# MicroPulse and MicroShift for Ground Bevel Gearsets

Dr. Hermann J. Stadtfeld

*Editors' Note: The June issue of Gear Technology contained the technical paper, "Surface Structure Shift for Ground Bevel Gears," by Sebastian Strunk of Gleason Corp. The following paper, "MicroPulse and MicroShift for Ground Bevel Gearsets," by Gleason's Dr. Hermann J. Stadtfeld, addresses the conclusion subsequently made to combine MicroPulse and structure shift techniques in one package, which were then programmed into summaries and machine controls.*

## Introduction

Grinding of bevel and hypoid gears creates on the surface a roughness structure with lines that are parallel to the root. Imperfections of those lines often repeat on preceding teeth, leading to a magnification of the amplitudes above the tooth mesh frequency and their higher harmonics. This phenomenon is known in grinding and has led in many cylindrical gear applications to an additional finishing operation (honing). Until now, in bevel and hypoid gear grinding, a short time lapping of pinion and gear after the grinding operation, is the only possibility to change the surface structure from the strongly root line oriented roughness lines to a diffuse structure. Lapping after grinding was never a process combination of choice for several reasons. The additional operation is costly and it causes abrasive grit to penetrate into the surface, just as the case as if lapping were the only finishing operation. Also, for short a time lapping pinion and gears are mated after they leave the lapping machine. This in turn reduces or eliminates some of the advantages grinding would provide over lapping (Ref. 1).

However, the surface structure from lapping superimposed to a precisely ground flank surface presents a combination of accuracy and texture which could significantly enhance the rolling performance of bevel gearsets. In generating grinding for bevel pinions and generated bevel ring gears, the grinding wheel represents a tooth of the generating gear to the work, while the work rolls on the generating gear to finish profile and lead. The contact zones are lines that lie under an inclination angle $\alpha_t$ (Fig. 1).

The regularities in the generating flats and in the roughness lines are the sources of certain noise excitations. The frequencies induced can be high multiples of the tooth mesh frequency, but are often also reflected in the first three mesh harmonics. Figure 2 shows in an exaggerated way the generating flats and the tracks of the tool roughness. In grinding, the generating flats are very small, but the grinding grain tracks are dominating with respect to surface roughness.

Generating flats in grinding, however, are *theoretically* nonexistent because the grinding wheel surface represents a continuum of microscopic cutting edges. But *practical experience* teaches us differently. The explanations for those generating marks are the texture on the grinding wheel surface, run out and imbalance in the grinding wheel, and inaccuracies caused by the wheel dressing cycle. In addition to the wheel-based effects, the machine movements could also cause generating marks. The part program that consists of basic settings is converted into a table of axis positions; i.e. — it can be visualized as several hundred lines, where each line has a position value for each axis of the free form machine (X, Y, Z, A, B and C). As the machine moves from one line of axis positions to the next, the controller software tries to connect the discrete positions with a smoothing function. However, the machine might pause for some milliseconds in each position and generate a "microflat." Figure 1 shows a tooth surface with a number of microflats, which is in reality a factor of 10 higher then shown. Each flat has a cone envelope function that can be modified in different ways (Ref. 1).

Until today, no attention had been paid to the fact that not only are the microflats consistent with the timing of each tooth

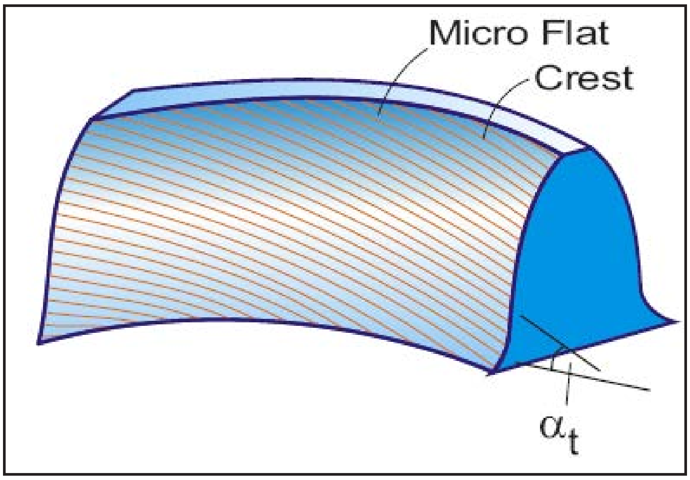



**Figure 1 Micro flats on a ground flank surface under inclination angle at.**

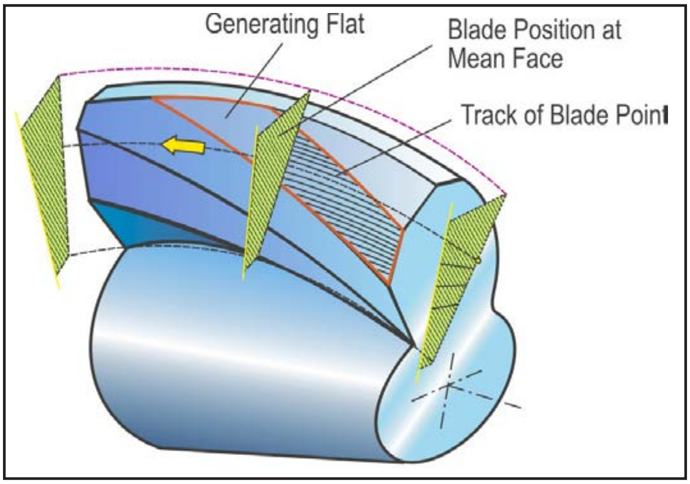



**Figure 2 Generating flats and grinding wheel roughness traces.**

mesh, but also with each other imperfection as well as desired flank surface modifications such as UMC relief section and, for example, Flankrem are located along the path of meshing at the same roll position. The roll positions of each tooth around the circumference of a gear repeat with a phase shift from tooth to tooth which is equal to one pitch:

$$q_i = q_1 + i * 360°/z \quad (1)$$

where:

