engineers, Antosiewicz says.

The computer programming committee created a program, which will operate in DOS or Windows environments, to allow the user to input data and perform the calculations required by ISO 6336.

For most of the gear ratings, the software will compute according to the B method of ISO 6336, which is the highest level of accuracy that can be computerized. Only the calculation of the load distribution factor uses the C method.

With the gear industry heading more and more toward global standards, the development of this computer program becomes extremely significant. The amount of time the program will save engineers is "exponential," says Antosiewicz. Manual calculation would probably cost more in engineers' time and effort than the program will cost itself, Antosiewicz says.

AGMA hopes to be able to distribute the program at prices that are readily affordable. Look for the ISO 6336 software to be released by early 1998.

Fairfield Manufacturing Company's *Gear Design Software* has been developed over the past 30 years from simple calculations designed to run on a mainframe system to the current version, which runs on a DOS-based PC.

Fairfield's *Gear Design Software* performs data, rating, stress and life calculations for spur, helical, bevel, planetary and spiral bevel gears. Calculations are based on AGMA 2001-B88 and publications of the Gleason Works. Other features include a quick pin-size routine and a two-bearing shaft routine to estimate bearing life.

While it may seem odd that a company manufacturing gears would sell one of its best design tools to its competitors, Fairfield has done so for some time.

"Back when we first offered this, gear engineering was still somewhat of a black art. Dudley and the others who were writing about gear design weren't giving anybody an easy way to perform all of these complex calculations," says Jim Dammon, VP of engineering. "So in the beginning, we kind of kept the software to ourselves."

But in the 1970s, the industry saw big companies laying off experienced workers, says Dammon. Many of these individuals started their own consulting firms and other sources of software became available. "Then it became to our advantage to go ahead and release it so that everybody could be speaking the same language," says Dammon. Cost: $850.

Gearsoft Design's GearCAD software is a graphical gear design tool for the development of spur and helical gears and gear sets, including options for adjustable addendum, nonstandard center distance, selectable backlash, tooth sizing and load checking.

The graphic display allows the user to zoom in to check for interference, and changing any of the gear parameters will cause the part to be redrawn instantly. Pressing a key will cause the gears to rotate in mesh. The display identifies pinion, gear, pitch circle, outside and inside diameters, root circle, base circle, trochoidal fillet, line of action and other parameters by different colors on the screen.

GearCAD comes with subwindows for cutter selection; preliminary estimation of tooth size, center distance and gear ratio; permissible load approximation; measuring roller calculation; and AGMA geometry factors J and I.

GearCAD also includes warning messages and help screens in case certain geometry parameters go outside permissible ranges. For example, interference between the tips of the pinion teeth and the internal gear teeth as the teeth go out of mesh, will bring up a warning message that tip interference is present.

Designs can be created and printed or saved to DXF or XY file format to export to CAD/CAM programs. The program comes with a detailed manual, including gear terminology, formulas used for calculation and examples of specific design problems and how they are solved using the software. Cost: $1130.

Geartech Software sells a trio of programs for designing and analyzing gears. *GearCalc* designs spur and helical gears for optimum surface durability and bending strength. *AGMA-218* calculates power ratings and tooth pitting and bending fatigue life ratings for gears. Although the program uses AGMA standard 218.01, which has been superseded by AGMA 2001-B88, developers say that the calculations are still acceptable for all gears except those made of Grade 3 carburized material. Finally, *Scoring+* analyzes the scoring and wear probabilities of a gear set.

Geartech's programs work closely in conjunction with one another. A single keystroke will take you from one to the next. For example, you could design a gear set with *GearCalc*, check to see that it will perform as required with *AGMA218*, and determine if there are likely to be any lubrication, scoring or wear problems with *Scoring+*. Cost: $2,490 for all three programs.

Hexagon Mechanical Engineering Software has developed several programs for designing and analyzing spur, helical, spiral bevel and worm gears. *ZAR1 Gearing Calculation Soft-ware* calculates geometry and strength of external and internal spur and helical gears with involute teeth in conformance with DIN 3960, 3961, 3967 and 3990. Once the user has entered pressure angle, helix angle, normal module and other gear parameters, *ZAR1* calculates the complete gear geometry, tool dimensions and contact ratio factors.

After the basic gear design has been calculated, the user can enter a gear quality level and tolerance zone to determine the final gear data, tooth thickness, backlash and measurements over balls or pins. In addition, *ZAR1* will calculate the load-bearing capacity with respect to tooth root fatigue, fracture and pitting. The *ZAR1+* option includes a database of materials. Otherwise, users can build their own database.

The graphic display of *ZAR1* draws the gear form on screen. Users can see the tooth form as generated by a simulation of the cutting tool action. In addition, the gears in mesh can be shown in animation. Cost: $1,060 per user without materials database; $1,180 with materials database.

ZAR2 Software for Spiral Bevel Gear Calculation uses the Klingelnberg method to calculates the dimensions of bevel gears with cyclopalloid teeth in accordance with The program incorporates safety margins against root fatigue fracture, pitting and corrosion in accordance with DIN 3991.

ZAR2 will calculate axial and radial forces during push/pull operations. These values can also be transferred to Hexagon's shaft calculation program *WL1*. Cost: $840 per user.

ZAR3 Software for Worm Gear Calculation calculates all the geometry and strength factors for worm gears. The strength calculation computes the fatigue fracture and pitting resistance along with tooth forces on the worm and worm gear. In addition, *ZAR3* calculates the efficiency of the gear set and provides recommended values and help graphics for determination of the tooth friction value. Cost: $430 per user.

