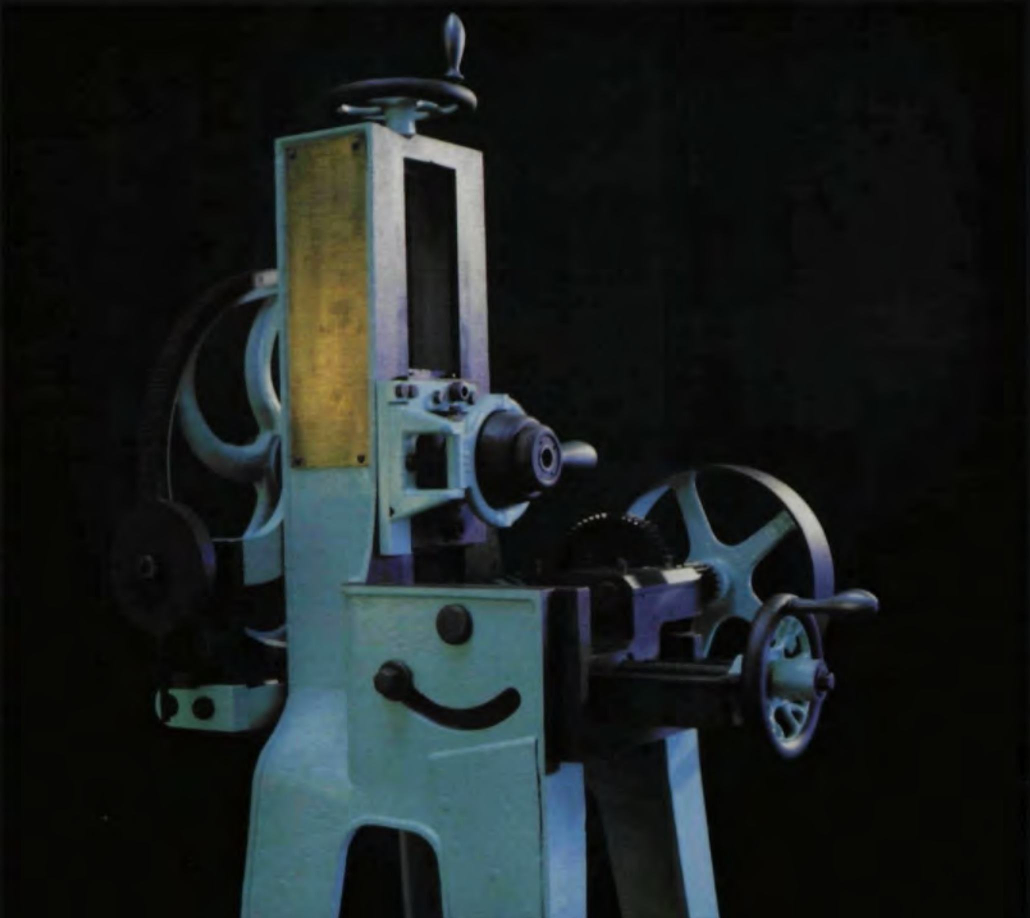
Gear Expo '89

SHOW ISSUE

GEAR TECHNOLOGY

The Journal of Gear Manufacturing

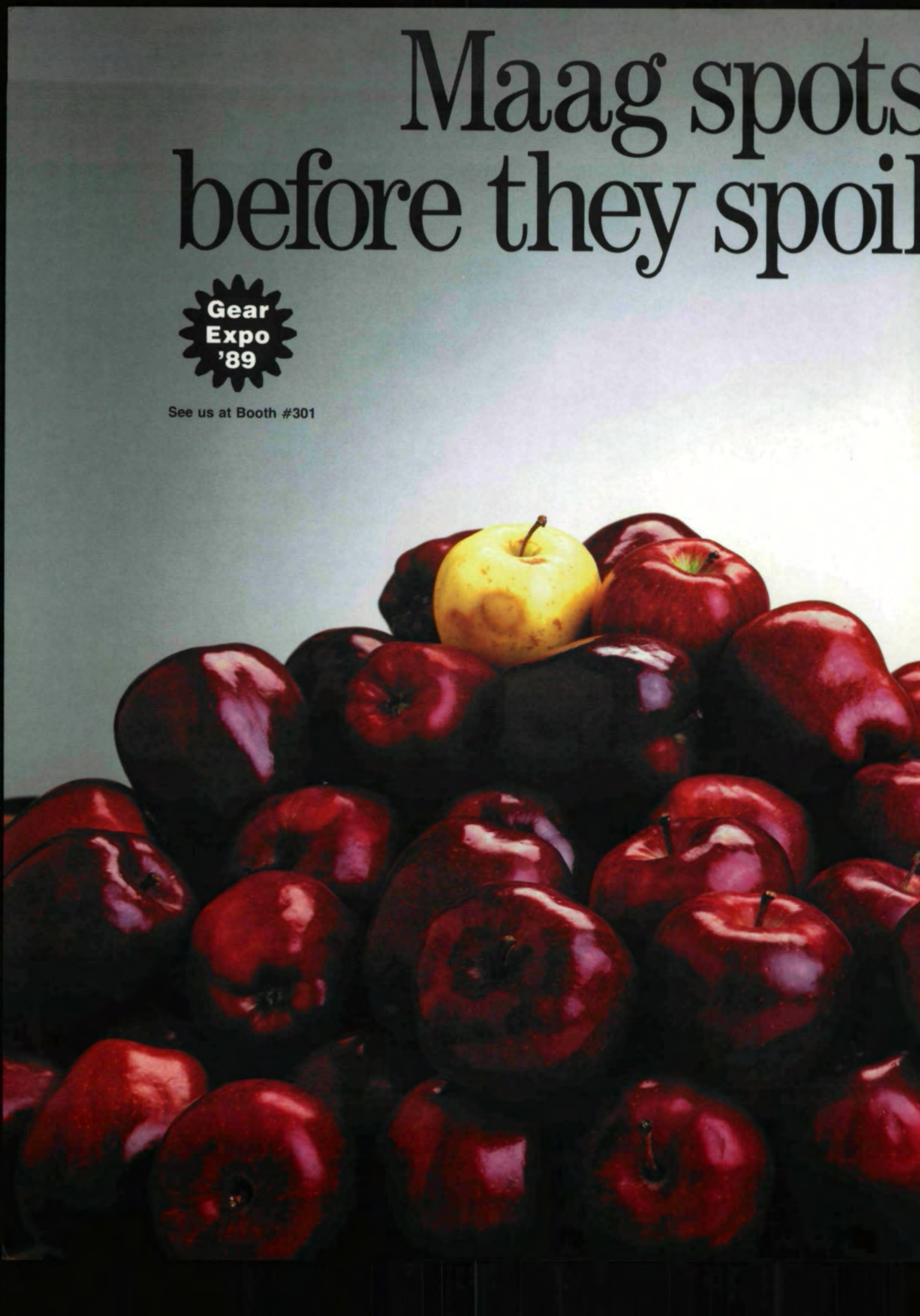
SEPTEMBER/OCTOBER 1989



White Etching Areas on Case-Hardened Gears

Hard Finishing and Fine Finishing — Part I

Gear Grinding Fundamentals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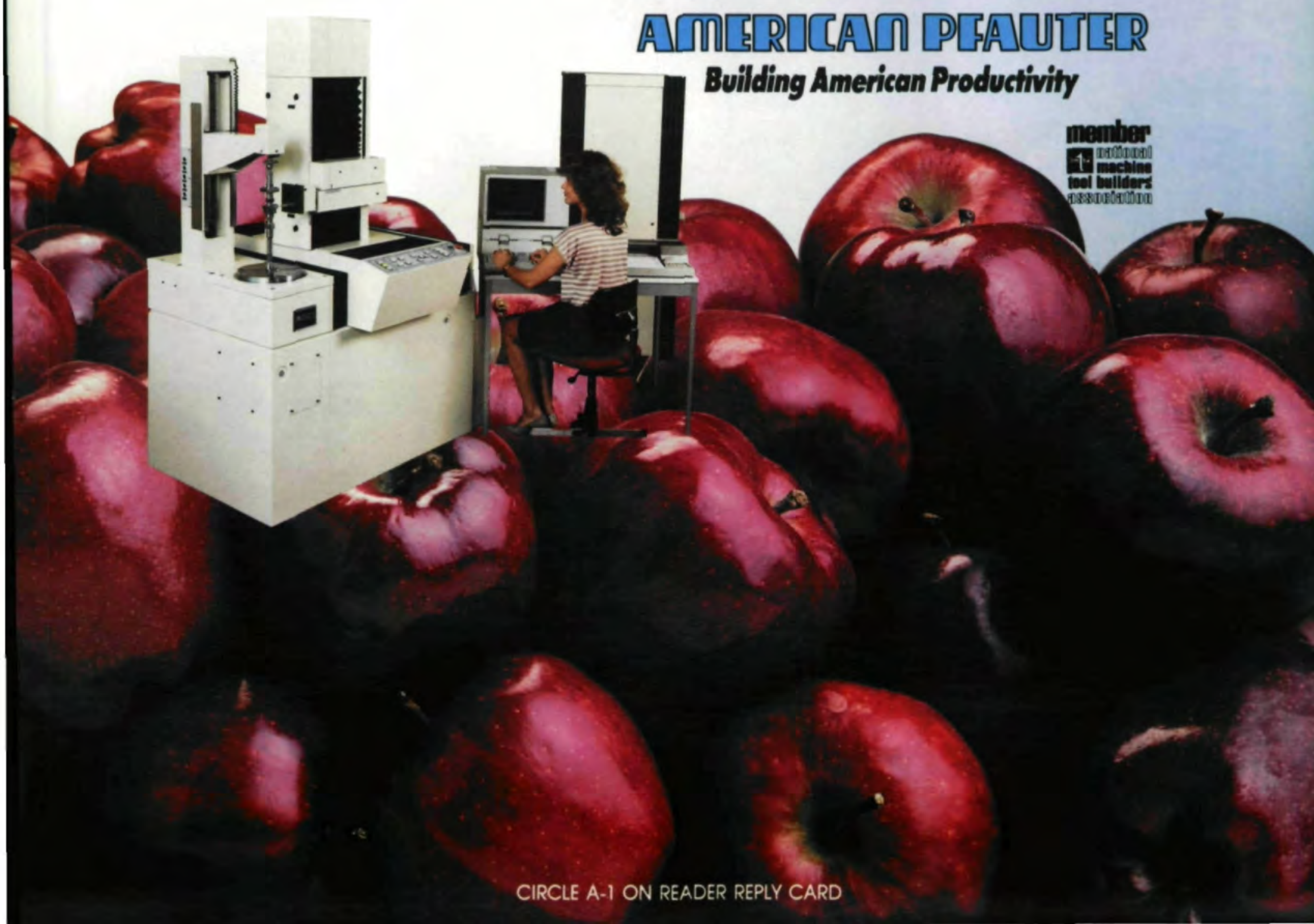

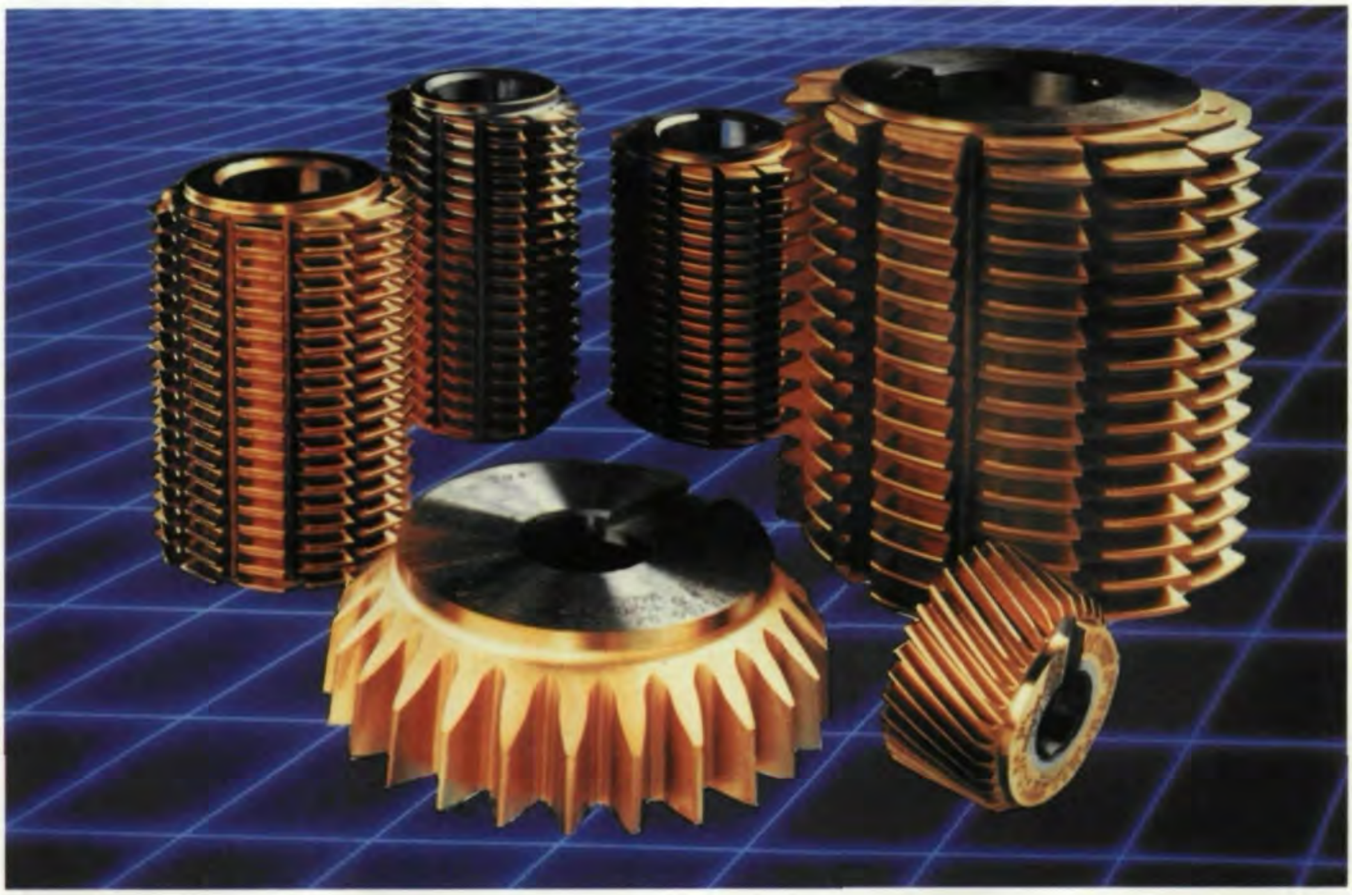

190 Booths At Bigger, Better Gear Expo '89

Over 190 booths displaying the latest in gearing technology, equipment and processes will be on display at AGMA's Gear Expo '89. The show opens at the David Lawrence Convention Center in Pittsburgh, PA, on Nov. 6 and runs through Nov. 8.

A special feature of the show this year is a display centering on a completely restored working model of a very early Gould gear cutting machine. Hand-restored by Paul S. Morales of Chicago Gear/D.O. James Corp., Chicago, IL, the machine will be shown along with a video tape of it in operation. After the show, the 140-year-old machine will be on permanent display at AGMA headquarters in Alexandria, VA.