$q_i$ particular roll position; e.g. start roll position on tooth $i$
$q1$ particular roll position on tooth number 1
$i$ number of any chosen tooth on observed gear → $\{1 \leq i \geq z\}$
$z$ number of teeth of observed gear

All disturbances or dynamic events that repeat from tooth to tooth during the operation of a gear set will repeat, depending on the manufacturing tolerances very precisely to one pitch. The consequence of this is, for example, that flats or imperfections will generate audible sound with a frequency equaling the number of their occurrence per tooth mesh, multiplied with the fundamental tooth mesh frequency. It is worth mentioning that such frequencies that are commonly between two and twelve times the tooth mesh frequency will also increase the intensity of the amplitude of the tooth mesh frequency. This phenomenon is called "ghost fundamental" (Ref. 2).

***The main topics of this paper are:***

- Surface structure caused by generating roll
- Scramble of tooth mesh events
- The principle of MicroPulse
- Surface structure generated by MicroPulse
- The principle of structure shift
- Generic structure shift
- Natural structure generation
- Application of structure generation and structure shift
- Conclusion

## Noise Reduction by "Scrambling"

The expression "scrambling" has been used for the determined or random change of geometrical features from tooth to tooth on gears. One example is the introduction of a random spacing error (Fig. 3). The goal of this "tooth position scrambling" was to reduce the fundamental tooth mesh frequency generated by the tooth mesh impact, and precisely repeats with the timing of one pitch — depending on the gear quality. It was expected that the existing tooth impact energy would now be partially re-directed to the side bands and therefore provide an additional masking of all harmonic amplitude peaks. Ground gears show a very high gear quality, which is why the intensity amplitude of the tooth mesh frequency is particularly high. The attempt to break the high intensity down by adding spacing errors failed for several reasons. The random tooth spacing errors reduce the gear quality rating, which makes it difficult to monitor the soundness of a grinding production. Furthermore, tooth spacing variations reduce the effective contact ratio under load, which affects the load carrying capacity of a gearset (Ref. 3).

However, the original goal — to reduce the vibration and noise emission of gearsets — also failed. In the example in Figure 3 the rack is shifted with a constant speed. The gear rotates