***GearCAD* gear design software allows for output of gear designs in DXF or XY file formats.**

Hexagon Software has other engineering modules available. Package pricing and discounts for multiple users are available.

Involute Simulation Softwares produces the *HyGEARS* advanced gear modelling software for spiral bevel and hypoid gears, which has been used for two years in the Japanese and Korean automobile industry. Version 2.0, soon to be released, will also include support for spur and helical gears and planetary gear trains.

HyGEARS supports Fixed Setting, Spread Blade, Formate and Helixform spiral bevel and hypoid gear manufacturing processes. Modified Roll and Duplex Helical processes are under development for inclusion in the software. Spur and helical gear cutting processes include rack and pinion cutters.

In addition to the standard gear calculations for geometry and manufacturing, *HyGEARS* includes some advanced modelling and analysis functions. Tooth contact analysis and loaded tooth contact analysis can be calculated, and motion error curves and bearing patterns are used to evaluate the behavior of the gear set under no load or under a given load.

One of the more important applications of the *HyGEARS* software is the calculation of corrective machine settings to bring the machined tooth surface as close as possible to the designed tooth surface. The software will accept data from a coordinate measuring machine and display errors between theoretical and measured surfaces.

Another advanced feature of *HyGEARS* is finite element analysis for tooth and web/hub meshing, concentrated point loads, distributed constant loads and distributed linearly varying loads. The FEA model is based on the actual tooth definition from the inputted machine settings, and it can contain up to 3,000 elements and 15,000 nodes. Finite strip analysis is available for calculation of the bending deformation and stresses.

Involute Simulation Softwares will customize the program to match your existing equipment. Cost: $50,000 for a lifetime license.

Mechanical & Structural Design & Software produces a series of computer programs for gears and splines that will produce complete manufacturing and inspection data, stress analysis and life ratings.

Programs include packages for spur, helical, straight bevel, spiral bevel and hypoid gears. In addition, MSDS offers programs for simple epicyclic spur and helical gear trains, involute splines, roller bearings, threaded fasteners and helical compression springs.

The programs have very limited graphics capabilites. Cost: between $500 and $1000 per module.

Romax Technologies is a consulting firm in the field of mechanical power transmissions. Their *RomaxDesigner* software is made for transmission concept, design and analysis, and it includes a 3D solid modeller for gears and bearings.

RomaxDesigner allows simple design of multiple-pocket bearings; gears and bearings mounted on support shafts; split powers and power take-offs; CVTs, belts and chains; and planetary gears as differentials or range changers.

The software calculates load, life and speed ratings, offers dynamic simulation of gear shift behavior and includes a feature for calculation and design of gear cutting tools and calculation of cutter paths.

The 3D modeller allows the user to interactively rotate the transmission model in real time to view the design. The design data appears in a separate window on the same screen so that the user can make changes and see the results instantly. Cost: $41,950 for the *RomaxDesigner* Core Modeller; $51,950 includes a Gear Optimization Module.

Universal Technical Systems offers one of the most complete gear design software selections available. They have recently released their programs in Windows format. UTS has both stand-alone programs, such as their *Program #500* for external involute gear analysis, and various programs for gear calculation and design to be used with their *TK Solver* program for numerical problem-solving.

Program #500 is the main software available through UTS for external spur and helical gear design. The program, based on AGMA 908-B89, analyzes spur or helical gear sets to be sure that each gear will be compatible with its mate. *Program #500* will verify that your tools will be able to produce the gears. Also, the program computes the AGMA strength factor, J, and the AGMA durability factor, I. The basic program for hobbed gears costs $1,950. Other options include the basic program for shaper cut gears and options for the use of shaving cutters, calculation of specific sliding ratio, use of tip relief, topping or semi-topping hobs, J-factor balancing, fillet grinding, output to CAD/CAM, and an integrated tooling database. Cost for additional options ranges from $500 to $1,700 per option.

TK Solver allows the solving of complex formulas and problems on a PC. The display combines plots, formulas and text with charts, graphs and drawings, and the program allows you to output reports based on the results. *TK Solver* is fully customizable, and it can be set up to solve many gear design and manufacturing problems. Cost: $349.00.

Universal Technical Systems has more than 75 preprogrammed models to accompany *TK Solver*. *First Gear* is a model for determining preliminary design calculations for external spur and helical gears. *First Gear* will calculate dozens of design parameters for gear geometry, provide K and unit load factors, produce a plot of the teeth in mesh, and determine measurement over pins for the gear. Cost: $599.

Other *TK Solver* models include load stress & life analyses based on AGMA standards, spline geometry and machining, internal gear and shaper cutter design, and many other options. Cost: ranges from $50 to $1,200 per module.

UTS also offers bundles for certain types of gear manufacturing. Prices range from $3,000 to $25,000 per seat. For example, a complete plastic gear design and manufacturing bundle is available for $7,379.

Van Gerpen-Reece Engineering also has several software modules available for gear design and manufacturing. All together, the modules create a package that takes the gear from design through manufacturing and inspection.

The basic *Gear Design Program* calculates tooth beam strength factors, surface durability factors and all the dimensions required to manufacture the gears. The designer can create nonstandard gears with either standard or nonstandard tooling.

Additional modules available from Van Gerpen-Reece include cutting tool search programs that enable the user to locate the shaper cutters, shaver cutters and hobs that will generate the geometry of a gear designed with the *Gear Design Program*. A master gear module allows the user to determine a master gear that will satisfactorily mesh with and check a particular gear. Cost: Varies depending on the exact modules required. ○

IF YOU WOULD LIKE MORE INFORMATION ON ANY OF THE COMPANIES MENTIONED IN THIS ARTICLE, PLEASE SEE THE BUYERS GUIDE ON PAGES 26 – 31 FOR COMPLETE CONTACT INFORMATION.