In conjunction with the show and also at the Lawrence Convention Center is the AGMA Fall Technical Conference. The conference will be held Nov. 7-9 and will feature papers on a variety of gearing subjects including worm gears, gear dynamics, vibration analysis, lubrication, and gear geometry.

Show hours are 9:00 a.m. to 6:00 p.m. on Monday and Tuesday and 9:00 a.m. to 4:00 p.m. on Wednesday.

Editorial

AGMA'S "BABY" GROWS UP

From tiny beginnings, the AGMA Gear Expo is growing into a fine, strapping show. This year's effort, Gear Expo '89, "The Cutting Edge," will be bigger and better than ever. What started as a few tabletop exhibits in Chicago four years ago has now grown to a full-size, international exhibition at the David Lawrence Convention Center in Pittsburgh. With over 160 exhibitors, including major gear manufacturers and suppliers from around the world, this year's show promises to be a great success as well.

AGMA has provided the nearly perfect forum to look for and/or sell gear machinery, supplies and auxillary equipment. At Gear Expo '89, you can concentrate on gear machines and related products without wandering through a maze of other machinery and equipment. By scheduling the Fall Technical Conference on overlapping dates at the same location, AGMA has provided attendees with a financially efficient opportunity to keep abreast of the latest in gear research. For virtually the same price, you can view both the latest products and the latest research. Presidents, managers, engineers and operators can all come away with valuable knowledge. This is a double-barrelled opportunity that serious competitors in the gear market should not overlook.

The last two years have been good for both gear customers and manufacturers. The economy has been growing along with capital expenditures. The need for new equipment and the wherewithal to buy it are more in balance than they have been for some time. But as we should have learned from recent past history, the good times don't last forever. Current economic indicators have levelled off, although business remains strong all over the Northern Hemisphere. We have a window of opportunity now that will not stay open indefinitely. There may never be a better time to invest in new equipment and training for you and your company.

Gear Expo '89 is the perfect place to start. Pittsburgh, with its lower costs and central location, and the combination show and technical conference provide the most efficient way to keep up with both the latest in products and research. For many, the chance to see the cutting edge of the gear product market does not even require an overnight stay.

Gear Expo '89 and the Technical Conference continue to need your support in order to remain successful and useful. More important, your attendance at these events will help keep your company competitive and better able to take advantage of this window of opportunity.

Michael Goldstein,
Editor/Publisher

Night view of Pittsburgh skyline.

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OUR COVER

An early Gould rotary cutting machine, probably for spur gears, circa 1850. This machine was donated to AGMA and has been restored by Paul S. Morales of Chicago Gear/D.O. James Corp., Chicago, IL. In the 1840s Gould produced approximately two machines a year; this machine is numbered 13. At some time, one of the legs of this machine was patched by means of a cold hammer weld. The repair is over 100 years old now and still holding.

GEAR TECHNOLOGY

The Journal of Gear Manufacturing

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MANUSCRIPTS: We are requesting technical papers with an educational emphasis for anyone having anything to do with the design, manufacture, testing or processing of gears. Subjects sought are solutions to specific problems, explanations of new technology, techniques, designs, processes, and alternative manufacturing methods. These can range from the "How to . . ." of gear cutting (BACK TO BASICS) to the most advanced technology. All manuscripts submitted will be carefully considered. However, the Publisher assumes no responsibility for the safety or return of manuscripts. Manuscripts must be accompanied by a self-addressed, self-stamped envelope, and be sent to GEAR TECHNOLOGY, The Journal of Gear Manufacturing, P.O. Box 1426, Elk Grove, IL 60009, (312) 437-6604.

Hard Finishing and Fine Finishing Part 1

Dr. -Ing. H. Schriefer
C. Hurth, Munich, West Germany

AUTHOR:

Dr. – ING. HERBERT SCHRIEFER *is with Hurth Company, Munich, where he is technical manager for the Division of Machines and Systems. He studied at the Technische Universität in Berlin and worked at the Laboratory for Machine Tools (WZL) at the Technische Hochschule Aachen where he developed the geometry and kinematic part of a program sequence for bevel and hypoid gears. This program system represents the most extensive and universal computer analysis of the running and stress conditions of complex gear drives today.*

Introduction

Profitable hard machining of tooth flanks in mass production has now become possible thanks to a number of newly developed production methods. As used so far, the advantages of hard machining over green shaving or rolling are that elaborately modified tooth flanks are produced with a scatter of close manufacturing tolerances. Apart from an increase of load capacity, the chief aim is to solve the complex problem of reducing the noise generation by load-conditioned kinematic modifications of the tooth mesh.[2,3,5,6] In Part II, we shall deal with operating sequences and machining results and with gear noise problems.

Geometry of Gear Flanks

Noise generation of teeth in mesh has two causes. The first, a modulation of gear mesh rigidity,[3,5,6] is mainly influenced by the implemented geometry, such as the helix and pressure angles chosen, the addendum/dedendum modification on high tooth design, etc., and, thus, depends only to a small extent on the precision geometry of flanks via contact rigidity.[5-6] The second cause is meshing errors,[8-9] which, however, are due directly to the precision geometry of flanks as a function of the load. Fig. 1 shows influences on the geometry precision of flanks determined by the load and by manufacturing, and from the qualitative viewpoint, the relative tooth contact and generating behavior.[1,8,9]

The left column lists the reasons for various tooth modifications. The second column shows the topological modification of flanks, while the third column illustrates the tooth contact without load and under load. The fourth column is a qualitative representation of the single flank displacement error without load and loaded on account of the modifications of individual flanks.

Suitably designing modifications require that the generated impact and torsional vibrations produced by the single flank displacement errors are kept within close tolerances over the total load range of the gear unit. In practice, such modifications are determined by means of the measurement analysis of the noise emission under operating conditions. The result is a flank geometry having several superimposed modifications as shown in the lower part of the illustration. Since the modifications are within a range of a few micrometers, their kinematic effectiveness requires a production method with the least possible scatter of tolerances.

As an empirical value, tooth quality grade 5 - 6 acc. DIN 3962 is sufficient for the finished flank. The possible ranges of scattered tolerances could then be absorbed by the modification band width (such as crownings) of the gear flanks without producing harmful single flank displacement errors.

Fig. 2 shows the reduction of tolerance from precut tooth quality grade 9 to finish tooth quality grade 5-6, and also the percentage to which the influences of the systems' components on the result should be evaluated.

It will be noted here that the column "machine + tool" has the highest influence altogether. The reason is that deviations of the tool or of machine kinematics will show directly, while other deviations, such as those of fixtures, will only have an indirect influence. This means that, in case of profile error, the machine together with the tool may have profile errors of $\pm 3\ \mu m$. The influence of only $\pm 0.5 \mu m$ for reclamping and measuring will be possible only if the toothing deviations are referred to the same position as for machining. This would require a theoretical definition of the tooth gearing axis. This is feasible by a computerized alignment of the topographies of several flanks that are distributed over the work gear periphery.

With conventional measuring instruments the influence by reclamping and measuring should be assumed to be higher.

With such demands on precision, the border line for metal cutting processes in mass production has been reached. A solution will only be possible with processes featuring a minimum of kinematic settings and where the tool flank geometry is either an accurate conjugated mating gear or a conjugated linear section with reference to the flank geometry required.

Kinematics of Hard Finishing and Fine Finishing

Since the work gear flank geometry is composed of linear elements, the linear contact also applies to the gear mesh when machining with a conjugated tool.[8] The three setting parameters which have precedence for generating a conjugated tool flank geometry from a preset cylindrical gear flank geometry are

a. crossed-axes angle
b. externally or internally tool
c. center line distance of crossed axes.

Fig. 3 shows the tool used for the crossed-axes angle range

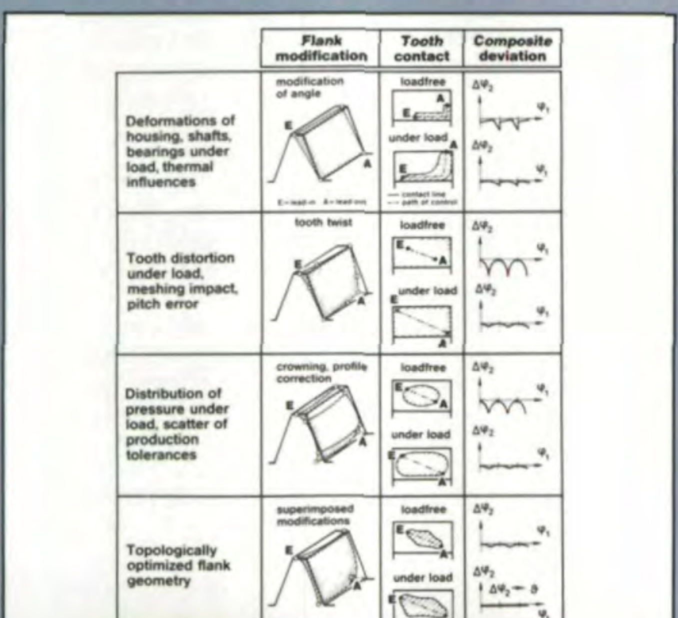

Fig. 1 – Systematic diagram of superimposed modifications of flanks for noise reduction.

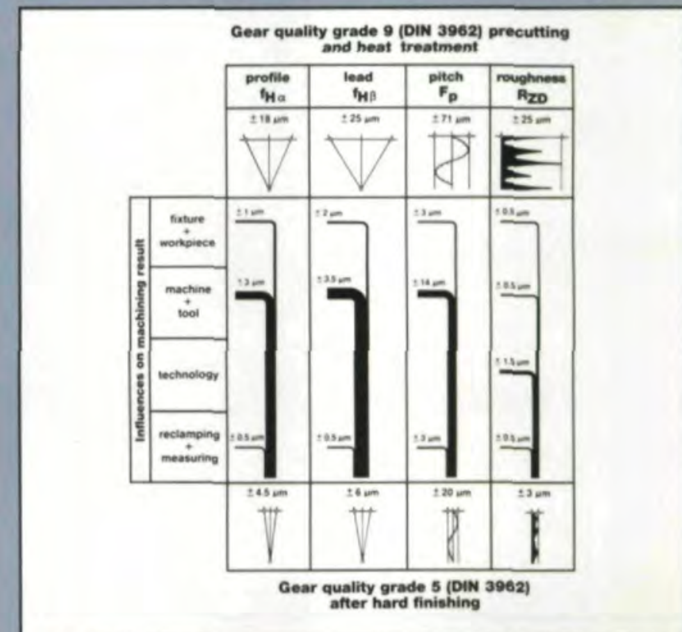

Fig. 2 – Reduction of tolerance from premachining to finishing of tooth flanks.

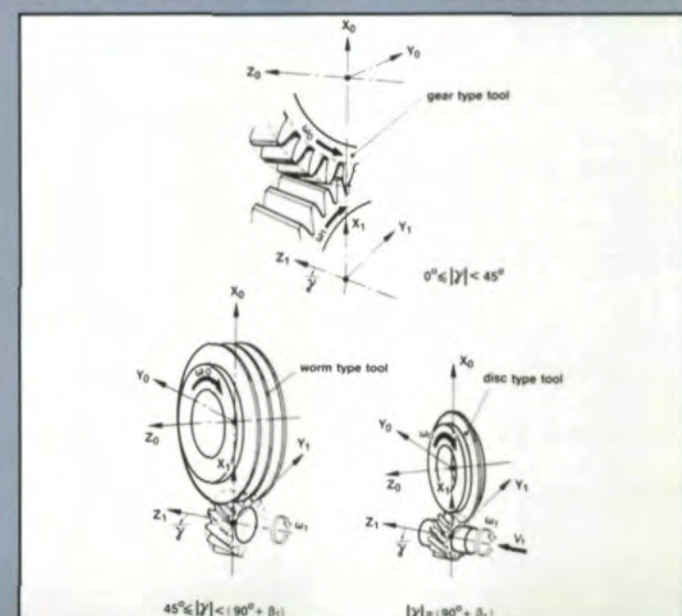

Fig. 3 – Relative position between the tool and work gear.

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$0° < /\gamma/ \leq 45°$.[4] A conjugated crossed helical gearing is produced. The effective cutting velocity is the vector sum of the sliding velocity along the profile v_H and along the lead $v_L = v_U \cdot \sin\gamma / \cos\beta_1$. Assuming the peripheral velocity v_U of the tool and the helix angle β_1 of the work gear to be constant, the longitudinal velocity v_L depends sinusoidally on γ.

Assuming further that the external tool diameter is constant, an increasing γ will result in a lower number of tool teeth, since $\gamma \approx \beta_0 + \beta_1$.

Chip Forming Mechanisms During Hard Finishing and Fine Finishing

Fig. 4 shows a tooth of a work gear in conjugated mesh with a tooth of the abrasive tool. Chip removal occurs at every point of the momentary contact line only in the direction of $\vec{v}_{Rel} = \vec{v}_L + \vec{v}_H$.

The momentary kinematic condition of a cutting edge when cutting into the material could be described as a rolling and sliding of the rolling circles ζ_0 and ζ_1 in the direction of $\vec{v}_{Rel}$. The direction of $\vec{v}_{Rel}$ depends mainly on γ. If $\gamma = 0$, $\vec{v}_{Rel}$ will be oriented exclusively from addendum to dedendum. If γ moves towards $(90° + \beta_1)$, $\vec{v}_{Rel}$ will be increasingly parallel to the lead direction.

Accordingly, the relative conditions of curvature diverge considerably from each other. If the circles of curvature are small, as shown in Fig. 4, the cutting grain will penetrate very steeply into the material and will leave the cutting path after a short contact length. The condition for the next cutting grain to have sufficient material for actual penetration and not be shoved elastically away will be decisive for the structure of the cutting surface.[10,12]

With small effective circles of curvature and high rolling velocities, the cutting structure requires a higher density of cutting edges than for large circles of curvature and low rolling velocities. That means, with an increasing γ, the structure of the tool must be more open.

This short survey of metal cutting mechanisms is intended to illustrate that in gear finishing, the geometric and kinematic process parameters dependent on the tool and the work gear will substantially affect the choice of a suitable cutting and bonding material, as well as optimal structure of cutting surface.

Drive System For Hard Finishing and Fine Finishing

Another essential mark of distinction between these two modes of finishing is the type of drive system used. Fig. 5 shows

Fig. 4 – Operating conditions of a cutting grain during relative sliding and rolling of the momentary equivalent circles of curvature.

the various modes of current drive systems.

The left side of the picture shows the radial load connection with a two-flank contact.[4] The work gear is in free mesh with the tool without controlling the drive gear. This hard finishing process is similar to the green shaving process and produces similar quality grades, but before heat treatment. The two-flank method is not discussed in this paper.

The drive mode shown in the middle of the illustration can only be used to improve the microstructure of the flanks, for flank modifications, and for removing defects from gears. Due to the braking force, there is only a one-flank contact, so that the various divergences of right-hand and left-hand flanks have no influence.

Both drive modes shown are not able to specifically generate a definite flank geometry, since the tool follows the pitch geometry produced by premachining.

From Fig. 2 we see that in order to produce a specific definite flank geometry based on a usual premachining, a stock removal of about 50 to 100 μm per flank is required. To this effect the tool and the work gear must be in constrained mesh, as is shown symbolically on the right side of the illustration.