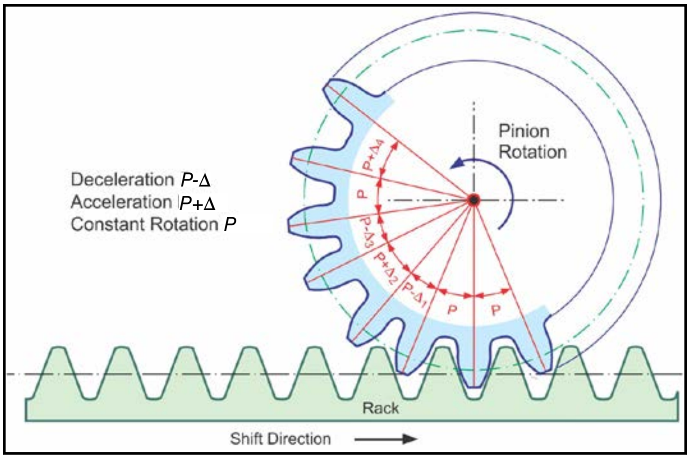



**Figure 3 Introduced spacing error.**

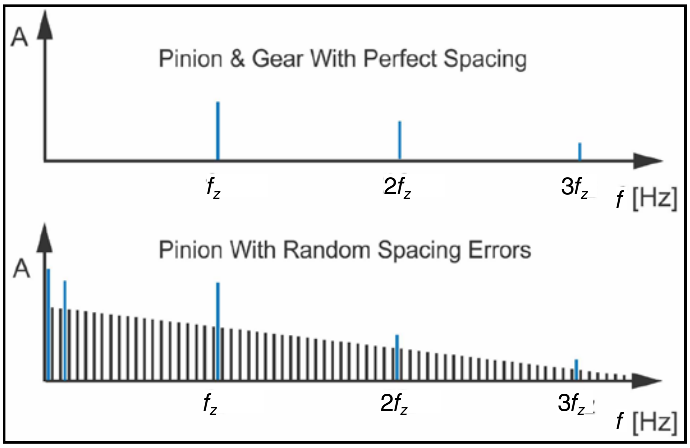



**Figure 4 FFT of gear with perfect spacing (top) and random spacing errors (bottom).**

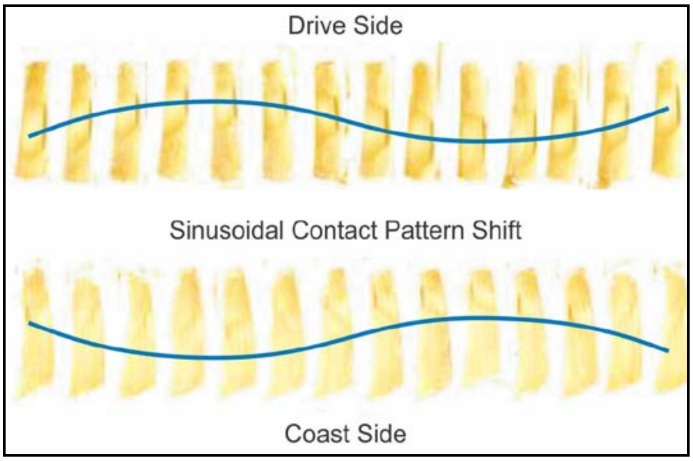



**Figure 5 Sinusoidal contact pattern shift (Ref. 3).**

with a constant RPM while the teeth with a spacing of $p$ are in mesh. When the first tooth with a lower spacing $p$-$D_1$ contacts the rack, an increased meshing impact and an additional deceleration occur. The following tooth with a larger spacing $p+D_2$ causes a lower mesh impact and an acceleration of the pinion rotation. Figure 4 (top) shows the fast Fourier transformation (FFT) of a single flank test working variation in case of a meshing pinion and gear with high spacing quality. Analysis results of trial gears manufactured with spacing errors $D$ of 5 micro-radiant showed increased first harmonic amplitudes, while additional low-frequency amplitudes in the range of the pinion and gear rotational frequency had also been created. Additionally, bars in the entire frequency range that reduce their amplitude with increasing frequency (impulse effect) were present.

The attempt to develop a more sophisticated approach was proposed with the position change of the tooth contact pattern from tooth to tooth, in an either random or, for example, sinusoidal pattern. For the amounts of change, the period of one sine function is used (Fig. 5). The first trial was not successful because the first order corrections, which had been used to realize the contact pattern position change, induced spacing errors. The elimination of the spacing errors also did not lead to a noise reduction. The spacing errors in bevel and hypoid gears are measured in the center of the flank surfaces. With respect to the constantly changing tooth-to-tooth location of the first meshing impact, the spacing errors were still present; and, the frequency spectrum of a single flank analysis post processed with a fast Fourier transformation (FFT) also showed high first harmonic amplitudes and disturbingly low frequency peaks.

## The Principle of MicroPulse

The basic idea of MicroPulse grinding is the use of machine motions of different frequencies in order to generate a surface texture that will break up the orientation and the regularities, due to the grain movements on the surface of the grinding wheel relative to the flank surfaces. Micropulsing is the change of one or more axis positions with the frequency of the axis position commands. Since the axes already move simultaneously from one roll position to the next — which takes milliseconds — small amounts of movement can be added or subtracted without causing a vibration like the term "pulse" may suggest. An example for the frequency of the micro modifications is shown below:

$$f = 1/t$$
$$t = 1\text{sec}/299\text{flats} = 0.0033\text{ sec}$$
$$f = 299\text{ Hz}$$

where:

$f$… Frequency

$t$… Time of machine movement from one flat to the next

The frequency can also be lower (every second or third position command), but not higher. The principle is the modification of the axis position table, which is executed by the free form machine controller allowing movement from one microflat to the next. A line in the axis position table with, e.g., 300 lines of X, Y, Z, A, B and C positions, is modified by adding a linear or angular dimension (e.g., 2 microns or 3 angular seconds) to one of the linear dimensions (e.g., Z-axis or B-axis). The next line of positions is used to subtract the amount previously added from the same axis designation.

The amount added and subtracted can also follow a linear or higher-order function, or can be randomized. This has to happen within certain limits to limit the change from flat to flat below, e.g., 5 microns, and to limit the change between the extreme changes, e.g., first and last flat below e.g. 5 microns in order to assure trueness of flank form and to preserve the effect of a noise optimal surface structure.

***Preferred vector directions for micro pulsing:***

a. tangential to the flat
b. tangential to the grinding wheel cone (in axial plane)
c. axial movement represents the compromise of b) for outer and inner grinding surface
d. radial movement towards flank (normal to flat)
e. sideways movement tangential to flat (different to a)
f. combination of a), b), c), d) and e), combination can change from flat to flat
g. single movement a) through e) but changing axis from flat to flat
h. combination movement similar to f) but with changing quantity from flat to flat
i. single axis movement with changing quantity from flat to flat, axis designation can also change from flat to flat

The axis movement (micropulsing) is a superimposition of delta values upon the theoretical axis positions. The surface form modification cannot be detected by a regular coordinate measurement, which assures that no sacrifice in measurable part quality is made by applying MicroPulse.

The grinding developments using MicroPulse give the optical appearance of the flank surface of a more irregular structure, compared to conventionally ground surfaces. Figure 7 (right) shows the result of a MicroPulse grinding, using 5 mm pulse amplitude in Z-axis direction (Fig. 6) and a random contents of ±2 µm. Compared to the left photograph of a conventionally ground flank surface, the MicroPulse structure appears to have more wave amplitudes and higher roughness peak amplitudes. This is only an optical illusion, as surface roughness measurements show better results for *Ra* and *Rz* in case of the MicroPulse-treated surfaces (Ref. 1).