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MITSUI MACHINE BECOMES IKEGAI DISTRIBUTOR

Mitsui Machine Technology, Inc. of Glendale Heights, IL, has been appointed by Ikegai Corp. as its exclusive U.S. and Canadian importer and distributor. Ikegai manufactures CNC chuckers and universal horizontal turning machines, CNC vertical turning machines, CNC vertical and horizontal machining centers, CNC horizontal boring mills, CNC vertical internal grinders and CNC gear hobbing and hob sharpening machines.

KILLOP NAMED MANAGER OF GENERAL BROACH SPLINE ROLLING DIVISION


"Tom" Killop

James Thomas "Tom" Killop has been appointed manager of the newly formed Spline Rolling Division of General Broach & Engineering Co., Inc. Killop will be responsible for developing and marketing of the company's new line of electromechanical driven spline rolling machinery and the design and manufacture of spline rolling rack tooling.

BISON GEAR WINS GRAND PRIZE

Bison Gear and Engineering of St. Charles, IL, was the Grand Prize Winner in the National Association of Manufacturers (NAM) Awards for Workforce Excellence competition for small manufacturers. The Bison TQM Team, whose work program was highlighted in Bison's entry, received the trophy and the $10,000 prize at a gala award dinner in Washington, D.C.

Bison's entry was based on the work of its Product Quality Team to assure customer satisfaction. The Product Quality Team operates as an integral part of Bison's Total Quality Management program. For the winning entry, Bison described the work of the team in reducing defects in the assembly process by 60%, resulting in improving the company's record for on-time deliveries and reducing the potential for products with defects reaching the customer.

The members of the team whose work won the award are Farouk Abushaaban, Nathan Kaminskas, Bing Olivares, Michael J. Zingen and Fred Fontana. Marty Kopp is Bison's TQM facilitator who coordinated the team's efforts.

PHILIP JAMES TO HEAD BROWN & SHARPE MEASURING SYSTEMS

Philip James has been named Group Vice President of Brown & Sharpe's Measuring Systems business. Mr. James will report to Frank T. Curtin, B & S's chairman, president and CEO, and will be responsible for managing the company's global Measuring Systems Groups which comprises Commercial Operations; Brown & Sharpe-USA; Leitz-Brown & Sharpe, Wetzlar, Germany; and DEA-Brown & Sharpe, Torino, Italy.

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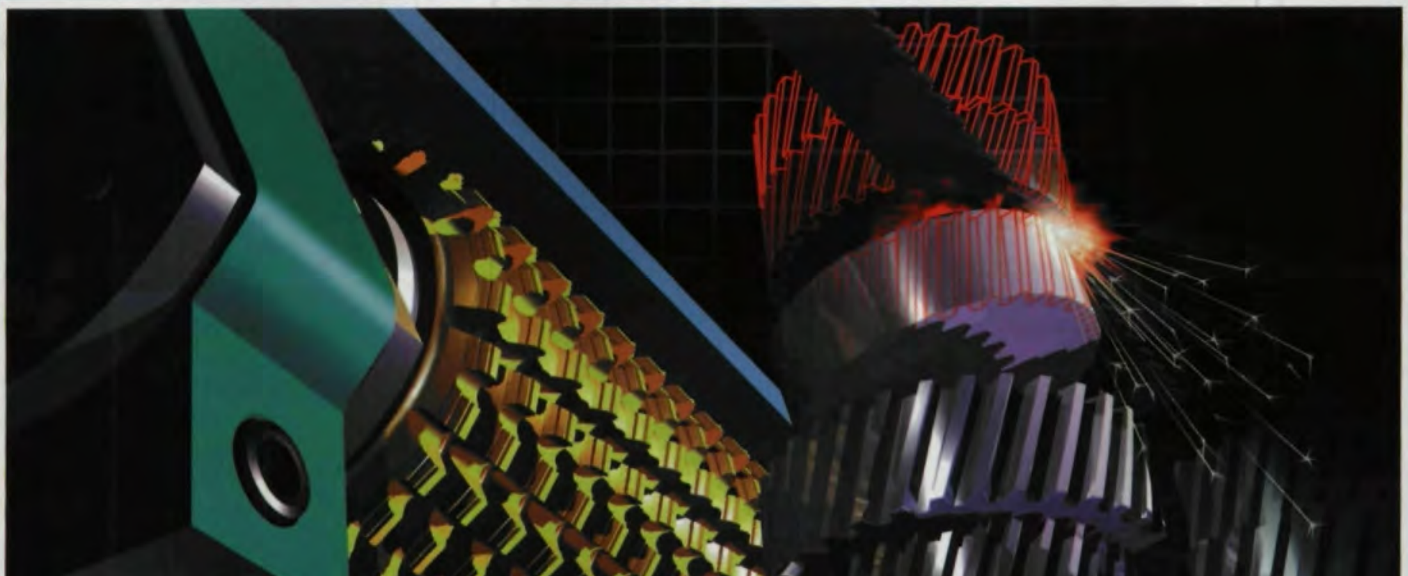