The left part of Fig. 6 shows a mechanically constrained mesh using helical toothed conical gears.[4] The relatively simple and safe mechanically constrained mesh meets the requirements for high torsion rigidity and dynamic transmission. The tool – a CBN-coated cutter – and the work gear are coaxially mounted on the spindles of the helical toothed gearing, work being done with single-flank contact. The stock is removed by a relative tangential displacement.

Relative tangential displacement is achieved by obtaining a contact of flanks of both gearings beyond the nominal center line distance. When the gearings approach radially up to their nominal center line distance, they must make way for each other while rotating; this is achieved by making one flank of the tool penetrate into the flanks of the work gear during rotation.

By knowing accurately the relative tangential displacements on a change of the center line distance, one will be able to maintain accurate backlash tolerances.

Tools For Hard Finishing and Fine Finishing

As was said initially, the main problems with hard finishing processes are encountered in the high accuracy required in mass production, because the result of the machining must be reached with statistical reliability. Deviations from the tool flank geometry are reproduced on approximately a 1:1 scale as deviations of the work gear flank geometry. From the overall tolerances for the work gear profile, for instance, a separate tool tolerance of $\pm 3\mu m$ will have to be kept for the machine and the tool (Fig. 2).

Fig. 7 shows various possibilities of production for hard finishing and fine finishing tools.

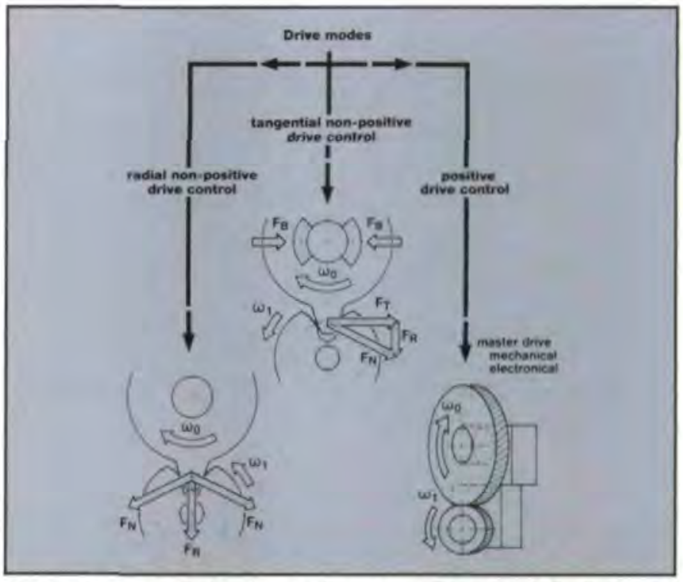

Fig. 5 – Drive modes for hard machining processes with a non-defined geometry of the cutting edge.

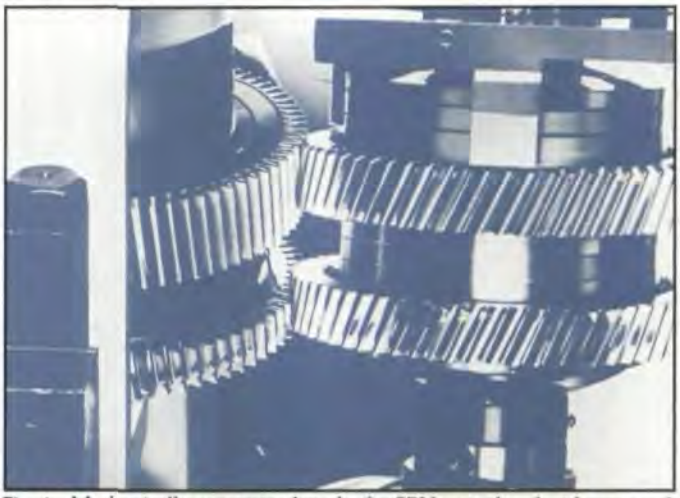

Fig. 6 – Mechanically constrained mesh of a CBN-coated tool with a crossed helical gearing.

The method for tool production shown on the left of the figure consists of producing a coarse positive replica of the tool by a technique like hobbing. From this gear a negative mold is made. A mixture of synthetic resin and abrasive grains is cast into this mold, which then sets to form the tool gear with an approximate shape of flanks.

The accurate flank profile of the tool is obtained by means of a diamond dresser. In its coated condition, this wheel has precisely the flank profile of the work gear flank desired. The synthetic resin bonded tool is used predominantly with drive modes without a constrained mesh. It is most suitable for improving surface finish and for removing damages.

The production of the vitrified bonded tool is shown in the central part of the illustration. The disk type gear is given a preliminary profile by a form grinding wheel, while the accurate flank profile is again obtained by means of a diamond dresser. This tool version is mainly used for drive modes with constrained mesh. The chip removal here is proportionately higher than for the synthetic-resin bonded tool version.

On the right side of the illustration is the drawing of a tool coated with abrasive material. The flank geometry, including all necessary modifications of flanks, is ground. After coating it may be possible to either dress the tool with a diamond dresser[7] or to use it directly for hard finishing.

The close admissible tolerances within a range of a few micrometers for the tool emphasizes the problem of tool wear. It may be solved either by dressing the tool in the machine with a diamond dresser or by using wear-resistant cutting materials which will be removed from the basic tool after the end of the service life. In this case, the basic tool could be recoated several times.

Computer Assistance

Since geometrical and kinematical correlations with regard to the production of basic hard alloy coated tools are quite complex, they require an extensive assistance by computers. Its aim would be to produce all manufacturing data and machine settings automatically on the basis of the data of the desired tool flank geometry.

Fig. 8 shows a detail of the manufacturing drawing for hard

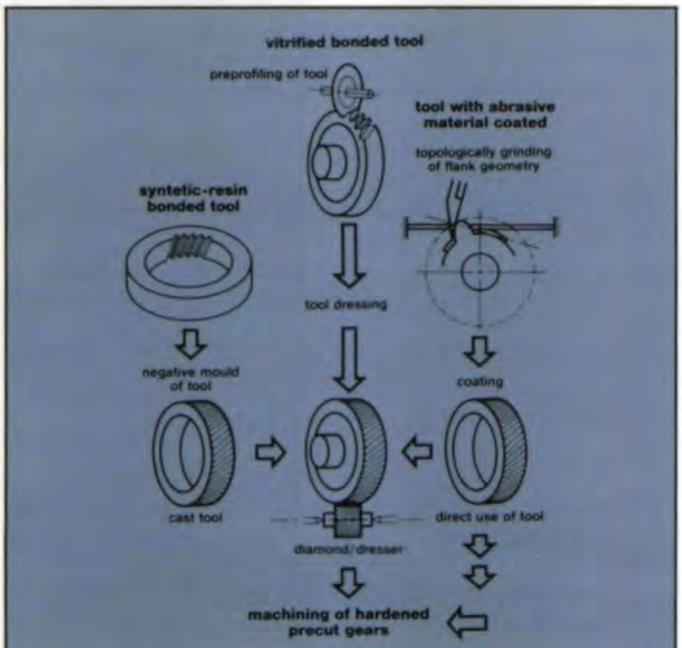

Fig. 7 – Basic possibilities of producing gear-like tools.

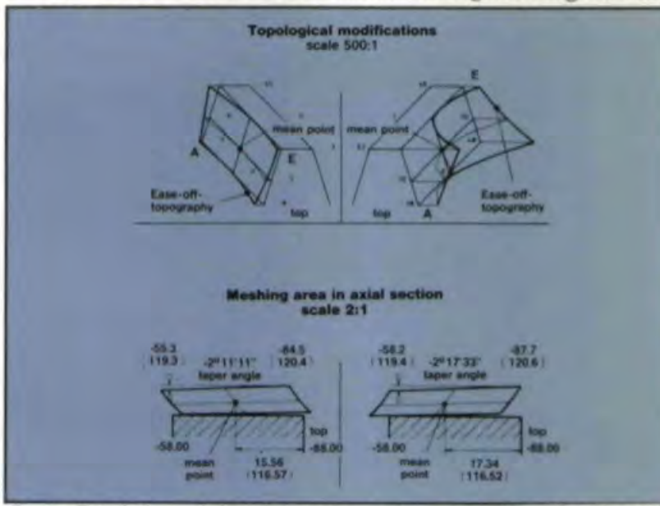

Fig. 8 – Detail of a workshop drawing for producing coated hard finishing tools.

alloy coated tools. The upper part of the illustration shows topological deviations with regard to the enveloped involute surfaces. Such deviations are strongly affected by the crossed-axes angle and by the axial position of the gearing with reference to the crossing of axes. The lower part of the illustration shows the meshing conditions of the tool in the axial section. The required flank limiting geometries of the tool can be gathered from these drawings.

Machinery for Hard Finishing and Fine Finishing

Machinery for hard finishing and for fine finishing have similar designs. Essential differences, due to different aims, concern the drive system and the controls.

The "fine finishing" mode aims at removing damage and at improving the microstructure of flanks. The process is characterized by the unconstrained mesh of the tool and the work gear.

The "hard finishing" mode aims at producing gears ready for assembly, starting from the work gear that has been hardened before finishing. It is characterized by the constrained mesh of the tool and the work gear. On the one hand, this finishing mode should have a metal removing capacity of 10 to 100μm per flank, while at the same time, the microstructure of flanks should make further finishing unnecessary.

Editor's Note: Part II of this article will discuss Operating Sequences and Machining Results and Gear Noise With Hard Finished and Fine Finished Gears.

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White Etching Areas on Case-Hardened Gears

Professor Dr. -Ing. Hans Winter,
Dr. -Ing. Gerhard Knauer
Technical University of Munich
John J. Gamel
Solar Turbines, Inc., San Diego, CA

AUTHORS:

PROFESSOR DR. – ING. HANS WINTER *is the head of the Laboratory of Gear Research and Gear Design at the Technical University of Munich. He has held positions in the German gear industry since 1956 working for Zahnradfabrik Friedrichshafen and DEMAG Duisberg in manufacturing, development, design and research. He received his doctorate from the Technical University of Munich and studied as an associate of Prof. Dr.-Ing h.c. Gustav Niemann.*

DR. – ING. GERHARD KNAUER *is a graduate engineer of FZG and is an engineer at Zahnradfabrik Friedrichshafen.*

MR. JOHN J. GAMEL *is a senior design engineer with Solar Turbines, Inc., San Diego, CA. Prior to coming there, he worked at the Naval Ship Systems Engineering Station in Philadelphia, PA. He studied at FZG during 1986.*

Abstract:

The phenomenon of white layers, which arises from high stress, can be observed under a microscope after the white layers have been treated with a weak nitric acid solution. Their occurrences in zones of high shear stress can provide qualitatively valuable indications of the size and direction of the stress, and they can point out possible starting points for flank damage. An investigation of this phenomenon is described.

Introduction

It is known that on the surface and just under the surface of rolling elements of hardened steels, so called "white layers" can be observed. This phenomenon, also called "white etching areas (WEA)," arises from high stress. These white etching areas are structured zones which are affected when etched with diluted nitric acid and which then form a light contrast with the matrix when observed with a microscope.

In References 1, 2, 6, 7, 10, 12 and 13, the different forms of appearances have been described and their appearances in connection with the actual stress have been analyzed. In the same way, the structure of these structured zones can be regarded as known to a large degree. The conditions for the appearance of WEA on the surface are high friction and/or impact stress; whereas, WEA were observed beneath the functioning surface only in elements which were at the same time exposed to strong hydrostatic pressure and a shear stress.[10] In the cited reference, the origin of WEA beneath the surface resulted because the presence of a mechanical thermodynamic state induced such high tensions, that in the areas, the shear resistance of the material had been exceeded. The flanks of the crack which run in the direction of the greatest shear stress are heated to the melting temperature in an extremely short time because of the plastic deformation of the structure. In this process the carbides dissolve and the carbon enters the gamma-matrix. After self-cooling, because of the surrounding structures with considerably lower termperatures, we get a highly oversaturated martensite.

Until now the investigations of WEA phenomena have been carried out largely with rolling element bearings. It is known that rolling element bearings are exposed to substantially higher Hertzian pressure than gears under similar conditions. This is probably why the occurrence of white etching areas on gears has so far been noticed in only a few cases, and it is still not clear whether WEA can be regarded as a cause of flank damage. This article will describe further some forms of occurrences of WEA on the highly stressed flanks of case-hardened gears. In addition, we will discuss whether there is a connection with fatigue failures.

This research is based on a number of operating tests with case-hardened gears for the investigations of pitting resistance, which have also been subsequently analyzed through metallographic investigations*. It is, therefore, not the purpose of this article to analyze the microstructure and triggering mechanism of WEA (We refer here rather to the abundance of existing literature), but we will investigate the occurrence of WEA in connection with the stress of the tooth flanks and the consequences of it.

*All operating tests and metallographic investigations were performed at the Gear Research Laboratory (FZG) of the Technical University of Munich, West Germany.

White Etching Areas in the Area of the Tooth Flank. Material Fatigue on Non-metallic Inclusions Beneath the Surface

The sliding-rolling motion under high Hertzian stress in the contact of two mating tooth flanks leads to a three-axis-pressure-stress state, which is superimposed by a shear stress resulting from the friction load. The main shear stress, which can be regarded as the cause of the crack[6,11] has, with ideal geometrical bodies, a path to the depth, as shown in Fig. 1.

According to investigations of References 4 and 5, micro-Hertzian fields of tension are formed on machined surfaces due to previous damage as well as scratches and roughness. These fields of tension lead to paths of tension that are different from those that should be taken in an ideal geometrical body. In Fig. 1, the path of the main shear tension for a rectangular notch with a depth of 0.1 b_H and a length of 0.2 b_H has been added. According to this, the main shear stress directly beneath the surface is considerably greater than the maximum, which follows the current hypothesis about the endurance. When reaching a depth of 0.5 b_H the influence of the surface roughness has decreased. After that depth, the path of the tension follows the pattern of the Hertzian pressure distribution on the ideally smooth surface. In this area the main shear stress is directed against the surface just under 45°. In addition to this, in the area of non-metallic inclusions peaks of tension occur, as pointed out in Fig. 2, which can lead to localized exceeding of the allowable shear. (See References 3 and 4.)

The calculation derived from Fig. 2 is confirmed by Fig. 3. An oxidation inclusion, whose E-modulus is about two times as large as for steel, lies in the area of the inner point of single contact, about 0.14 mm below the surface of the flank in the area of high main shear stress. (See Fig. 1.) In an undisturbed structure, the main shear tension did not reach a value which would be critical for a case-hardened steel. However, the approximate 2.5-fold increase in tension due to the inclusion (compare Fig. 2) led to the occurrence of cracks and WEA, which, in accordance with the path of main shear stress, are approximately 45° with respect to the surface. The gear data and the operating conditions for this experiment are listed in Table 1.