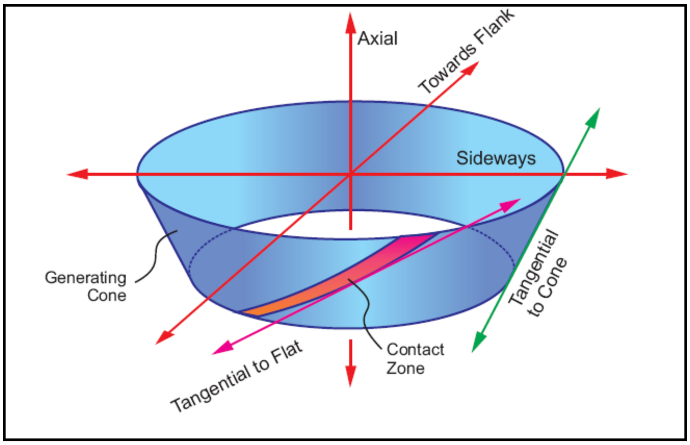



**Figure 6 Possible directions of micro motions.**

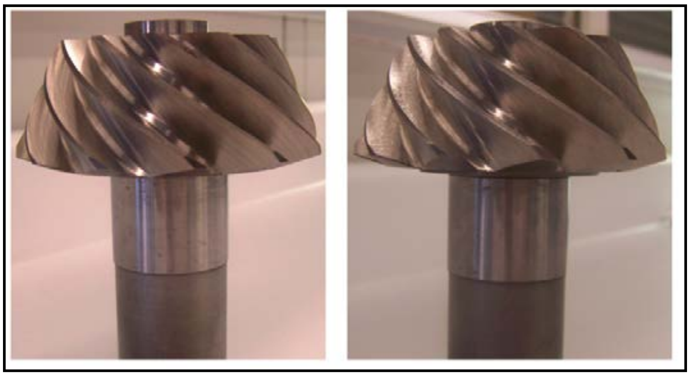


**Figure 7 Standard surface structure (left), MicroPulse structure (right).**

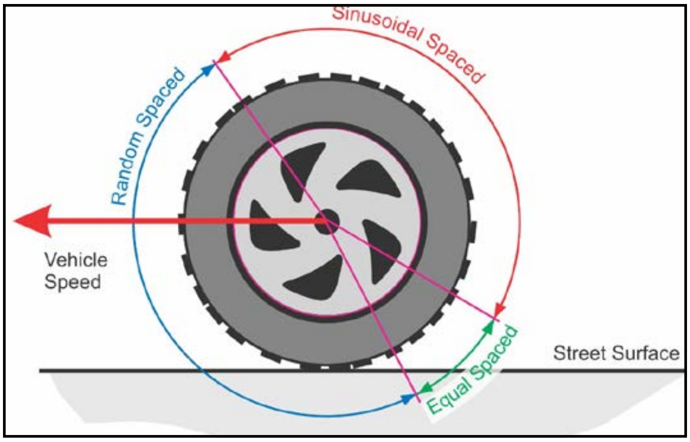



**Figure 8** Differently spaced treads on an automobile tire.

## Controlled Surface Structure Shift

The idea of purposely introduced spacing errors between the teeth was literally taken from the pitch variation of automotive cooling fan blades and the irregular spacing of the pattern on vehicle tires (Ref. 4). Although the tire with its differently spaced treads (Fig. 8) suggests a similarity to the gear with tooth spacing variations in Figure 3, the physical principles that are applied in both cases are quite different. The wheel in Figure 8 will not change its RPM, nor will the vehicle speed change as a result of the random- or sinusoidal-spaced tire treads. The treads merely have an influence on the dynamics and noise generation due to the changing contact frequency between rubber sections and street surface. The analogy in gearing is also the modulation of the contacting surfaces — not the phase location of those surfaces. In other words, this means that the teeth have to be equally spaced in order to assure proper function of a gear transmission but the surface texture should be shifted within each tooth and from one tooth to the next.

Carrying the principle of the tire treads a step further would result in different tread pattern shapes around the tire, in addition to the unequally spaced treads. A useful analogy in gears is shown in Figure 9; the left vertical sequence of pinion flank surfaces of three consecutive teeth shows from tooth to tooth a sinusoidal shift of the first generating flat, which is also mathematically represented in the diagrams on top of each tooth. The right vertical sequence of flank surfaces of three consecutive teeth shows that the generating flats no longer have equal distance. The flat widths follow a sinusoidal function that is phase shifted from tooth to tooth according to the sine-graphs plotted in the diagrams above each tooth.

It appears that a modulation that utilizes both principles according to Figure 9 is redundant. The right column (Fig. 9) has sinusoidal-spaced generating flats where the sine function is phase shifted from tooth to tooth. This modulation function already contains all the elements for variable generating flat spacing, as well as an individual tooth-to-tooth shift of the generated surface.

It has to be considered that tooth flanks are not rolling onto each other like the tire on the street surface. In the case of hypoid gears the contact area moves from entrance to exit point due to a combination of a relative rolling and a relative sliding motion between the contacting pinion and gear flank. Rolling and sliding velocity vectors that indicate the directions of those