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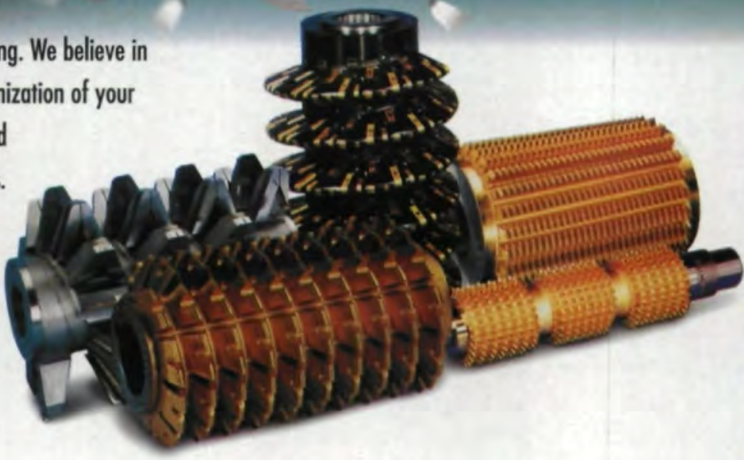

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CIRCLE 104

Gear Shaving Basics – Part II

Don Kosal

In our last issue, we covered the basic principles of gear shaving and preparation of parts for shaving. In this issue, we will cover shaving methods, design principles and cutter mounting technique.

Shaving Methods

There are four basic methods for rotary shaving external spur and helical gears: axial or conventional, diagonal, tangential or underpass and plunge. The principle difference between the various methods is the direction of reciprocation (traverse) of the work through and under the tool.

***Axial or Conventional*:** Axial shaving (Fig. 1) is widely used in low and medium production operations. It is the most economical method for shaving wide face width gears. In this method, the traverse path is along the axis of the work gear. The number of strokes may vary with the amount of stock to be removed. The length of traverse is determined by the face width of the work. For best results, the length of traverse should be approximately 1/16" greater than the face width of the work, allowing minimum overtravel at each end of the work face. In axial shaving, in order to induce lead crown (Fig. 2), it is necessary to rock the machine table by use of the built-in crowning mechanism.

***Diagonal*:** In diagonal shaving, the traverse path is at an angle to the gear axis (Fig. 3). Diagonal shaving is used primarily in medium and high production operations. This method can reduce shaving times by as much as 50%.

In diagonal shaving, the sum of the traverse angle and the crossed axes angle is limited to approximately 55° unless differential type serrations are used; otherwise, the serrations will track. The relative face widths of the gear and the shaving cutter have an important relationship with the diagonal traverse angle. A wide face width work gear and a narrow shaving cutter restrict the diagonal traverse to a small angle. Increasing the cutter face width permits an increase in the diagonal angle. The gear teeth can be crowned by rocking the machine table, provided the sum of the traverse angle and cross axes angle does not exceed 55°.

When using high diagonal angles, it is preferable to grind a reverse crown (hollow) in the lead of the shaving tool. In most cases, the diagonal traverse angle will vary from 30° to 60° to obtain optimum conditions of cutting speed and work gear quality.

With diagonal traverse shaving, the center line of the crossed axes is not restricted to a single position on the cutter, as it is in conventional shaving, but is migrated across the cutter face, evening out the wear. Consequently, cutter life is extended. Although conventional shaving requires a number of table strokes, each with its increment of upfeed, diagonal shaving of finer pitch gears may be done in just two strokes with no upfeed and a fixed center distance between cutter and work. An automatic upfeed mechanism on the shaving machine materially enlarges the scope of diagonal shaving by also making it available for multi-stroke operations. This device feeds the work into the cutter in a series of small increments, instead of two large increments, further increasing cutter life. It also makes the process feasible for gears requiring more stock removal than can be handled on a two-stroke cycle. When upfeed is completely automatic, there can be no danger of an error in selecting feed rates. Inasmuch as the cycle starts and stops in a position of maximum backlash, loading and unloading can be very fast.

Tangential or Underpass: In the tangential (underpass) method of shaving (Fig. 4), the traverse path of the work is perpendicular to its axis. Tangential shaving is used primarily in high production operations and is ideally suited for shaving gears with restricting shoulders.

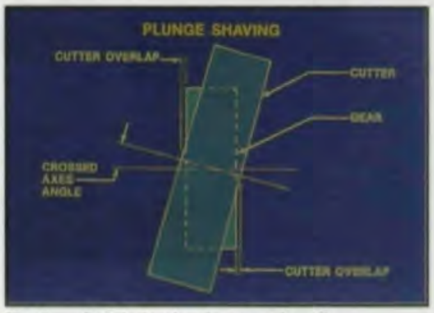

Fig. 1 — Axial shaving (conventional).

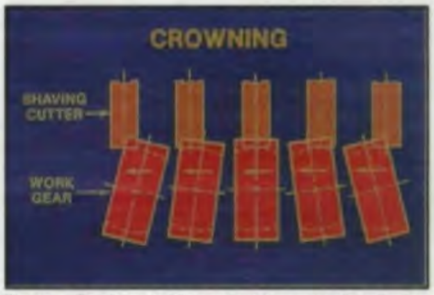

Fig. 2 — Rocking table action for crowning during conventional shaving.

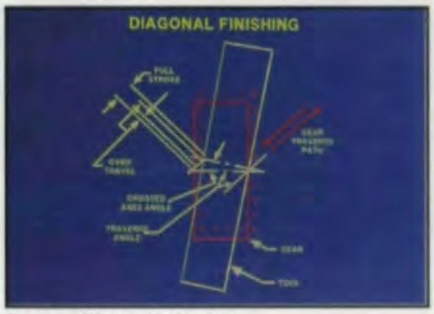

Fig. 3 — Diagonal shaving.