In different publications, for example, References 6 and 10, an increase of WEA in connection with a greater number of revolutions has been noticed. This leads to the conclusion that also with non-metallic inclusions, WEA do not appear immediately after the first stress cycle. They only occur after a certain period of stress due to plastic deformation which causes change in the state of the residual stress. Possibly the crack expands very quickly once a critical state of deformation is reached, and the crack travels in its environment to temperature regions which are above melting temperature. (See Reference 10.) The high impact stress that occurs with roller element bearings can apparently also be reached locally with gears. In Reference 6, it is noted that a minimum impact stress of $\tau_{45} = 725$ n/mm^2 (105,200lb/in^2), at the inner ring of a roller element bearing, leads to the occurrence of WEA. Also, with case-hardened gears, the main impact stress of this dimension can occur in the area of inclusions.

The cracks which occur on non-metallic inclusions below the surface of case-hardened gear flanks generally extend very little. So far, it has not been proven whether they extend to the surface and cause damage at the flank.

The strictly local limitation of WEA to non-metallic inclusions and the connection with the relation (E inclusion/E steel) become apparent in the example of sulfur content in case-hardened gears made of *(continued on page 22)*

Table 1
Gear Data and Operating Conditions

Module (Diametral Pitch)
m = 5mm (5.08/in.)
Number of teeth (1 = Pinion/ 2 = gear)
$z_1/z_2 = 17/18$
Face width
b = 16mm (0.63 in.)
Center distance
a = 91.5mm (3.60 in.)
Torque
M = 360Nm (265 ft-lb)
K − factor
K = 12.1 N/mm^2 (1650 psi)
Hertzian Pressure at rolling point C
Pc = 1440 N/mm
Revolutions of the driving pinion
n = 3000 min^{-1}

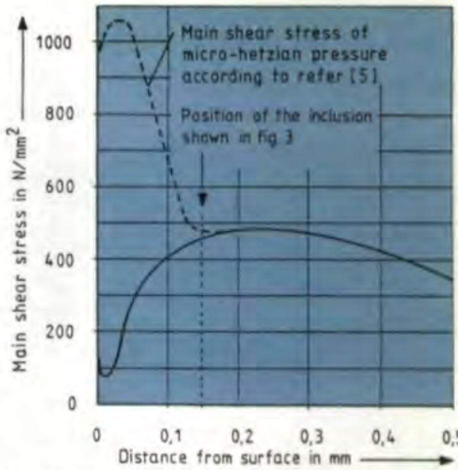


Fig. 1 – The path of the main shear stress into the depth with over laying of the Hertzian pressure and friction stress on a tooth flank. (See Table 1.)

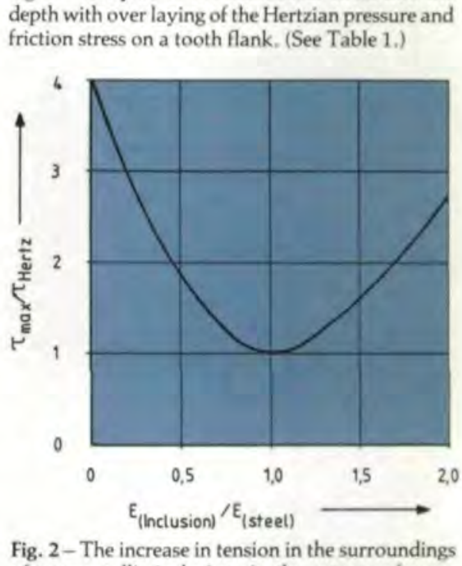
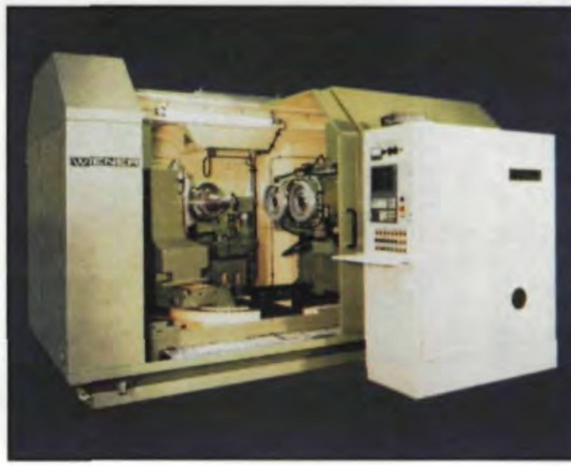


Fig. 2 – The increase in tension in the surroundings of non-metallic inclusions in the process of overrunning bearing steel 100 Cr 6. Reference 3: Findings from optical tension model tests in simulating the stress distribution on a contact line of a ball bearing inner ring 6309 for F_r = 19200 N radial load.

Fig. 3 – WEA starting from an oxide inclusion beneath the flank surface of a case-hardened gear of 16 Mn Cr 5.



16MnCr5 (See Table 2), with globularly formed sulfide inclusions in which a great number of very small WEA can be noticed in the area of high impact stress. These WEA result exclusively from inclusions; whereas, such occurrences cannot be found with long strips of manganese sulfide. Globular sulfides are harder than manganese sulfides due to combination with the sulfide influencing elements. The cracks that have been examined are never longer than some μ m and never have connection to the surface. (See Fig. 4.) The inclusions themselves are spread out very finely.

The Stress of the Gear Flank at the Beginning of Contact

It is a fact that WEA frequently occur in surface areas which are exposed to strong shock stress. In highly stressed gear pairs, the gear teeth that are in contact are deformed, so that the following gear tooth tip strikes against the flank of the driving pinion in the area of the gear tooth root too early. (See Reference 8.) This leads to an impact shock. Shown in Fig. 5 is the tooth stretching signal of the driving pinion under the conditions described in Table 1, which shows a very steep increase at the beginning of contact which points out a very high shock-type stress at the beginning of contact.

Metallographical examinations show that the greatest number of and the most prominent WEA could be found in this area. (See Fig. 6.)

Fig. 7 shows WEA at the surface which have occurred due to high stress caused by the impact shock. Their extension in depth is between 30 and 50μm. Beneath the surface, the WEA are limited by a crack which runs almost parallel to the surface. Due to the contact shock, there occurs locally high pressure as well as strong friction forces, because of which the flank surface is exposed to an extreme shear stress in this area. Shown in Fig. 8 is the path and the direction of the main shear stress relative to the local pressure on the flank for two friction values as a function of depth from the surface.

Only with increasing depth does the direction of the main shear stress come closer to an angle of 45° relative to the sur-

Table 2
Material and Heat Treatment

Chemical Composition

C: 0.16%
Si: 0.29%
Mn: 1.12%
P: 0.015%
S: 0.015%
Cr: 0.92%
Al: 0.026%

Heat Treatment

Carbonizing
940° C/3 hours/Carbon-Level 1.1
940° C/3 hours/Carbon-Level 0.8
830° C/1 hour/Carbon-Level 0.8

Hardened: Oil 60° C

Tempered: 180° for 3 hours

Fig. 4 – White etching areas at globular form sulfide inclusions beneath the flank surface.

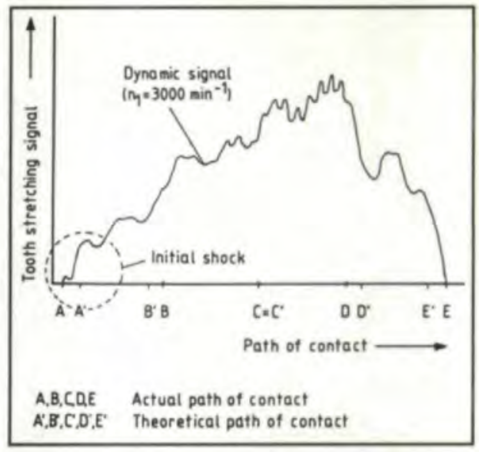


Fig. 5 – Tooth stretching signal in root of the pinion over the length of gear contact. (See Table 1.)

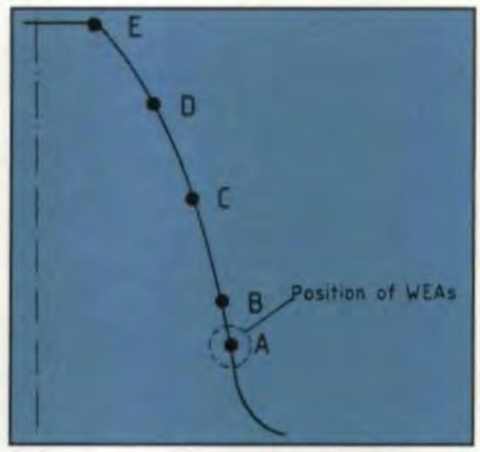


Fig. 6 – Position of the white etching areas in the area of the beginning of contact on the flank of the driving pinion.

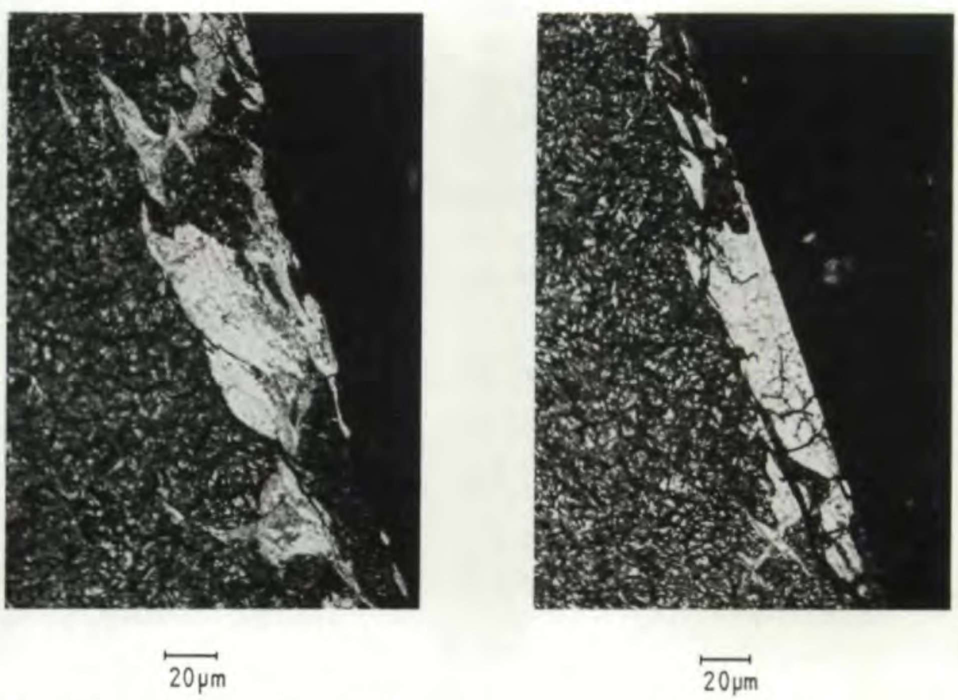


Fig. 7 – White etching areas in the area of the beginning of contact on the surface of a case-hardened pinion made of 16 Mn Cr 5.

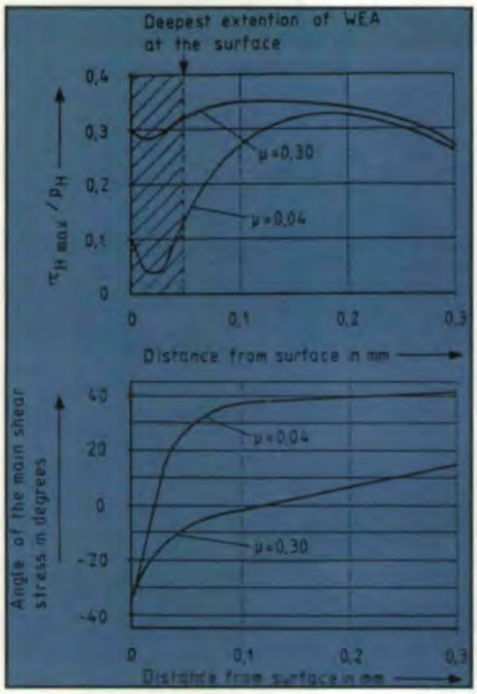


Fig. 8 – The path and the direction of the main impact stress for two different friction values.

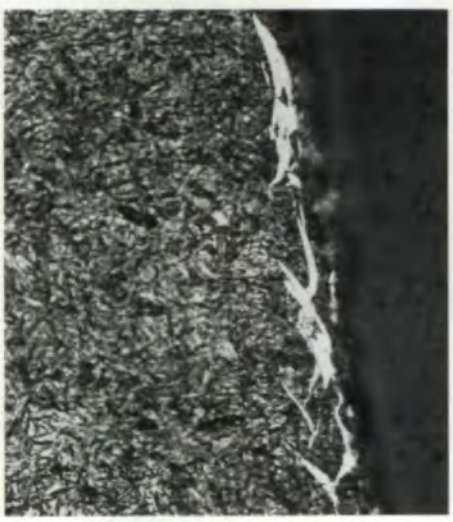


Fig. 9 – White etching area in the area of the surface in the direction of the main shear stress.

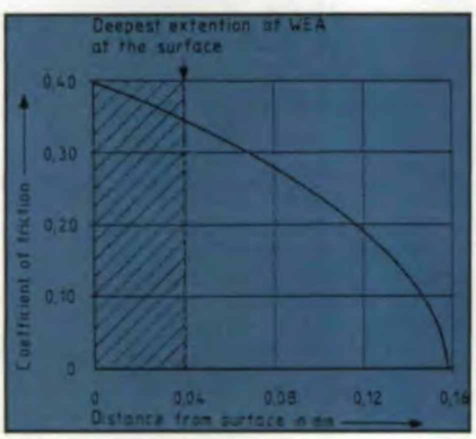


Fig. 10 – Location of the maximum impact stress with $P_H = 1440\ N/mm^2$ $b_H = 0.20mm$ in relation to the friction value.

face. Correspondingly, the angles of the WEA change as is pointed out in Fig. 9.

The position of the main shear stress minimum depends on the magnitude of the coefficient of friction. As shown in Fig. 10 from $\mu = 0.40$ onwards, the maximum main shear stress lies at the surface. As friction stress increases, the point at which the direction of the main shear stress reaches the 45° limit can be found as it travels deeper.

This connection, again, is valid only for ideal geometrical bodies. Since tooth flanks can be considered as technical surfaces, we have to take also into account the tension-increasing effect of the notches directly in the area of the impact shock beneath the surface according to Reference 5. (See Fig. 1.) Also favoring the formation of WEA is the local flash temperature, which again is largely dependent on friction value.

Caused by the effects of running-in, the

(continued on page 36)

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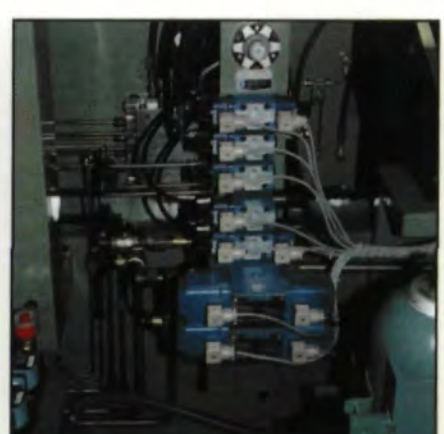

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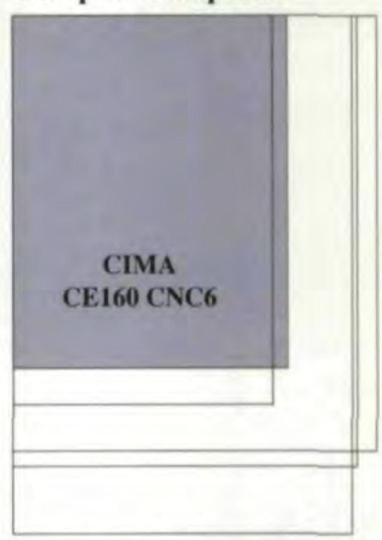

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Gear Grinding Fundamentals

Yogi Sharma, P.E.,
Philadelphia Gear Corporation
King of Prussia, PA

AUTHOR:

YOGI SHARMA *is employed in gear manufacturing and design at Philadelphia Gear Corp. He holds an M.S. degree in mechanical engineering from Villanova University and one in industrial engineering from Penn State. Mr. Sharma is a licensed mechanical engineer in the state of Pennsylvania and a senior member of SME.*

Introduction

This article deals with certain items to be taken into consideration for gear grinding, common problems that arise in gear grinding and their solutions. The discussion will be limited to jobbing or low-batch production environments, where experimental setup and testing is not possible for economic and other reasons.