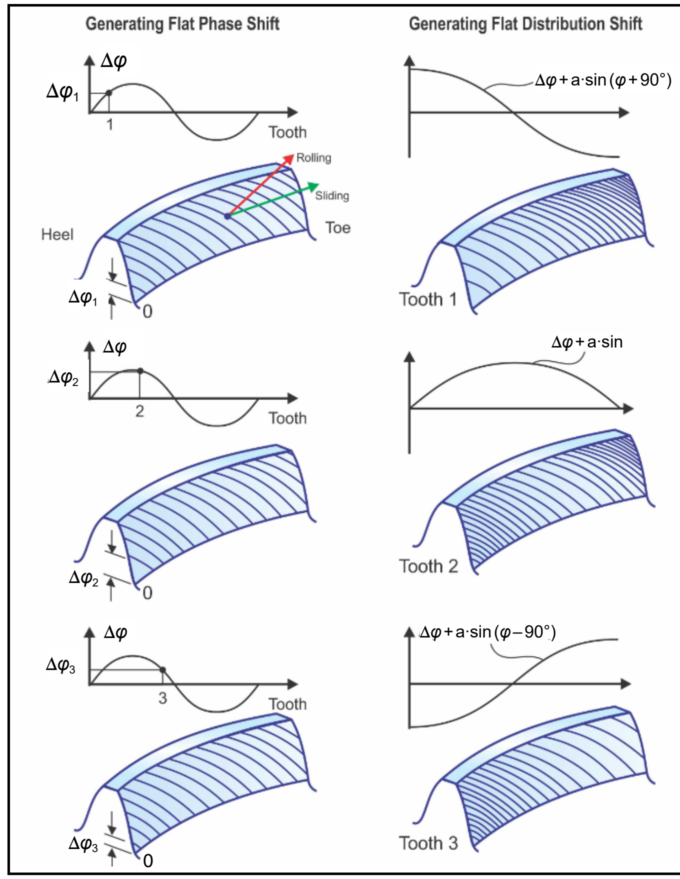



**Figure 9** Structure shift within one flank and from tooth to tooth.

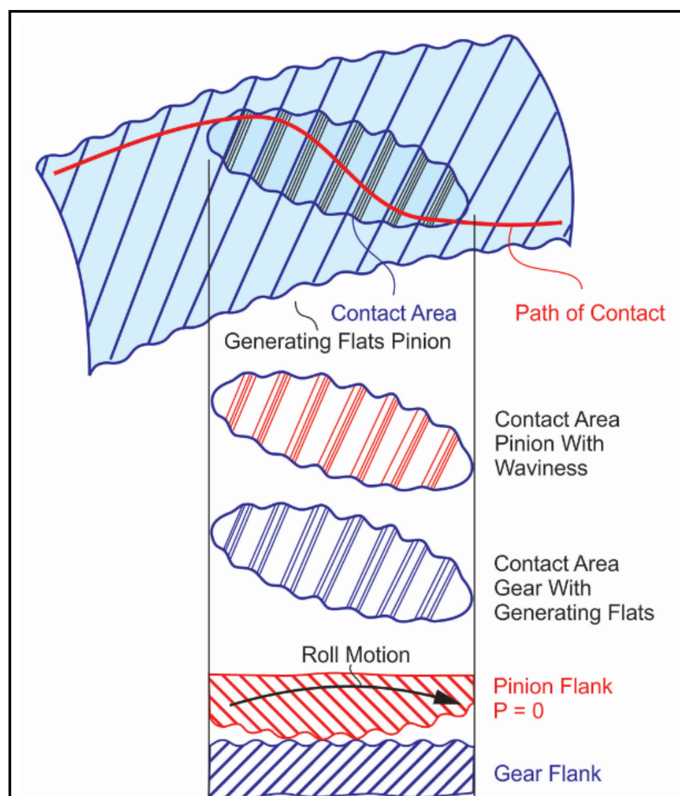



**Figure 10** Generating flat interaction between pinion and gear.

motions are shown (Fig. 9, upper-left tooth). While the rolling velocity direction is mainly perpendicular to the generating flat direction, the sliding velocity changes its direction between entrance and exit point. If the gear flank surfaces that mate with the generated pinion surfaces are manufactured with the Formate process, then there will be no additional kinematic excitations induced by the gear, excepting some influence from the surface roughness. The sliding in connection with the surface roughness will provide some dampening of the dynamic excitation generated by the rolling process.

If both pinion and gear flanks are manufactured by the generating process, then both members will show some generating flat structures. Figure 10 shows the interaction of two generated flanks within their contact pattern area. The excitations induced by the two surface textures are rather complex. Without any modulation of the generating flat locations and distances, there will already be variations in the distances of the generating flats of spiral bevel and hypoid gears between toe and heel due to the changing spiral angle. There will be additional modulations based on machining tolerances that will influence the phase relationship of the generating flat waves shown in the bottom graphic in Figure 10. It would be difficult and unrealistic to achieve a sophisticated generating flat shift and spacing variation that will sustain its rolling noise significant shape and location due to realistic production conditions and the customary assembly tolerances.

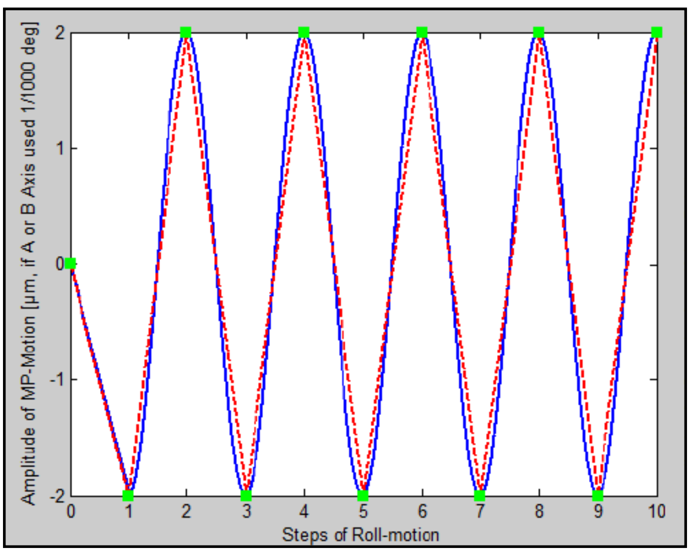



**Figure 11** Approximated sine wave with 3 anchor positions N per wave (Ref. 5).

## Robust Structure Shift for Productive Grinding Production

The combination of a generated pinion and a Formate gear seems particularly well suited for the application of an advanced MicroPulse and MicroShift process. The gear member will not exhibit any generating flats independent from the speed of plunging. Thus, surface texture form generating flats can be only created on the pinion. Depending on the roll rate, there may not be any existing surface texture on the pinion flanks (except the roughness streaks).