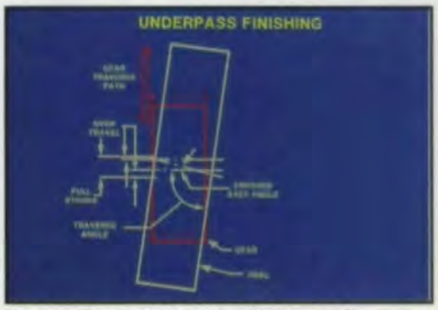

Fig. 4 — Tangential shaving (underpass).

When using this method, the serrations on the cutter must be of the differential type. Also, the face width of the cutter must be wider than that of the work gear.

Plunge: Plunge shaving (Fig. 5) is used in high production operations. In this method, the work gear is fed into the shaving cutter with no table reciprocation. The shaving cutter must have differential type serrations or cutting action will be impaired. To obtain a crowned lead on the work, a reverse crown or hollow must be ground into the shaving cutter lead. In all cases of plunge shaving, the face width of the shaving tool must be greater than that of the work gear. The primary advantage of plunge shaving is its very short cycle time.

Shaving Internal Gears

Internal gears can be shaved on special machines on which the work drives the cutter or by internal cutter head attachments on external shavers.

Because of the crossed-axes relationship between the cutter and the work gear in internal shaving, the cutter requires a slight amount of crown in the teeth to avoid interference with the work gear teeth. Crowning of the teeth on gears over 3/4" wide is best achieved by a rocking action of the work head similar to the rocking table action used in external gear shaving.

When internal gears are 3/4" wide or less, or when interference limits the work reciprocation and crossed-axes angle, plunge shaving can be used. In this method, the cutter has differential serrations and is plunge fed upward into the work. If lead crown is desired on the work gear, a reverse crowned cutter is used.

The Shaving Cutter

Rotary shaving cutters are high precision, hardened and ground, high speed steel generating tools held to Class "A" and "AA" tolerances in all their principle elements. The gashes in the shaving cutter extend the full length of the tooth, terminating in a clearance space at the bottom. These clearance spaces provide unrestricted channels for a constant flow of coolant to promptly dispose of chips. They also permit a uniform depth of serration penetration and increase cutter life.

The shaving cutter is rotated at high speeds up to 400 and more surface feet per minute. Feed is fine, and the tool contact zone is restricted. Cutter life depends on several factors: operating speed, feed, material and hardness of the work gear, its required tolerances, type of coolant and the size ratio of cutter to work gear.

Design

Rotary gear shaving cutters are designed in much the same manner as other helical involute gears. The serrations on the tooth profiles, in conjunction with the crossing of the axes of the cutter and the work gear, make it a cutting tool. In designing rotary gear shaving cutters, the following points must be considered:

- Normal diametral pitch and normal pressure angle must be the same as those of the gears to be shaved.
- Helix angle is chosen to give a desired crossed-axes angle between the cutter and work. The crossed-axis is the difference between the helix angle of the shaving cutter and the work gear. The desired range is from 5–15°.
- The number of teeth is chosen to give the required pitch diameter, considering helix angle and diametral pitch. Hunting tooth conditions and machine capacity are also important factors.
- Tooth thickness of the cutter is selected to provide for optimum operating conditions throughout the life of the tool.
- The addendum is always calculated so the shaving cutter will finish the gear *profile slightly below the lowest point of* contact with the mating gear. The tooth thickness and the addendum of the cutter are not necessarily given to the theoretical pitch diameter.
- Cutter serrations are lands and gashes in the involute profile of the tool. They extend from the top to the bottom of the tooth, clearing into a relief hole at its base. The width or size is determined by the work gear to be shaved. Differential serrations with a control lead are produced on shaving cutters used for plunge shaving and diagonal with the traverse angle over 55°.
- The involute profile of the shaving cutter tooth is not always a true involute. Very often, it must be modified to produce the desired involute form or modifications in the profile of the gears being shaved.

Sharpening Shaving Cutters

The shaving cutter, like other tools, dulls with use. In sharpening, minimum stock is removed on the tooth faces. With normal dullness, the resharpening operation usually reduces the tooth thickness approximately 0.005". An excessively dull or damaged tool must be ground until all traces of dullness or damage are gone.

The number of sharpenings varies with pitch and available depth of its serrations. Usually a cutter can be sharpened until the depth of its serrations has been reduced to 0.006" – 0.012".

Shaving Machines

Rotary gear shaving machines are manufactured in various configurations. Gears smaller than one inch and as large as 200 inches require different approaches. Rotary gear shaving uses a shaving machine which has a motor-driven cutter and a reciprocating work table. The cutter head is adjustable to obtain the desired crossed axis relationship with the work. The work carried between centers is driven by the cutter. Machines ranging from mechanical ones having one CNC axis to those with a full five CNC axes are available.

During the shaving cycle, the work is reciprocated and fed incrementally into the cutter with each stroke of the table. The number of infeeds and strokes is dependent upon the method used and the amount of stock to be removed.

The Machine Setup

Mounting the Work Gear: The work gear should be shaved from the same locating points or surfaces used in the pre-shave operation. It should also be checked from these same surfaces. Locating faces must be clean, parallel and square with the gear bore. Gears with splined bores may be located from the major diameter, pitch diameter or minor diameter. When shaving form centers, the true center angle should be qualified, and the surfaces should be free of nicks, scale and burrs. Locating points of work arbors and fixtures should be held within a tolerance of .0002". The arbor should fit the gear hole snugly. Head and tailstock centers should run within .0002" for dependable results. Gears should be shaved from their own centers whenever possible. If this is not possible, rigid, hardened and ground arbors having large safety centers should be used (Fig. 6).