Gear grinding is basically performed either to finish hardened gears or to enhance the accuracy of gears or both. The accuracy from gear grinding includes desired lead and profile modifications, lower spacing and runout errors, and high surface finish. Most of the time, gear grinding is associated with case-hardened gears where teeth have been cut before heat treatment, but through-hardened gears are also ground for higher accuracies. In the case of fine pitch gears, many times teeth are ground in a finished blank without any previous teeth cutting operation.

Gear Grinding Preparation

Following are some of the items which should be considered carefully in detail for successful gear grinding.

Preparation of the Gear Blank. The common statement, "A good gear blank is

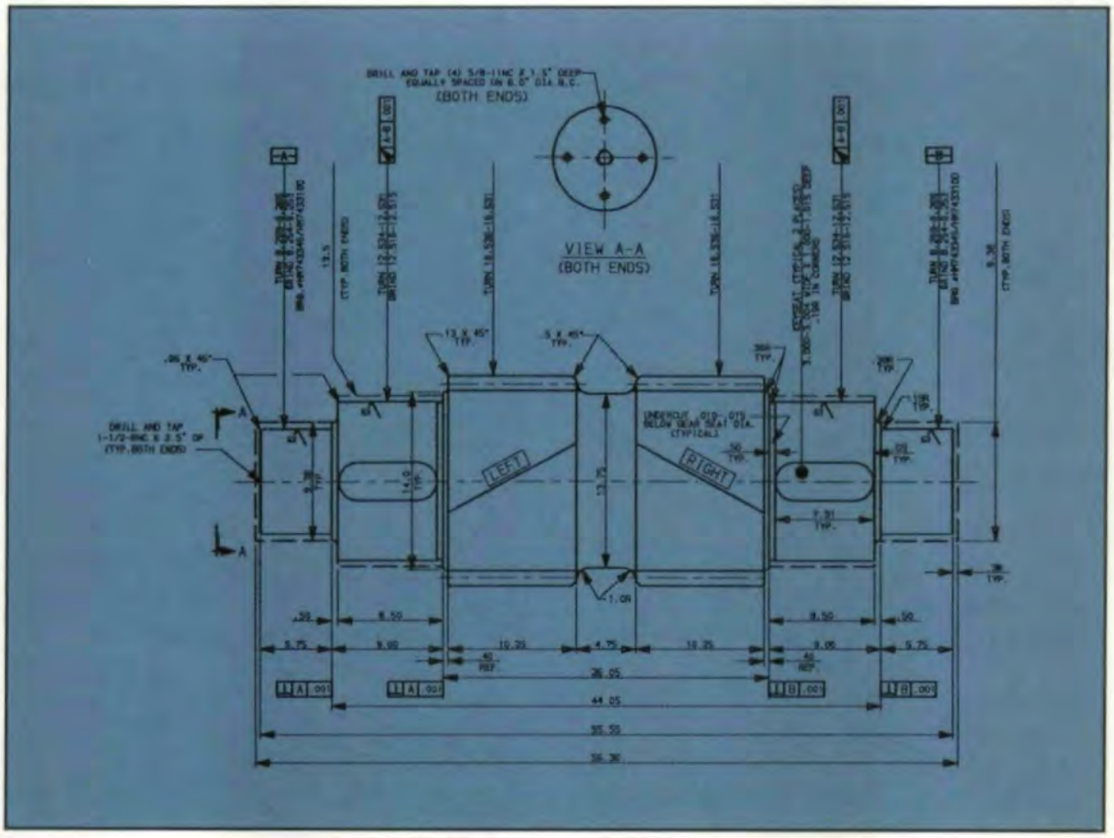

Fig. 1 – Double helical pinion shaft showing groove for grinding wheel clearance.

a must for a good gear," is very true for a successful gear grinding operation. As gear grinding is quite often the last operation in gear manufacturing, any compromise in gear blank design, processing, or manufacturing can cause unnecessary delays, poor quality, or rejected parts.

The following items should be considered for gear blank preparation.

Grinding Wheel Runout Clearance at Tooth Grinding. Gear blanks with constraints on one or both ends must be checked for proper grinding wheel clearance. These include double helical gears, pinion shafts with teeth running out in diameters higher than root diameter, etc.

The grinding wheel runout clearance is a function of many factors, such as grinding wheel diameter, helix angle, DPN, etc., but the grinding wheel diameter is the most influential item. One of the simple solution approaches is to provide designers a chart for runout clearance based on DPN, helix, and grinding wheel diameters on available machines, along with a machine capacity chart. This will allow designers to have a preliminary design with a reasonable accuracy, which must be verified by an appropriate person in manufacturing. Runout clearance values can also be included in gear design programs and provided to the designer with gear data. In cases of critical application, runout clearance can be fine tuned with dummy blanks on grinding machines.

Fig. 1 shows a double helical pinion; Fig. 2 shows a pinion shaft with runout

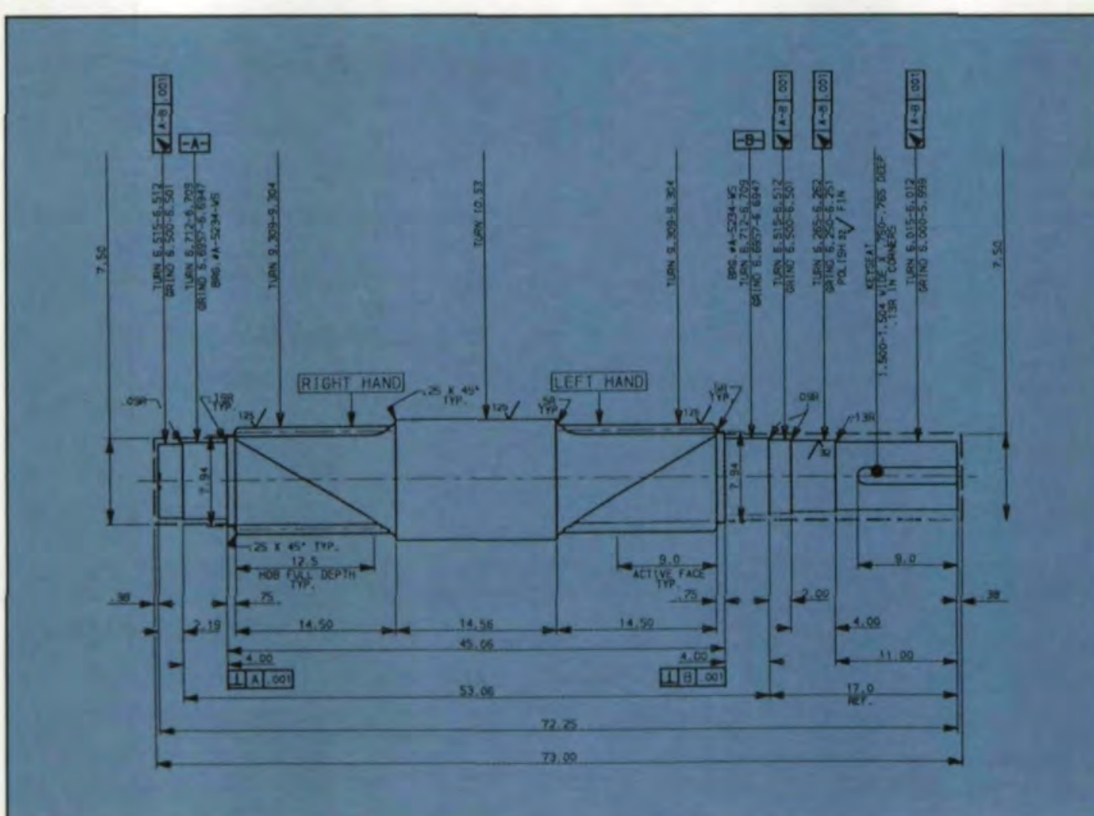

Fig. 2 – Double helical pinion shaft showing runout for grinding wheel clearance.

CIRCLE A-19 ON READER REPLY CARD

clearance for a grinding wheel, and Fig. 3 shows suggested values for double helical gear groove widths.

Selection of Proper Blank Tolerances. The tolerances of the blank, such as TIR of mounting or locating bore, squareness of the bore with mounting surface, etc., must be decided based on all related factors, including quality requirements. Fig. 4 shows some of these values on a simpler gear blank.

Preparation of Any Sub-Assembly Before Tooth Grinding. Fig. 5 shows a sub-assembly of a gear with a shaft. As in any final machining operation, prior sub-assembly work is quite helpful in achieving higher accuracies.

As shown in this sketch, if the teeth are ground after sub-assembly, the runout and squareness problems are minimized. These two problems arise because tolerances add up if the gear and shaft are sub-assembled after gear grinding.

Proper Indicating Proof Surfaces or Bands on Gear Blanks. Proof surfaces, a critical item in gear grinding, must not be overlooked. A gear reaching the tooth grinding stage without proper indicating surfaces can cause unsatisfactory quality and long delays. Fig. 6 shows an example of a gear with proof surfaces.

Blank Inspection Before Tooth Grinding. In certain critical applications, gear blanks must be checked for required values of runout and squareness of mounting surfaces to avoid poor quality and excessive delays. Random checks must be done on all work prior to tooth grinding.

Selection of Proper Quality Number. AGMA standard 390.03 is the most common gear quality reference guide in use in the U.S. The selection of proper quality class number is quite critical, as a lower number will not meet the design requirements, while a higher number will increase the cost. The selection of proper quality number should be made based on past experience, application, limitations of grinding machines, and many other factors.

Wherever possible, desired lead and profile charts should be defined clearly to avoid any confusion at gear grinding. The

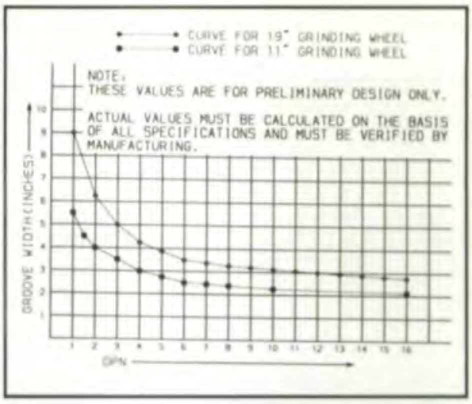

Fig. 3 – Groove width for double helical gears.

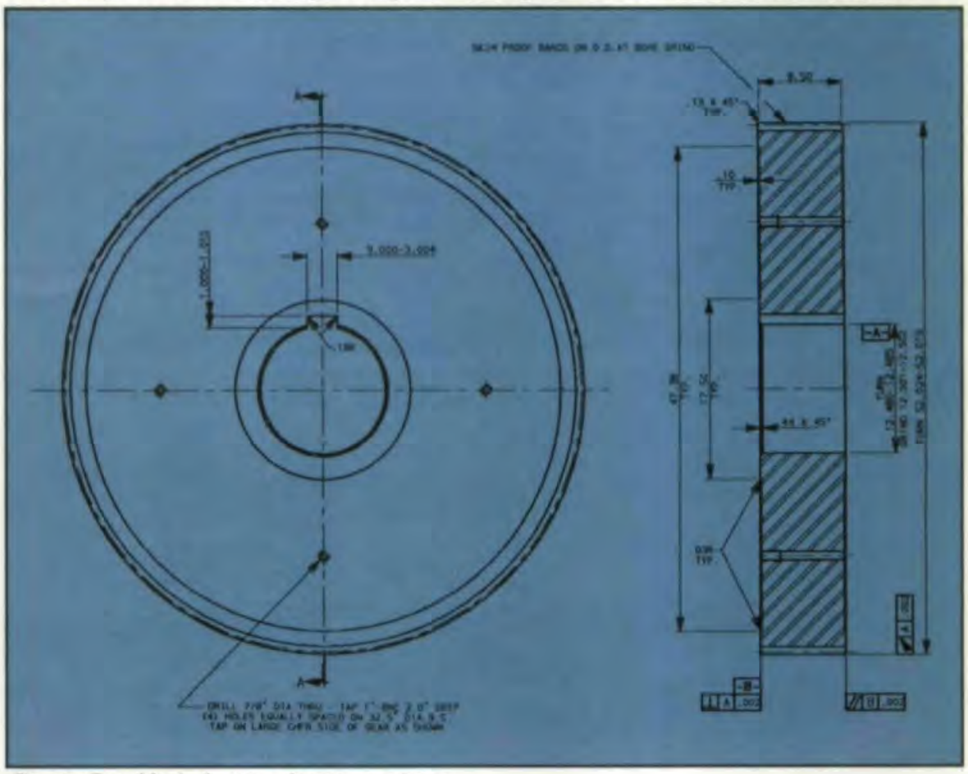

Fig. 4 – Gear blank drawing showing machining tolerances.

cost of tooth grinding increases at a much faster rate at higher quality levels than at lower levels. In other words, the cost of changing the quality number 10 to 11 is lower than changing 12 to 13. Cost is not the only factor to be considered. As quality number rises, the number of tooth grinding machines available to achieve the higher quality decreases, causing many other problems.

The matched sets approach is quite advantageous in high precision gears. In matched sets, the gear and pinion profiles and leads are matched in such a way that mismatch in a set does not exceed the tolerance on lead or profile for the applicable quality number. In matched sets conditions, one member, most frequently a gear with a higher number of teeth, is ground first and checked. The lead and profile charts are studied carefully, and modifications to achieve the desired match are made in the tooth grinding of the matching member. One disadvantage of matched sets is that any replacement in the future has to be made in sets, but on the other hand, in any critical application, replacement of one member is not desired anyhow. Also, in the case of matched sets, clear detailed advanced agreements between user and supplier can eliminate unnecessary misunderstandings and delays.

In some special cases, certain tolerance relief can be allowed in specific gear quality elements, which may reduce corrections at tooth grinding. Some examples are lead-in drives with eccentric cartridges and profile and lead-in hardened pinions over 55 Rc running with through-hardened gear less than 40 Rc.