In order to achieve a suitable surface texture, the X-axis is selected as the preferred pulsing axis and the number of generating positions describing one sine period is chosen at three. Three generating positions present the smallest number to guide a complete sine wave from 0° to 360° — as shown (Fig. 11; e.g. point 1 to point 3). The spacing of the points along the abscissa corresponds to the number of axes position lines in the CNC part program and therefore is generally constant. In order to avoid truncated sine waves, the number of sine function anchor points should start at three and always be odd. The finest sine wave along the path of contact is achieved with three anchor points, which means that a minimum of three roll positions (or generating flats) are required to form one sine wave. If for example the number of anchor points is increased to five, then the sine waves are twice as long (on the flank surface) and one wave requires five roll positions. This results in a courser wavi-

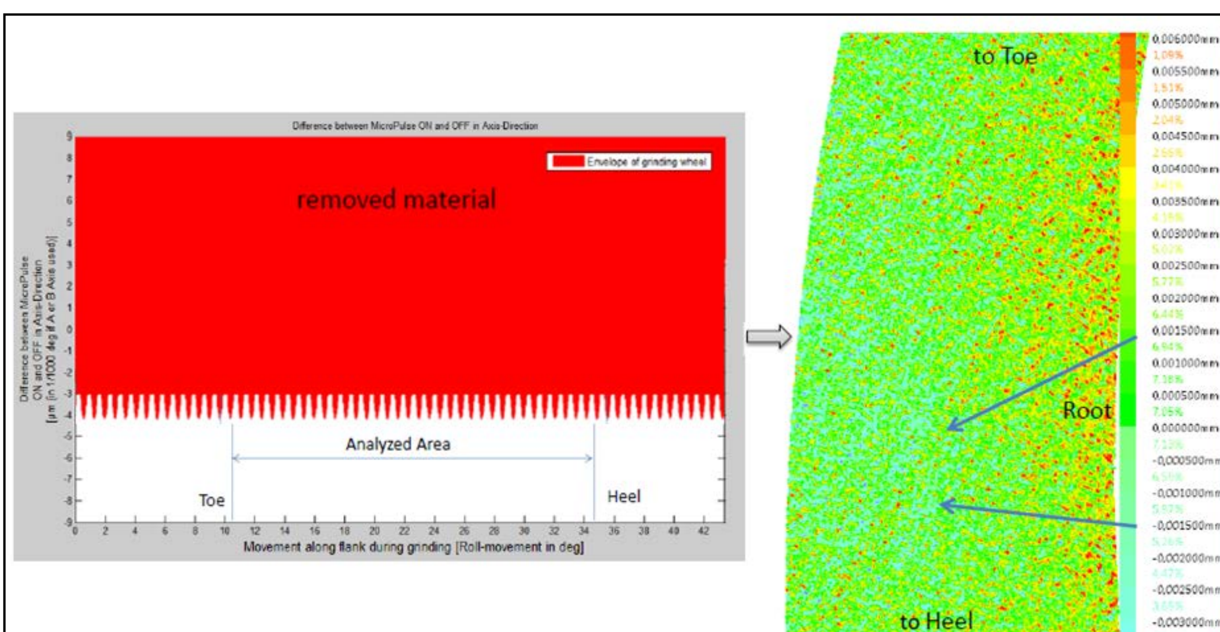



**Figure 12** MicroPulse surface modulation, X-axis, 3mm amplitude 3 position sine period (Ref. 5).

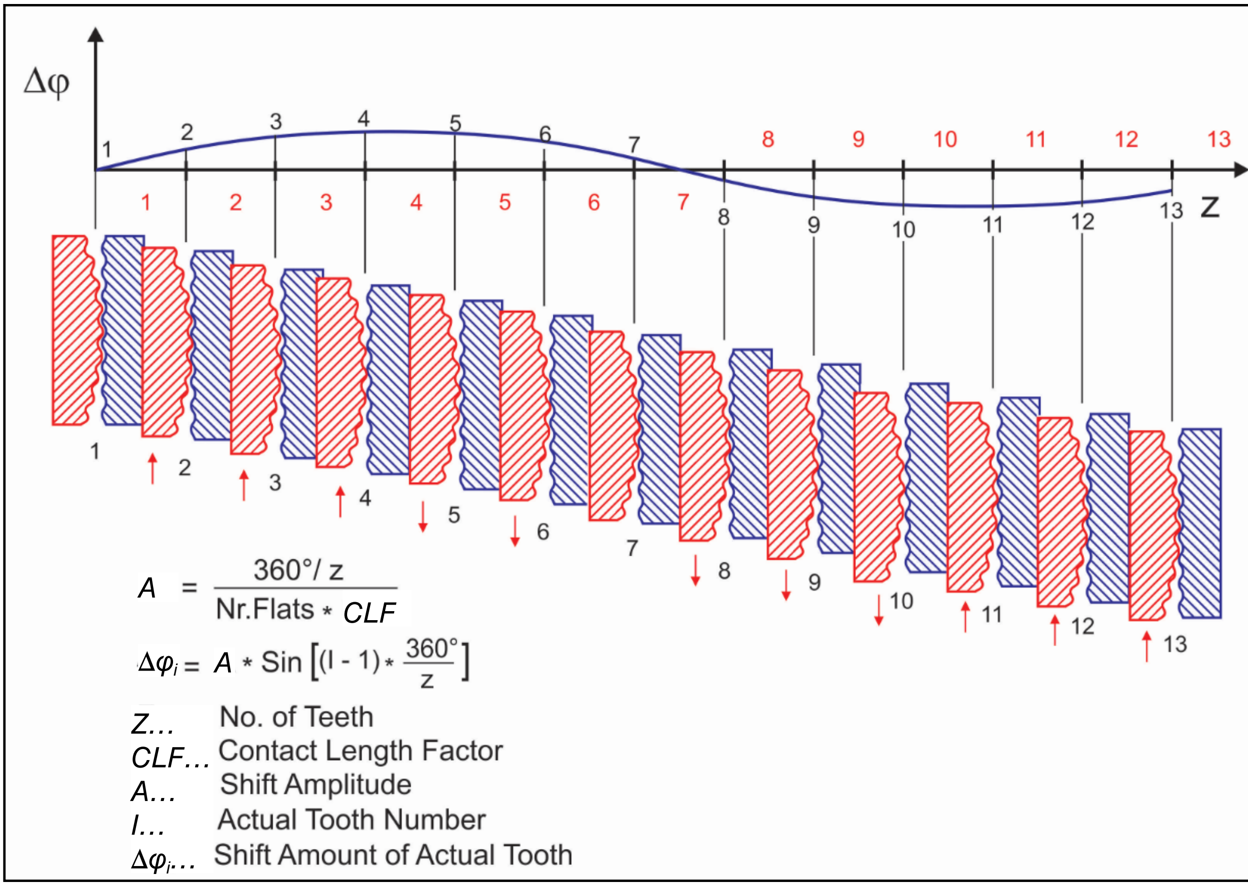



**Figure 13 Structure shifting sine function for 13 tooth pinion with 0.79° texture spacing.**

ness pattern, but the individual sine wave is approximated more accurately with two more anchor points.

If at light load, between 60 to 120 roll positions can be found within the active tooth contact, then 3 anchor positions for one full sine wave will result in 20 to 40 sine waves. Those are realistic numbers for a surface texture. A number of waves below 10 is undesirable because this results in a surface modification rather than a texture.

Figure 12 (left) is a simulation result, using waves with three anchor points and 3 mm amplitude. The enveloping effect of the used 6-inch grinding wheel reduces the effective amplitude of the waves from the initial 3 mm down to about 1.5 mm. Within the analyzed contact area, 35 periodic waves are generated. After a sample pinion with the parameters of the simulation was ground, a surface scan with a laser optical measurement machine was performed. The ISO graphic (Fig. 12, right) reflects the texture, generated with MicroPulse, very well. High areas are orange and low areas are blue.

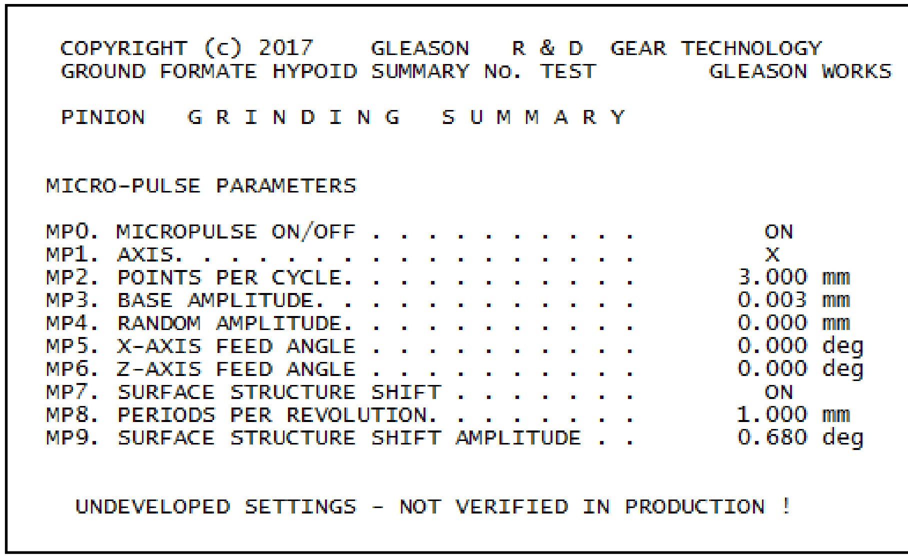