Integral tooling is another popular method of holding the workpiece, especially in high production. This consists of hardened and ground plugs instead of centers (Fig.7) mounted on the head and tailstock. These plugs are easily detached and replaced when necessary. They locate in the bore and against the face of the gear. It is therefore essential that the gear faces be square and bore tolerances held to assure a good slip fit on the plugs.

Mounting the Cutter

Great care is required in handling the shaving cutter. The slightest bump may nick a tooth. Until the cutter is placed on its spindle, it should lie flat and away from other objects. The cutter spindle and spacers should be thoroughly cleaned and the spindle checked before the cutter is mounted. The spindle should run within .0002" on the O.D. and .0001" on the flange, full indicator reading.

After mounting, the cutter face should be indicated to check mounting accuracy. Face runout should not exceed .0008" for a 12" diameter cutter, .0006" for a 9" diameter cutter or .0004" for a 7" cutter.

Feeds and Speeds

Shaving cutter spindle speeds will vary with the gear material hardness, finish and size of part. Normally, when using a 7-inch cutter on a 10-pitch gear having a 3-inch pitch diameter, spindle speed will be approximately 200 rpm, or using a 9-inch cutter, 160 rpm. This speed, figured on the pitch circle, is approximately 400 surface feet per minute, which in most cases produces good results.

The following are formulas for determining cutter and gear speeds (in rpms):

$$\text{Cutter rpm} = \frac{\text{Desired Surface fpm}}{\frac{\text{Cutter Diameter (in.)} \times \pi}{12}}$$

$$\text{Gear rpm} = \text{Cutter rpm} \times \frac{\text{No. of Teeth in Cutter}}{\text{No. of Teeth in Gear}}$$

For conventional shaving, about .010" per revolution of the gear is a good starting point and becomes a factor in the following formula:

$$\text{Table Feed Rate} = .010 \times \text{Gear rpm}$$

For diagonal shaving, an "effective feed rate" of approximately 0.040" per revolution of the gear is a good starting point. Effective feed rate is the speed at which the point of crossed axes migrates across the face of the gear and the shaving cutter. The following is the formula for determining the table traverse rate (ipm) to produce an .040" effective feed rate:

$$\text{Table Traverse Rate (ipm)} = \frac{0.040 \times \text{Gear rpm}}{R_f}$$

where

$$R_f = \frac{\text{Sine Traverse Angle}}{\text{Tangent Crossed-Axes Angle}} + \text{Cosine of Traverse Angle}$$

These suggested feed rates may be varied depending on individual operating conditions. If higher production is desired, the table feed rate can be increased, but this may result in some sacrifice in quality of tooth finish. Where surface finish is very important, as with aviation and marine gears, table feeds are reduced below the amounts indicated. In some cases, notably large tractor applications, feeds considerably in excess of those indicated are used. ⭘

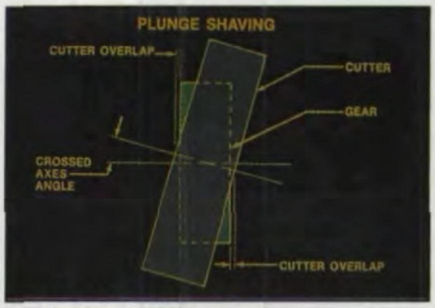

Fig. 5 — Plunge shaving.

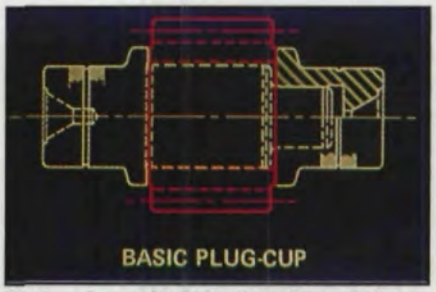

Fig. 6 — Gears should be shaved from their own centers, but if this is not possible, hardened and ground arbors having large safety centers should be used.

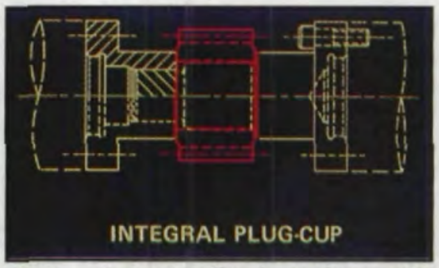

Fig. 7 — Integral tooling is another popular method of holding the workpiece.

Acknowledgement: *Presented by National Broach & Machine at the Society of Manufacturing Engineers 1st International Advanced Gear Processing & Manufacturing Conference, June, 1996.*

Don Kosal

provides technical sales support at National Broach and leads training seminars for customers. He is also the author of a number of papers and articles on gear subjects.

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LITERATURE MART

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SHAVEMASTER 220-400...

This brochure describes the new Shavemaster 220-400 high accuracy Gear Shaving machines. The Shavemaster is state-of-the-art hardware combined with CNC software that allows users to create more complex parts. With seven (7) axes and complex mixed movements, these machines allow gear finishing that is impossible with traditional machines. For more information please contact National Broach & Machine Co. at (810) 263-0100.

CIRCLE READER SERVICE #160

Welcome to our Product News page. Here we feature new products of interest to the gear and gear products markets. To get more information on these items, please circle the Reader Service Number shown.