Grinding Allowance and Heat Treatment. In simple words, grinding allowance in tooth grinding is extra material left on tooth flanks (and fillet, in cases where the fillet is to be ground). It is required to grind the tooth surfaces to proper profile, lead and other quality elements within specified tooth sizes. Excessive grind allowance causes many problems, such as longer grind time, loss of case depth, etc. On the other hand, insufficient grind allowance will result in undersize tooth thickness. Improper grind allowance (excessive or insufficient) will cause many problems, such as

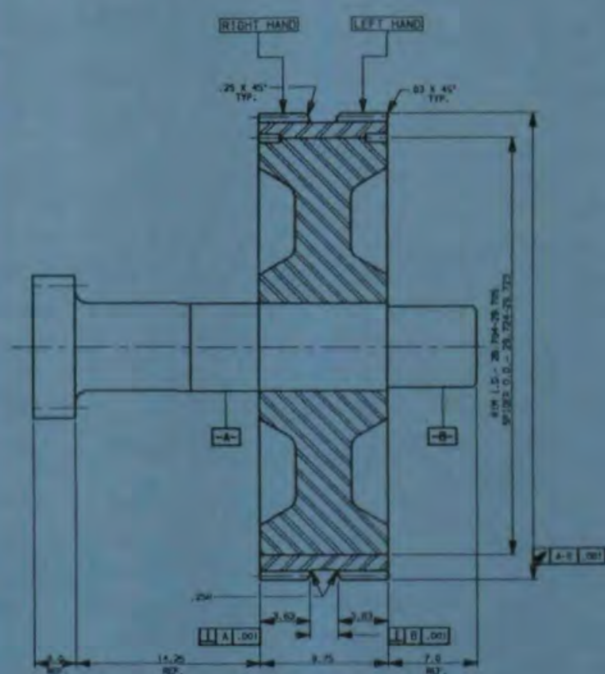

Fig. 5 – Sub-assembly gear and shaft.

higher costs, longer delays, and rejected parts in extreme cases or critical applications.

Following are some factors influencing grinding allowance.

Heat Treatment Method. The heat treatment method is very influential in selecting the amount of gear grinding allowance. Below are the commonly used heat treatment methods for gear teeth.

1. Case carburizing and hardening
2. Induction hardening (tooth-to-tooth and coil)
3. Case nitriding
4. Through-hardening

The distortions in nitriding are very low; whereas, they are quite predictable in the induction hardening process. Case carburizing and hardening distortions are quite complicated and magnify with size and shape. Many factors, such as design, material machining before heat treatment, shape of part, fixturing in carburizing, quenching, and machining after heat treatment, influence what a gear grinder will see when he makes a touch on a grinding machine.

Any compromise in one or more factors, affects the final outcome. Most of the factors are so interrelated and interconnected that many times the investigation and corrections are carried out at the wrong point. One of the most effective methods is to start with a completely open mind and record the results after every operation.

Machining of gears after heat treatment and before tooth grinding is very critical and must not be overlooked or neglected. A gear can be checked for runout in the plane of rotation on a turning or grinding machine with a roller in teeth, but there is no easy means of checking teeth in an axial plane. Quite often, overcorrections are made in one plane, causing extra problems in the other plane. One effective approach is to indicate proof surfaces created in machining before cutting and used in cutting in both planes. Another very effective method is to turn or grind proof surfaces after hardening and check the gear for runout and lead. Finish machine the gear bore and faces or shaft journals after making corrections based on runout and lead

Fig. 6 – Gear with proof surfaces.

charts, relative to proof surfaces created after hardening and used for setting on gear checking machines. The above method is effective, but needs two extra operations and a longer cycle. Also it is ineffective when a gear has irregular distortions, such as taper along length or oval shape of diameter.

Gear Blank Configuration. A well proportioned configuration of gear or pinion shaft will have fewer distortions in heat treatment. On the other hand, poor design will cause excessive distortions. Sometimes application or weight limitations make a blank unsuitable for case-carburizing and hardening. (See Fig. 6.) The above situation can be handled in a number of ways: either leave extra material all around or use quench press in final quenching. The use of quench presses with univeral dies in a jobbing enviroment needs much more planning and estimation than in mass or high production environments. In high production, customized dies are prepared and tested on sample pieces with different adjustments on quench press, and setups are completely optimized for production. On the other hand, a jobbing environment does not allow detailed testing or customized tooling. Whenever there is more than one piece in a batch, the first piece should be die quenched and measured before quenching the rest of the pieces, allowing the tool modification and setup adjustments for better results. Another recommended approach in quenching is to start with a lower clamp and expand pressures rather than high values, which may cause excessive growth, resulting in various problems at tooth grinding. (See Fig. 7.)

Tooth Size. DPN or module, helix angle, outside diameter, face width, etc., all affect the amount of grinding allowance required. For example, the working depth on a 2 DPN is twice that on a 4 DPN tooth.

Gear Application. Certain applications need much tighter control on tooth thickness than others. In the case of an application with tighter tooth thickenss requirements, higher grind allowances can avoid tooth thickness problems at tooth grinding.

Some other factors affecting grind allowance are gear cutting operation and equipment, gear grinding equipment, gear quality requirements, etc.

Selection of Proper Cutting Tools. High production allows the use of customized tools with optimized grinding allowance and protuberance, while low quantity production imposes the use of universal tooling as much as possible. The following steps are suggested to maximize the use of pre-grind tools with best possible conditions at gear grinding.

a. Standardize fillets for all new designs and use them wherever possible. Fig. 8 shows a comparison of standard fillets and full fillets.
b. Select and standardize grinding allowance on the basis of various factors discussed previously.

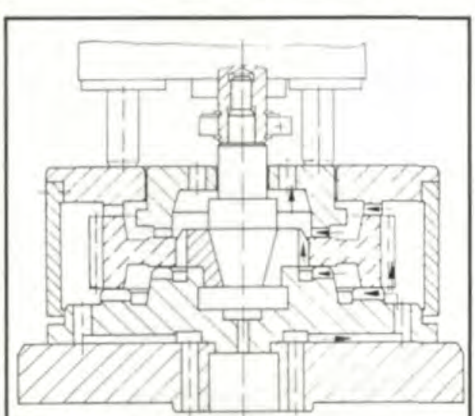

Fig. 7 – Quenching a cylindrical gear with special configuration. (Courtesy Klingelnberg Corporation.)

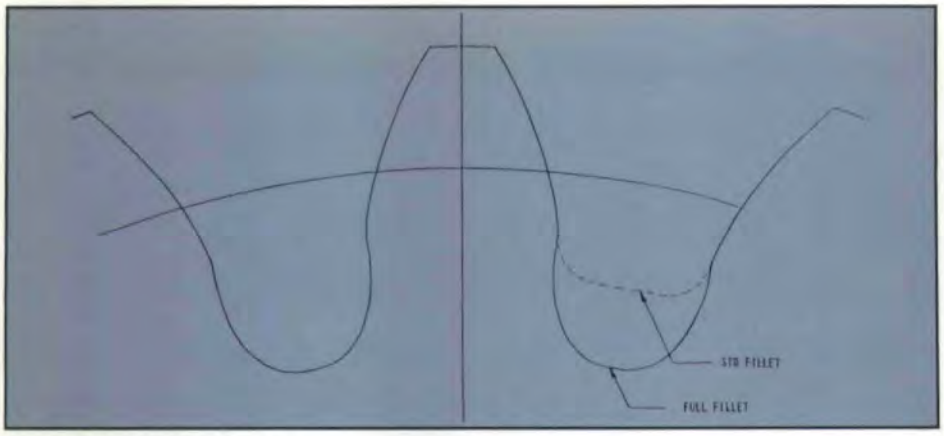

Fig. 8 – Standard fillet vs full fillet.

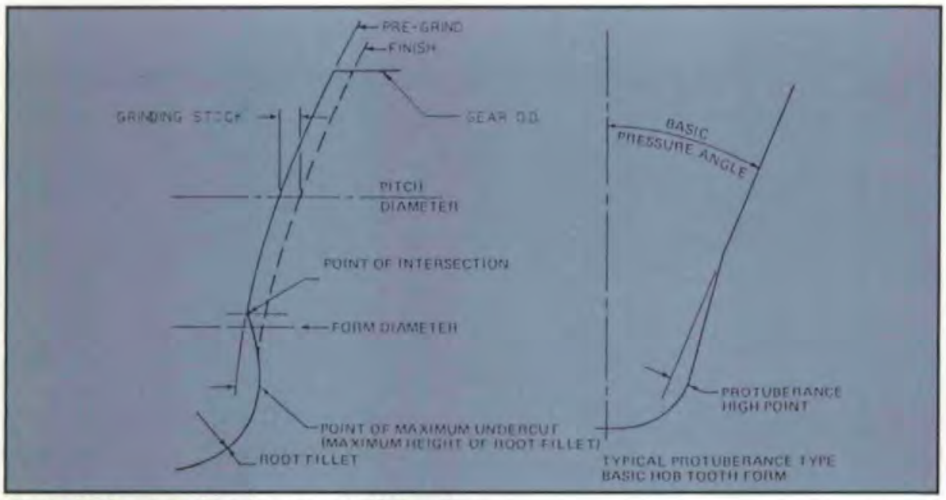

Fig. 9 – Undercut produces by a pre-grind hob and a protuberance type hob.

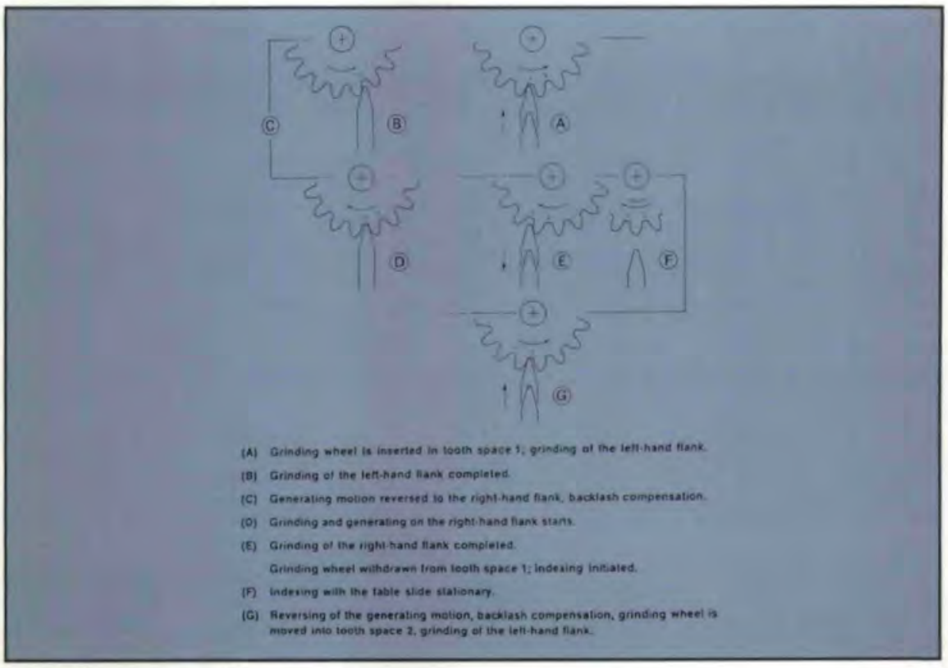

Fig. 10 – Representation of the gear grinding process. (Courtesy of BHS Hofler, Ettlingen, West Germany.)

c. Select protuberance on the basis of DPN. Excessive protuberance on gear cutting tools can cause unclean profile above TIF (SAP) at tooth grinding, while insufficient protuberance can cause grinding step problems. Fig. 9 shows undercut produced by a pre-grind hob and a protuberance type hob.
d. Adjust the thickness of all pre-grind tools on the basis of grinding allowance.

The universal tool selection always causes certain shortcomings at tooth grinding, and constant monitoring must be done to avoid major problems.

The importance and necessity of customized tooling for all critical and special applications cannot be overemphasized. In such cases, an optimized tool always avoids many problems at tooth grinding.

Grinding Process

Tooth grinding of gears can be classified into two main processes: generating grinding and form grinding. In generating grinding, the teeth are ground as the gear rolls in relation to the reciprocating grinding wheel. The process is similar to gear meshing with a straight sided rack. The three most common methods or machines are:

Conical Wheel Machines. As shown in Fig. 10, both flanks are ground independently. After each tooth is completed, the machine indexes to the next tooth until the gear is ground. Desired lead and profile and modifications are made on the machine. The profile is modified by grinding wheel dressing, and lead modifications are obtained through the use of cams.

Saucer Wheel Machines. In this method, the gear being ground has oscillating rolling-generating motion, while two grinding wheels sweep out the involute profiles by the relative motion. The two most common methods are 0° grinding method and 15°/20° grinding method.

The two most common types of these machines available are the horizontal type and vertical type, each suitable for different sizes, etc.

Threaded Wheel Machines. Threaded wheel machines operate on the same principle as gear hobbing machines. Threaded wheel machines are quite productive, but have limitations in pitch and overall size.

Form Grinding. This process uses a form grinding wheel to grind both flanks, while the work piece is maintained in a fixed radial position. Form grinding is quite useful in many applications, and both external and internal gears can be ground by this method.

Grinding Wheel Selection. Selection of the grinding wheel is quite important in gear grinding. Following are some of the variables to consider when choosing a grinding wheel. (Fig. 11).

Abrasives. The four main abrasives in use are

a. Aluminum oxide (AL_2O_3
b. Silicon carbide (SC)
c. Cubic Boron Nitride (CBN)
d. Diamond

The use of "cubic boron nitride" is increasing every day. It is still mainly limited to form grinding in gears but much research into its use in grinding is being done. Diamond is rarely used in gear grinding.

The other variables in grinding wheel selection are grit size, grade or hardness, and structure. A properly selected wheel should maintain its form for a reasonable period and produce the required surface finish without burning the tooth surface. Grit that is too hard and fine will maintain its edge and give good surface finish, but material removal is slow and chance of burning is too high. On the other hand, soft and coarse grit will remove metal fast without burning, but the edge wear will be high. The consumption of the soft wheel is also high.

One simple rule of selecting grade or hardness is "the harder the material, the softer the grind wheel and vice versa". To get satisfying results from grinding wheels, the following are suggested.

a. Monitor the performance of the grinding wheel constantly.
b. Maintain good records.
c. Work with a limited number of suppliers.
d. Select the grinding wheel based on heat treatment, pitch, surface finish, and other factors.
e. Continue some kind of program to upgrade the grinding wheels. Besides grinding wheels, the dressers and dressing equipment must be maintained properly.

Coolant for Wet Grinding. The importance of the proper selection of coolant in wet gear grinding must not be underestimated. The use of coolant reduces the grinding wheel loading, lowers

(continued on page 37)

Abrasives Standard Marking System

This chart presents symbols found in a typical grinding wheel specification — they represent the variable components of a grinding wheel. The marking sequence conforms to the standard system used throughout the grinding wheel industry.