Although the texture in Figure 12 can be viewed as advantageous for the rolling process between flank surfaces, an excitation with the same or a fractional frequency can be expected in the gear mesh. The structure shift from tooth to tooth (Fig. 9, left) is required in order to assure that the generated surface structure will only generate side bands in the Fourier analysis of the single flank testing results. The answer to the question about the amplitude and the frequency of the shifting sine function can be derived from the characteristic of the texture. In the case of a 13-tooth pinion, one pitch is approximately 27.69°. With 35 periodic waves along one pitch, the angular distance between the waves (equal to the distance between generating flats) is 0.79°. The maximal value that the sine wave has to shift the structure one flat distance equals 0.79°. The shift function should only be one full period per one pinion revolution. This means that the sine function will be split into 13 sections. The first point is at the beginning of section one (with no shift). The second point is at the end of section one, and so on until the thirteenth point is located at the end of section 12. Section 13 connects the thirteenth and the first tooth, which is why the shift value at tooth number thirteen is not back to zero (Fig. 13); because the sine function needs to shift from tooth thirteen to tooth one in order to regain its zero point and start over again.

In the top of Figure 13 it is shown how the shift amounts $D_J$ are gained by the sine function. The black numbers are the points of shift (equal to the location of the teeth) spaced by the angle of one pitch; the red numbers are the 13 sections between the teeth. In the example in the mean (lower section of Fig. 13), the waves in the surface of the first pinion tooth fit exactly into the texture of the first gear tooth. The shift amount is the largest at tooth four, where the peaks of the mating tooth structures are in contact. After that the shift amount is reduced, passes zero at tooth number seven, and develops an increasingly negative amount that reduces after tooth ten — but doesn't reach zero at the last tooth. Doubling the amplitude will shift the structure beyond two surface waves. However, the range of recommended amplitudes is minimally A and maximally 5*A (see equation in Figure 13).