Equotip Hardness Testers

The Equotip Hardness Testers from Equotip Associates provide a comparable degree of accuracy (+/- -0.5%) irrespective of the position from which measurements are taken. The basic or standard "D" unit covers the hardness ranges of HRC (20–68), HRB (38–100), HS (30–100), HV (81–955) and HB (81–654). Six other impact devices can be connected to the standard unit. These are the DC for very confined areas, such as holes or cylinders; D+15 for grooves or recessed areas; G for solid components such as heavy castings or forgings; C for surface-hardened components and coatings; E for parts manufactured with synthetic diamond test tips for hardness in excess of 50 HRC; and DL for confined spaces or at the base of grooves.

Equotip is ISO 9001-certified and is standardized to ASTM A956-96.

Circle 301

New Magnetic Scale Magnifier

GEI International announces the availability of a magnifier with mounting magnets incorporated within its body. This magnifier is specifically designed for reading the fine graduations on instruments such as rulers, verniers, calipers, protractors, etc.

The ONS-0385 is a 5-power magnifier which will conveniently attach to both vertical and horizontal steel surfaces. The magnets within the clear plastic housing firmly hold the magnifier in contact with a steel surface. Using this magnifier, extremely fine graduations, such as 1/100" marks on measuring scales, can be easily read without error. The magnetic base of the magnifier enables a workpiece to be manipulated with both hands.

The small size (1.73" x 0.79" x 1.18") and 0.53-ounce weight enables the magnifier to be carried in a shirt pocket ready for immediate use.

Circle 302

Miniature CCD Camera For Bore Inspection

A new surface texture measurement system from Mahr Corp. combines skidless tracing with an on-board CCD camera for complete inspection of interior cylindrical surfaces.

When inserted into a cylinder, the PMB automatically calculates the length of the machining pattern, cross plateau honing angle and distances between parallel lines. It also includes an integrated datum plane for waviness assessment and other typical surface texture evaluations. It comes with a built-in CCD camera so users can optically check the measuring point and visually inspect honed surfaces via a PC monitor.

The PMB is shop-hardened and can measure bores of 2.9–3.9" inches to depths up to 7.8". Straightness error of the datum plane is 8.0μ in over 0.80" of travel. Measuring range is ± 10,000μm.

Circle 303

Laser System Breaks $10,000 Price Barrier

Optodyne Incorporated has introduced the MCV-500 linear calibration system for calibrating CNC machine tools, CMMs and other precision instruments, which is available for less than $10,000. The MCV-500 features an easy-to-use software package that runs under Windows and allows automatic data collection and analysis and is fully compliant with many national and international standards. Data is available in both graphic and table form. The system can be controlled with a laptop or portable computer, since the only connection required is through the RS-232 port, and no internal boards need to be added. The MCV-500 is calibrated and traceable to NIST.

Circle 304

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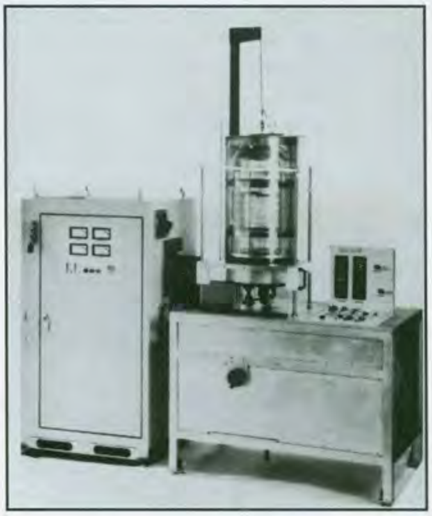

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Circle 305

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CIRCLE 174

The Jewels In the (Gear) Crown

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

Over the years the Addendum Staff has brought you odd, little known and sometimes useless facts about almost every conceivable topic concerning gears. This month, as part of our never-ending campaign to upgrade the *tone* of the industry, we are venturing into the world of high fashion. Lose those pocket protectors, gear fans. Welcome to the land of gear *haute couture*. Appearing now, in select magazines, are ads that rival those of Bulgari, Cartier and Tiffany. These gear "gems" come courtesy of Winzeler Gear, Chicago, IL.

The ads, shot in elegant and understated black-and-white, feature fashion model Bodil wearing Winzeler gears in her ears, on her arms and around her neck. John Winzeler, whose company specializes in small plastic gears, had some of his end product made into jewelry to be modeled by the lady in question. The reason for this venture into industrial chic? Winzeler wanted an ad campaign that would be noticed.

Winzeler and Dan Kennedy, president of Kennedy Advertising, Winzeler's agency, have been doing traditional gear ads for years, and doing them very well. One of them was *Design News'* Best Ad for 1997. But Winzeler was ready to move beyond the usual charts, cross section drawings, specs and product photos that are the staples of most manufacturing advertising. Winzeler's interest in fashion photography and art led him in a different direction.

Winzeler and Kennedy had talked about a new direction for their ad campaign for some time, but the jewelry concept came to Kennedy "about 3:00 in the morning." Why not draw a parallel between the craftsmanship and precision required to make fine jewelry and that demanded of gear makers, specifically those at Winzeler Gear?

A risky idea? Maybe, especially in an industry that tends to be conservative at best. But Winzeler, never one, in his own words, "to fly in formation," was intrigued by the notion and decided to run with it.

For Winzeler and Kennedy, the goal was to get the ads noticed and remembered. What better way to do that than to have a picture of a beautiful woman with a delicate worm gear dangling from one ear, right there among the formulas and photos of machine tools? Readers might not like what they saw (although early indicators are that they do), but they'd remember it.