9A	46	K	5	V
ABRASIVE TYPE	**GRIT SIZE**	**GRADE**	**STRUCTURE**	**BOND TYPE**

ABRASIVE TYPE

Reg. Alumn. Oxide	A
Spec. Alum. Oxide	2A
Spec. Alum. Oxide	3A
Spec. Alum. Oxide	5A
Spec. Alum. Oxide	8A
Spec. Alum. Oxide	16A
Spec. Alum. Oxide	17A
Spec. Alum. Oxide	19A
White Alum. Oxide	9A
Tough Alum. Oxide	27A
Tough Alum. Oxide	BA
Tough Alum. Oxide	TA
Reg. Sil. Carbide	C
Green Sil. Carbide	1C
1/2 Reg. Sil. Carbide 1/2 Green Sil. Carbide	3C
Combination of Alum. Oxide and Sil. Carbide	CA MA

GRIT SIZE

COARSE: 10, 12, 14, 16, 20, 24
MEDIUM: 30, 36, 46, 54, 60
FINE: 70, 80, 90, 100, 120, 150, 180
VERY FINE: 220, 240, 280, 320, 400, 500, 600

GRADE

SOFT: C, D, E, F, G, H, I
MEDIUM: J, K, L, M, N, O, P
HARD: Q, R, S, T, U, V, W, X, Y, Z

STRUCTURE

DENSE: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11
KOOLPORE WHEELS 12
KOOLPORE WHEELS 13, 14, 15, 16
OPEN

BOND TYPE

B=RESINOID
F=BAYFLEX
M=METAL
R=RUBBER
V=VITRIFIED

Fig. 11 – Standard marking system for abrasives. (Courtesy Bay State Abrasives Division, Abrasive Industries, Inc.)

stress in the area of the beginning of contact decreases with an increasing number of stress cycles. It can therefore be expected that the WEA would occur at this spot following a comparatively short amount of time.

Specific Characteristics of the Examined White Etching Areas

Structure and the composition of WEA have been metallographically examined on a broad basis in various research tests. The findings with case-hardened gears are largely in agreement with the aforementioned research. According to our measurements on our sample, the microhardness of the WEA at the surface is based on an average of 1200 HV_1, clearly higher than that of the surrounding matrix with about 850HV_1.

The WEA at the surface examined on the light electron microscope show a partly porous structure which points to a tempering process. (See Fig. 11.) Also, with the light microscope, regions of a darker color can be seen within the WEA. It is still unclear whether within the surface near the WEA, as shown in Fig. 12, such high temperatures can occur that can temper the

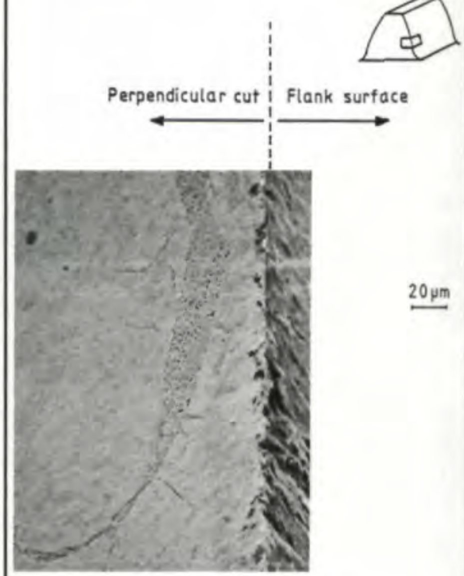

Fig. 11 – Porous structure in the surface area of a gear flank.

Fig. 12 – Partly tempered WEA at the flank surface.

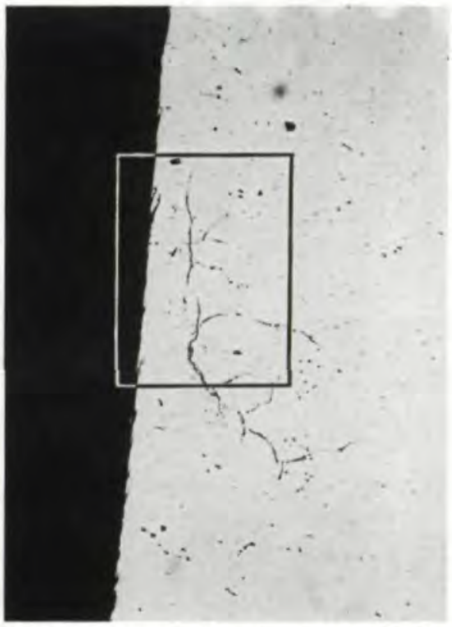

Fig. 13a – Crack near the surface (unetched slide).

Fig. 13b – View magnification of the crack shown in Fig. 13a that is bordered with white etching area. (Etched with HNO_3.)

(continued on page 39)

operating temperatures, increases grinding wheel life, and gives better surface finish on teeth flanks. The following considerations should be noted when selecting and using a gear grinding coolant.

a. The quality of gear grinding coolant must not be sacrificed in the name of coolant standardization.
b. Gear grinding coolant must be constantly monitored for contamination and dilution.
c. Samples from every machine or system should be taken out, periodically checked, and results recorded.
d. Wind deflectors should be used where necessary.

   The surface speed of a grinding wheel is quite high, causing an envelope of high-speed air to form around it. Consequently, the velocity of coolant must be high enough to penetrate the air layer. The use of a wind deflector is very helpful in this situation.
e. Sparking must be eliminated as soon as it occurs. Sparks during wet grinding usually indicate that coolant is not reaching the required spot in sufficient quantity. It indicates intermittent heating, which is highly undesirable, as it can lead to surface tempering or cracking or both.

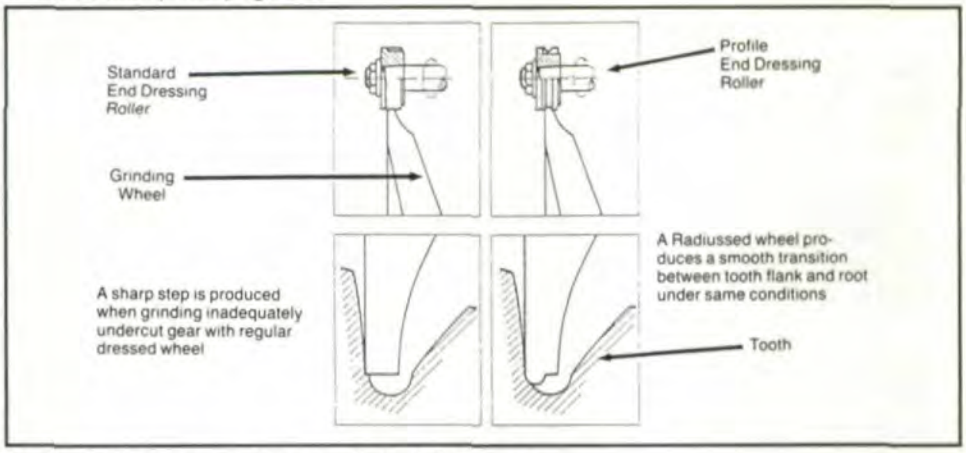

Fig. 12 – End dresser options for saucer wheel grind- ing machines.

Gear Grinding Problems and Suggested Solutions Approach

Gear Grinding Steps. Grinding steps in tooth fillets have various causes and are very detrimental. They act as stress risers and also reduce the critical case depth in tooth fillets. Any subsequent work performed to remove the steps raises the cost and can cause various other problems. Here are some suggested approaches to eliminate or reduce the steps in tooth fillets.

a. Always use a hob with proper protuberance, thickness, blend angle, fillet radius, etc.
b. Use the correct amount of grinding allowance on tooth thickness at cutting.
c. Grind the tooth flank to proper depth. Define and use the point of maximum undercut in grinding setup.
d. Continuously train and educate personnel.
e. Monitor and resolve problems by immediate attention.

Sometimes it will be quite difficult to avoid steps completely, because of excessive distortion at heat treatment, use of improper tools, excessive grinding allowance, etc. In such cases, use of a grinding wheel with tip radius can avoid sharp corners in grinding steps. The amount of radius can be selected on the basis of DPN, grinding machine, and all other factors. The same approach can be used in conical wheel machines. (See Fig. 12.)

Gear Grinding Cracks. Gear grinding cracks or grinding checks usually indicate that there is process control problem, either in heat treatment or in gear grinding or both.

Heat Treatment. The correct amount of case carbon content is very critical, as an insufficient amount can cause low hardness problems; whereas, excessive case carbon content can cause the presence of retained austenite. The grinding process generates pressure and heat, which causes transformation. Retained austenite transformation at grinding is considered a source of surface tempering or cracks or both.

Free carbides or carbide networks in case structures is another side effect of excessive case carbon content. Excessive hardness of the material (free carbides) can cause localized overheating. Overheating during the grinding operation results in surface tempering or cracks or both.

Heat treatment operations usually result in some film on the surface of heat treated parts. This scale must be removed before grinding, as it tends to load the grinding wheel. Surface oxidation in heat treatment produces a thin layer of decarburized and soft material on teeth flanks. This material loads up the grinding wheel, causing overheating, leading to surface tempering or cracks or both.

Excessive distortions in an irregular pattern make it difficult for machine operators to locate the highest point on the gear tooth surface. If the grinding cut is not started at this point, excessive amounts of material will be removed during the cut from high points. Excessive cuts will generate overheating and can lead to cracking or surface tempering or both. This problem can be handled easily by the machine operator on a machine with threaded wheels and continuous indexing.

Gear Grinding. The variables in gear grinding operations are the gear grinding machine, the grinding wheel, the grinding coolant in the case of wet grinding, and grinding machine setup.

Any problem with one or more variables can lead to various problems, including cracks on teeth. As discussed before, overheating or excessive heating at any point in the grinding operation can lead to surface tempering or grinding cracks or both. This overheating can be caused by a combination of factors, such as malfunction of the gear grinding machine, use of an improper grinding wheel, unsuitable coolant or improper positioning of coolant nozzle, and an excessive amount of cut or material removal.

Gear Grinding Cost. In a jobbing or low batch production, gear grinding cost is an important matter. The estimation is normally based on many factors in grinding, such as number of teeth, DPN, helix angle, face, material, grinding allowance, quality, method, machine, etc., and the final number is corrected on the basis of past experience. Somehow, the estimation usually falls short of actual time. In the current competitive world, the gear grinding cost has to be maintained at a reasonable level. Below are some suggested approaches.

a. Setup preparation cannot be overemphasized in a low production atmosphere. It is a good practice to have more than one item ready for the grinding machine. In case something goes wrong at the last minute with the first item on line, the next on line can be started without excessive idle time.
b. Heat treatment distortions or metallurgical characteristics and inadequate manufacturing process control will deliver gears with high inaccuracies to gear grinding, which will increase grinding time. Therefore, a good control at heat treatment and manufacturing process will not only cut grinding times, but will also reduce scrappage and enhance quality.
c. A good preventative maintenance of gear grinding machines will keep downtime minimum.
d. Training and education of personnel is quite critical and must not be overlooked.
e. Use of skiving hobs can be very helpful in many ways, such as removing most of the distortions and delivering a gear to grinding with limited grind allowance, reducing grinding time, removing any heat treatment scale or decarburized and soft layers of material from teeth flanks, reducing the possibility of the surface tempering or grinding cracks or both.

Miscellaneous

Stress Relieving After Tooth Grinding. A stress relieving operation after tooth grinding is highly desirable in all critical applications. This stress relieving minimizes the possibility of latent grinding cracks. Latent grinding cracks are the cracks that develop in the storage or early period of use. The typical stress relieving for case-carburized and hardened parts is around 320°F for four hours, which can be further refined for every application. This stress relieving must be carried out as soon as possible after tooth grinding, as any excessively delayed stress relieving may be too late.

Grinding Allowance at Tooth Cutting. As discussed earlier, excessive grinding allowance causes many problems. To avoid excessive material left at teeth cutting, all cutting personnel should be trained, parts must be checked, and sizes recorded after teeth cutting. In cases where Q.C. personnel are not available, these steps can be taken by shop supervisors.

Use of a Quench Press. The use of a quench press with proper setup can keep distortions well in control. Many complicated parts can be pre-machined to suit quench press use.

Prequenching and Tempering. Prequenching and tempering of rough-turned gear blanks can be advantageous in stabilizing and estimating growth of a gear in final heat treatment.

Checking. All ground parts must be checked for cracks after grinding. It is also very important to do frequent magnaflux inspection during the grinding operation, particularly in case of a large batch or big gears, to catch any problem at an early stage.

Handling of Gears With Grinding Cracks. Any part with severe grinding cracks or surface tempering cannot be salvaged. The suggested approach for parts with minor problems include: stress relief, regrinding to remove cracks, magnaflux inspection for cracks, checking final tooth sizes, and reporting all findings to the engineering department for disposition.

Gears With Close Tooth Thickness Tolerances. Many applications need close tooth tolerances. A practical approach is to keep an approved master in the same environment as gears being ground and compare sizes. For the most part, the first piece of a batch can be used as a master after complete inspection.

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WEA structure.[10]

As a condition for the formation of WEA under high stress, we must also consider the initial structure and the heat treatment of the steel which influences the distribution of the carbides.[11] The more even the carbides are spread out, the better conditions are for the formation of WEA. Table 2 lists the heat-treatment data for the examined gears.

Possible Connection Between White Etching Areas and Flank Damage

Fig. 13a shows a crack beneath the surface of a tooth flank on an unetched slide. Fig. 13b shows the crack at the HNO_3 – etched slide in an area magnification.

The fact that the crack is bounded with WEA, in accordance with the theory described in Reference 10, points to a very high crack propagation. The question whether the crack has a connection to the surface cannot be answered by just a single plane of a cut; however, we have to assume that such cracks can lead to pitting. Figs. 14 and 15 show slides of tooth flanks of a driving pinion with white etching areas near the beginning of contact and a frontal view of the damaged flank.

On both pictures, the lower part of the flank is characterized by strong fatigue scratches and pores due to the high stress of the impact shock. Starting in this zone, pitting stretches out in the negative slippage area which caused the failure of the pinion.

The WEA that are shown as a light electron microscopical picture lie directly on the surface. (See Fig. 16.) In the right half of the picture the strongly fatigued tooth flank around the WEA can be discerned.

Based on the theory in Reference 10 about the formation of WEA, there is the following connection between WEA and flank damage in case-hardened gears.

At hard, non-metallic inclusions, high shear stresses that lead to the formation of limited cracks can occur locally. If the inclusions lie deeply, the crack does not extend to the surface, but it can favor an outbreak of pitting by growing together with a crack originating at the surface. It cannot, however, be regarded as the cause of the pitting. Inclusions below the surface certainly do not primarily have an influence on flank damage.

In zones of high stress, for example at the beginning of contact, WEA occur at the surface due to strong friction and high flash temperature. Simultaneously, high shear stresses lead to the formation of cracks from which pores and, later on, pitting may arise. In this case WEA cannot definitely be seen as the cause of the large pittings. Rather, WEA are an indicator for the occurrence of high shear stress. Thus, as an example, they allow for the conclusion of high friction values at the beginning of contact.

Obviously, the material composition and the state of the structure are the criteria for the formation of WEA. A case-hardened outer layer with fine carbide distribution, as could be found in the examined gears, seems to favor the formation of white etching areas.

Conclusion

In this essay the phenomenon of white etching areas on the flanks of highly stressed case-hardened gears has been described. It can be assumed that WEA are not the cause of fatigue damage on tooth flanks. Their occurrences in zones of high shear stresses, however, can provide qualitatively valuable indications of the

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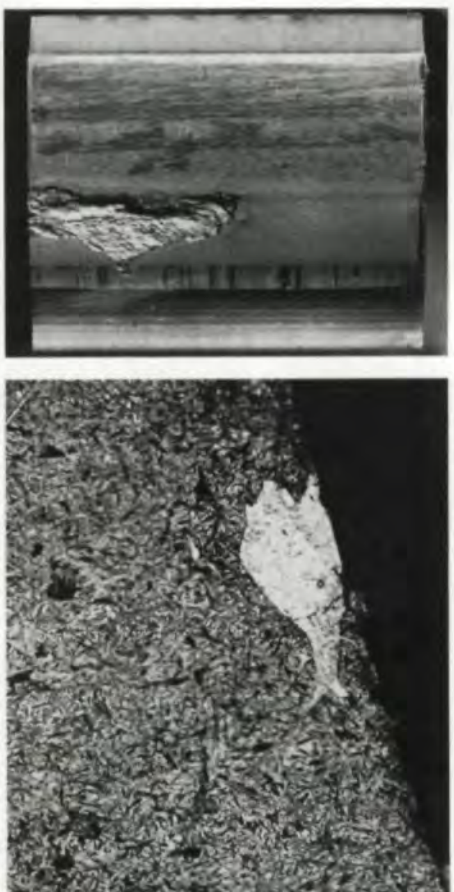

Fig. 14 – Flank damage on a pinion. WEA at the surface in the area of initial pitting (P_c = 1600 N/mm²).

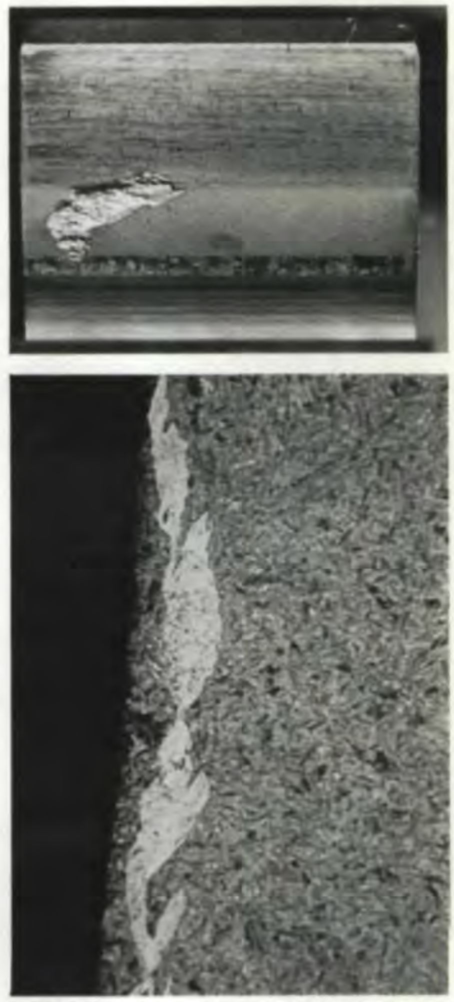

Fig. 15 – Flank damage on the pinion WEA at the surface in the area of initial pitting. (P_c = 1560 N/mm₂).

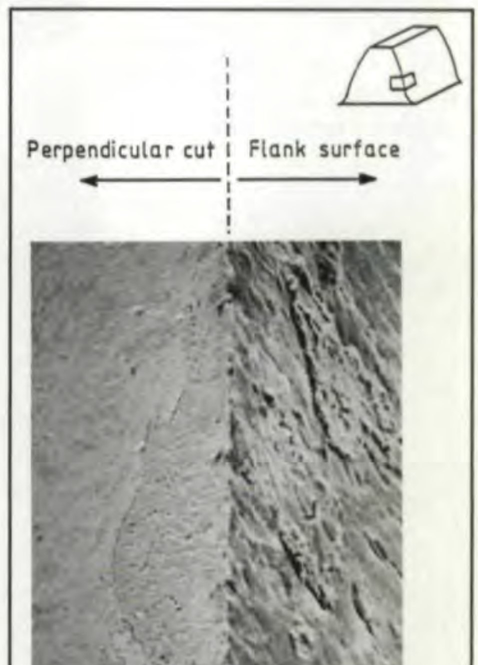

Fig. 16 – WEA on the fatigued flank surface of a driving pinion in the area of the first point of initial shock.

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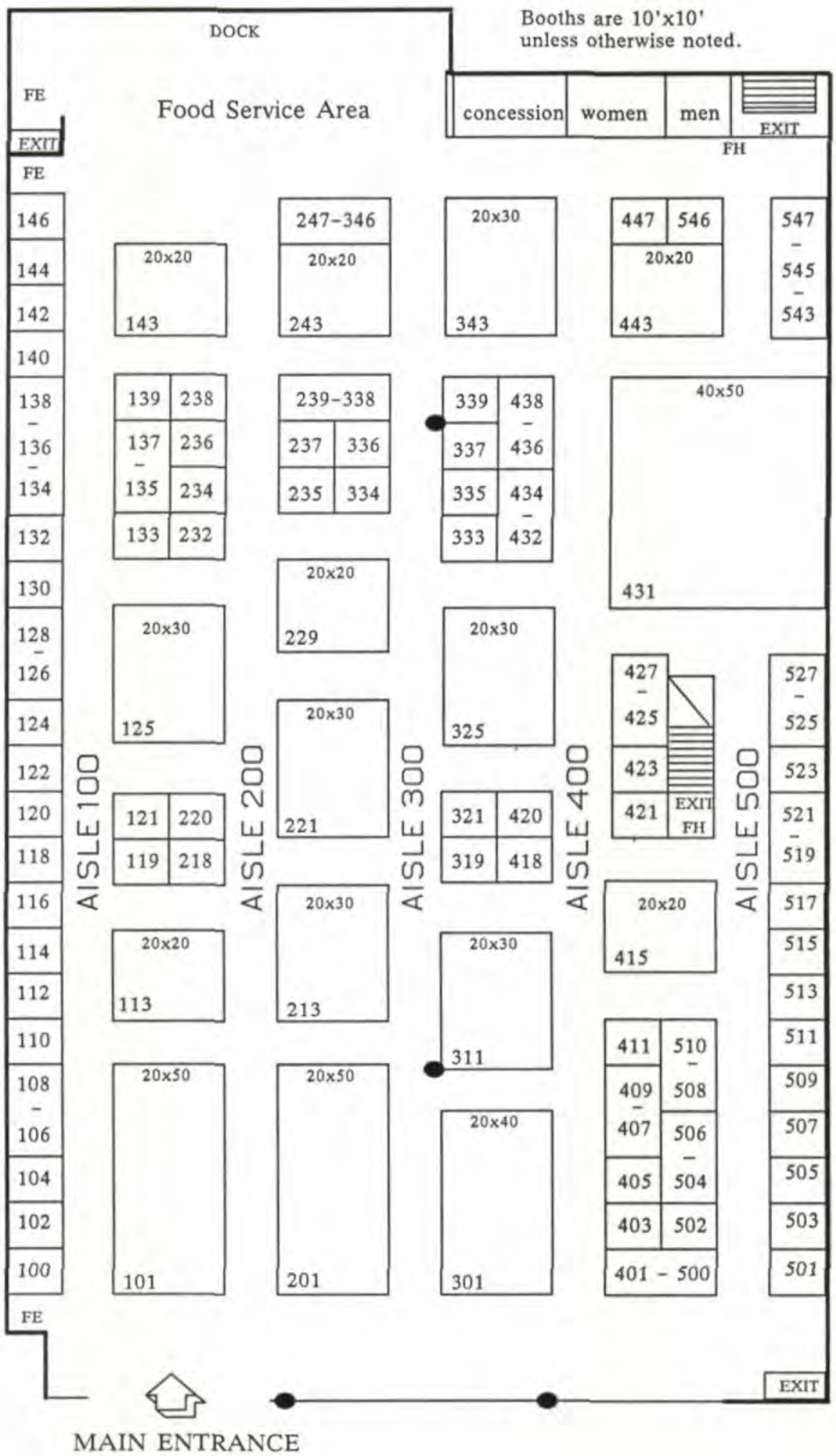

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WHITE ETCHING AREAS . . .
(continued from page 39)

size and direction of the stress, and they can point out possible starting points for flank damage.

In order to come to a quantitative conclusion about the definite connection between calculated paths of tension and the formation and direction of WEA on the tooth flanks, a further analysis must examine the influence of residual stress, which, especially at the surface, must not be neglected.

It is also unclear whether the temperatures that locally occur at the flanks can cause a tempering process, and, thereby, the decay of the WEA structure over a longer time.

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A world leader in Quality Gears and Transmissions has immediate openings in its Engineering Department at its Newton, N.C., manufacturing location.

Applicants should have C N C and gearing experience and M.E. Degree.

These entry level positions offer competitive salaries and a solid benefit package.

Send resume and salary requirement to:

R.G. Patrick – Personnel Director
Getrag Gears of North America
1848 Getrag Parkway
Newton, North Carolina 28658
EEO – M/F/H/V

Chief Engineers/Manufacturing Processing Engineers

$45,000-$65,000,
Gear Processing/Design/Quotes.

Ann Hunsucker, **Excel Associates**
P.O. Box 520, Cordova, TN 38018
(901) 757-9600 or Fax: (901) 754-2896

Manager Mechanical Engineering

Our company, a leading manufacturer of machine tool and related products, currently has an opening for a **Mgr./Mechanical Engineering.** The ideal candidate will have the following background and qualifications: 8-10 yrs. of mechanical engineering experience in gear production equipment and gear cutters, 3-5 yrs. in a supervisory capacity, strong leadership qualities and a BSME. Starting salary in 50K range, plus bonus plan participation. Send resume to: Box HM, c/o of Gear Technology, P.O. Box 1426, Elk Grove Village, IL 60007

Rates: Classified Display—per inch (minimum 3) **1X**-$130, **3X**-$120, **6X**-$110. Type will be set to advertiser's layout or *Gear Technology* will set type at no extra charge. **Word Count:** 35 characters per line, 7 lines per inch.

Payment: Full payment must accompany classified ads. Mail copy to *Gear Technology,* P.O. Box 1426, Elk Grove Village, IL 60009. **Agency Commission:** No agency commission on classifieds.

Material Deadline: Ads must be received by the 25th of the month, two months prior to publication. **Acceptance:** Publisher reserves the right to accept or reject classified advertisements at his discretion.

Just For Fun Gear Nomenclature

Gear – Equipment used for recreational activity (e.g., fishing gear or hunting gear)

Pinion – What everyone has. (Some are not worth much.)

Rack – To arrange billiard balls before a game.

Worm – Used with fishing gear.

Teeth – Hard bones in jaw. (Or in glass next to bed.)

Pitch – To throw.

Pressure Angle – To fish in a tournament.

Base Circle – Group of unsavory friends.

Pitch Line – Space between home plate and pitchers mound.

Base Pitch – A throw to first.

Normal Plane – One with wings.

Hand – An appendage with four fingers and a thumb. (Some are all thumbs.)

Lead – Element number 82 on the Periodic Table.

Mounting Distance – Space between rear end and saddle.

Backlash – Q.C.'s reaction to an engineering print change.

Tip – Sage advice from a gear expert.

Tip Relief – When gear expert finally stops giving advice.

Fillet – Boneless strip of meat.

Tolerance – Number of cups of coffee that an engineer can drink without relief.

Runout – When there isn't any more.

Mating Gears – Where other gears come from.

Tight Mesh – What mating gears need.

Addendum – When you take 2 + 2 and get 4, you have addendum up.

Shaft – What we all get now and then.

Bearing Surface – That part not covered by a bikini.

Key Way – The best route to the coffee machine.

Scrap – An argument with the foreman before parts are sorted.

Sort – What overtime is used for.

Engineering – (Railroad term) Train getting close, watch it!

Q.C. – Something we do before gears are shipped away.

Gear Blank – The look on a person's face when gears are mentioned.

Courtesy of CIMA USA

FORMASTER

Gear Expo '89
Booth #545

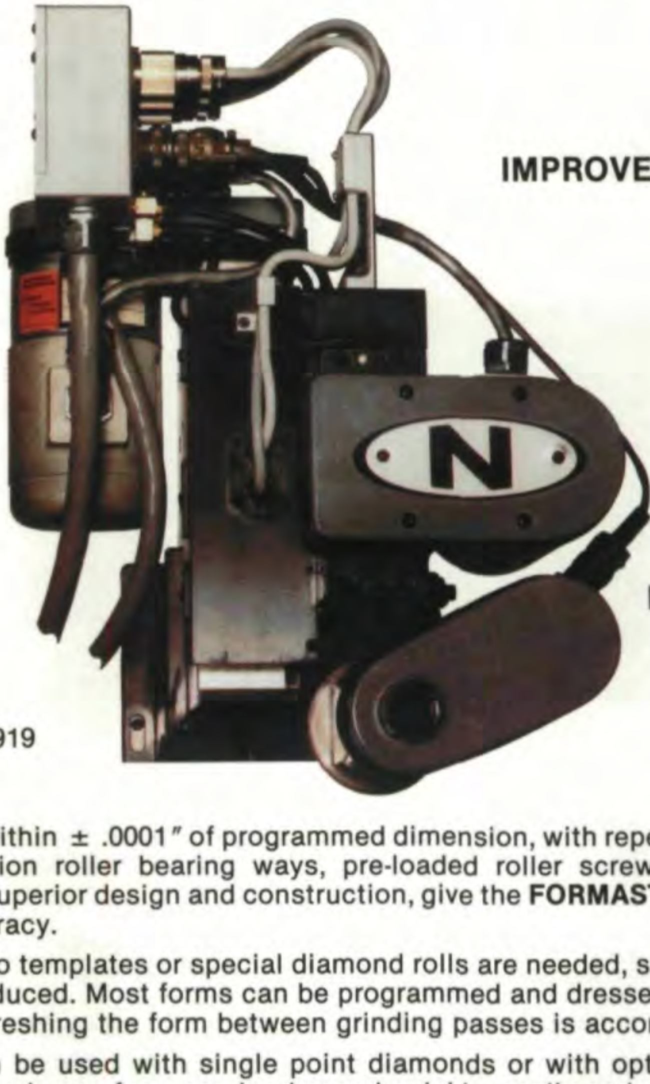
GRINDING WHEEL PROFILER

EASY TO INSTALL — Because of its small size and weight, the **FORMASTER** does not require major machine modifications and can be installed on nearly any grinder. Installation can usually be accomplished in less than a day.

EASY TO OPERATE — Two axis design simplifies programming and operation. You can choose between four popular controls that feature menu and G-Code programming, graphic simulation, automatic corner rounding, automatic diamond thickness compensation, and more.

IMPROVES ACCURACY

MADE IN U.S.A.



REDUCES WHEEL DRESSING TIME

Patent No. 4,559,919

ACCURATE — To within ± .0001″ of programmed dimension, with repeat accuracy to within .00006″. Extra precision roller bearing ways, pre-loaded roller screws and optical linear encoders, as well as superior design and construction, give the **FORMASTER** the ability to hold inspection gage accuracy.

PRODUCTIVE — No templates or special diamond rolls are needed, so lead times and tooling inventories are reduced. Most forms can be programmed and dressed in, ready to grind in 30 to 45 minutes. Refreshing the form between grinding passes is accomplished in seconds.

VERSATILE — Can be used with single point diamonds or with optional rotary diamond wheel attachment. Nearly any form can be dressed quickly, easily and accurately.

DURABLE — Hard seals are closely fitted and are air purged to totally exclude contamination. Sealed servo motors, automatic lubrication and totally enclosed encoders minimize down time and ensure long service life.

P.O. Box 69
Arden, NC 28704
(704) 684-1002

NORMAC

P.O. Box 207
Northville, MI 48167
(313) 349-2644