But the execution of this great idea turned out to be more complicated than it first appeared to be. Over a year of consultations between jewelry and gear designers, photographers, Winzeler and Kennedy went into the production and development. Ultimately the gear jewelry was made of plastic resin painted silver and fitted with jewelry hardware—earring backs, bracelet clasps and neck chains and ribbons—to make them functional. *Voila*! Worm gear earrings, a bevel and miter gear ring, spur gear bracelets and a gear sector necklace.

Next, after the gear jewelry was completed, up-and-coming fashion photographer Michael Voltattorni was brought on to do the photos. He took more than 400 shots of Bodil wearing the jewelry. From these, the pictures were chosen for the first three ads in the campaign. Several others were mounted and framed and are presently displayed in the lobby at Winzeler Gear.

The ad campaign was treated with all the secrecy of a hot new product release. Not even the staff at Winzeler Gear knew what was up. "Everyone knew something was going on, but didn't know what," says Winzeler.

Once the ad campaign was ready, Winzeler and Kennedy took another leaf from the world of high fashion and unveiled the new jewelry and the ad series with a big party attended by the Winzeler Gear staff, people from Kennedy Advertising, Michael Voltattorni, Bodil, and friends and clients of the company.

Since the kickoff, the first ad in the series, one featuring Bodil wearing worm gear earrings (gear-rings?), has run in *Machine Design*, *Design News*, and *Auto World*. Other gear jewelry ads are to follow.

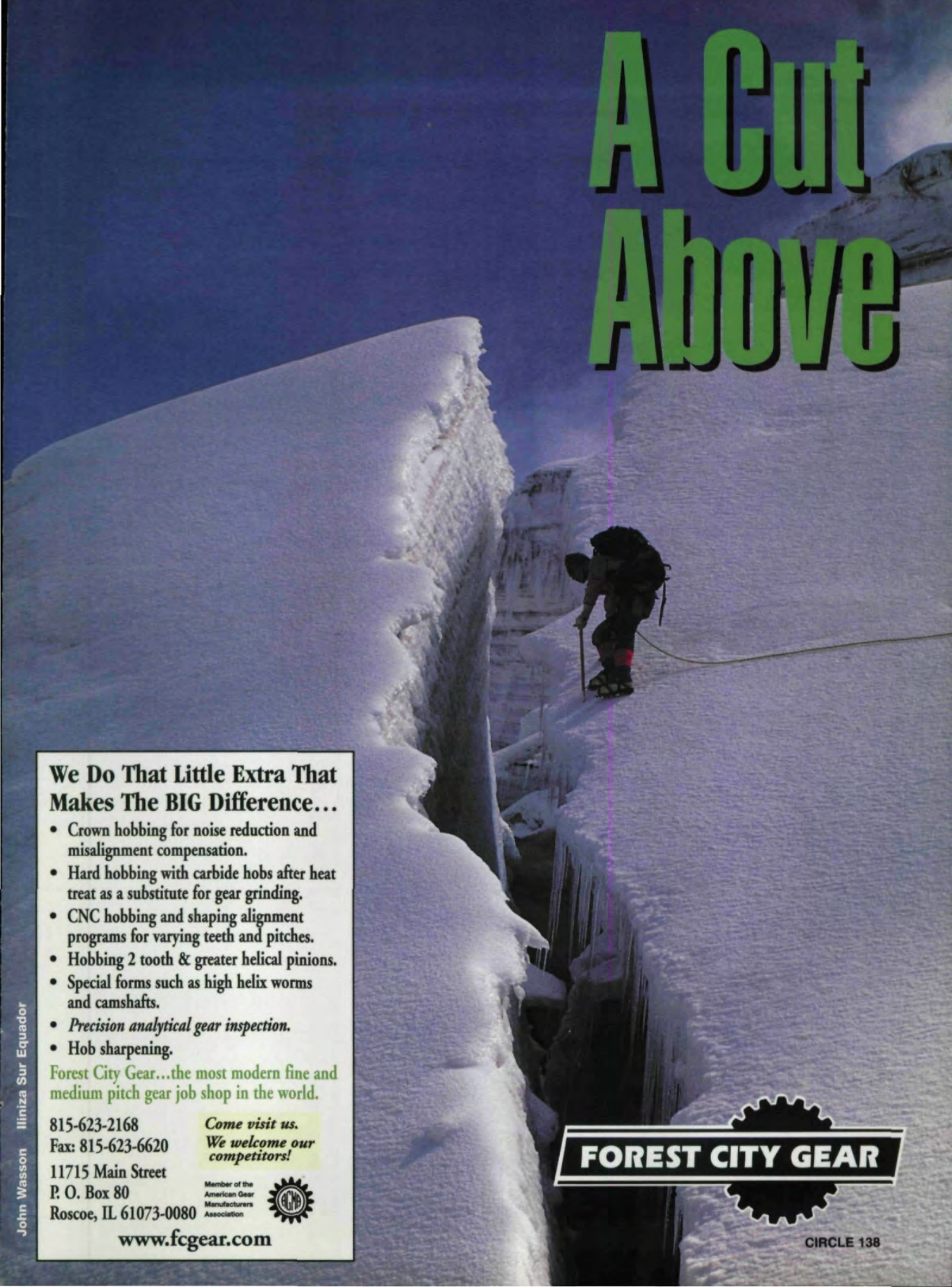
Winzeler is committed to the series. "We have about 400 other photos," he says. "We could be into this for the long haul." says Winzeler.

Winzeler Gear jewelry ads don't yet have the instant recognizability of an Absolut vodka bottle, but that's the direction Winzeler, never one to think small, would like to go.

Hey, it could happen. Look out, Tiffany. Here comes Winzeler Gear!

Photo by Michael Voltattorni.

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