The grinding summary program uses the equations in Figure 13 in order to calculate the default starting point for a MicroPulse development. Only three parameters should be changed — the shift amplitude A; the number of anchor positions N of the structure waves; and the amplitude of the structure waves. Figure 14 shows a section of a pinion grinding summary that lists the MicroPulse and MicroShift settings.

Regarding generated ring gears, it is possible to apply MicroPulse to the gear instead of the pinion. The higher number of teeth will reduce the angular shift amounts between teeth, which allows for larger shift amplitudes. If it is intended to use MicroPulse for both members, pinion and gear, it should be noted that both members should receive different amounts of wave anchor points and only the grinding of one member (preferably the ring gear) should apply a structure shift.

The structure shift from tooth to tooth is accomplished simply with a modification of the start and end roll position, which are now individually calculated for each tooth separately. Even though this is a straight forward and clean approach, it requires the calculation of a separate part program for each tooth. In the presently discussed example, thirteen different pinion summaries are compiled behind each other in order to accomplish the task of a controlled structure shift.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COPYRIGHT (c) 2017    GLEASON   R & D  GEAR TECHNOLOGY
GROUND FORMATE HYPOID SUMMARY No. TEST         GLEASON WORKS

PINION   G R I N D I N G   S U M M A R Y

MICRO-PULSE PARAMETERS

MP0. MICROPULSE ON/OFF . . . . . . . . . . .        ON
MP1. AXIS. . . . . . . . . . . . . . . . . .        X
MP2. POINTS PER CYCLE. . . . . . . . . . . .      3.000 mm
MP3. BASE AMPLITUDE. . . . . . . . . . . . .      0.003 mm
MP4. RANDOM AMPLITUDE. . . . . . . . . . . .      0.000 mm
MP5. X-AXIS FEED ANGLE . . . . . . . . . . .      0.000 deg
MP6. Z-AXIS FEED ANGLE . . . . . . . . . . .      0.000 deg
MP7. SURFACE STRUCTURE SHIFT . . . . . . . .        ON
MP8. PERIODS PER REVOLUTION. . . . . . . . .      1.000 mm
MP9. SURFACE STRUCTURE SHIFT AMPLITUDE . .        0.680 deg

  UNDEVELOPED SETTINGS - NOT VERIFIED IN PRODUCTION !
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**Figure 14** **MicroPulse grinding summary.**

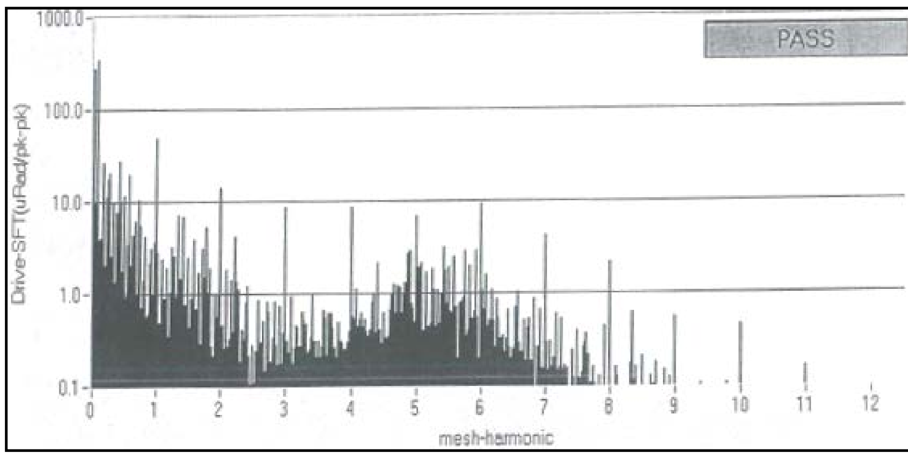


**Figure 15** **Single flank test Fourier analysis results of baseline gearset without MicroPulse (Ref. 5).**

## Practical Grinding Results with MicroPulse

In this section the results of one practical example are discussed. Figure 15 shows the results of a Fourier analysis after a single flank test of the automotive hypoid gearset without pinion-MicroPulse. The single flank test was conducted with a pinion speed of 60 rpm and a torque of 12 Nm. Along the abscissa, the fundamental frequency (first mesh harmonic "1") and its higher multiples are shown. The logarithmic ordinate scale shows larger bars at frequencies close to zero, which indicate the pinion and gear runout. All harmonic frequencies from one through 11 have pronounced amplitudes. It is an interesting observation that the amplitudes between the second and the sixth harmonic are almost constant at a value of 10 mrad, which most likely indicates objectionable noise at certain speeds of the vehicle.

The image in Figure 16 shows the surface finish of a 13-tooth pinion that was ground with 3 mm X-axis pulse amplitude and three anchor points per wave. The sinusoidal shift function uses one period-per-pinion revolution (Fig. 13), and the shift function amplitude was A = 0.79°. The pinion flank surfaces in Figure 16 have the earlier mentioned roughness streaks which are parallel to the root and a well visible surface texture with a generating

**Figure 16** **MicroPulse ground pinion (Ref. 3).**

flat orientation, similar to the laser optical image in Figure 12. This pinion is the result of a MiroPulse and MicroShift parameter study, with a complete matrix that was established according to a "design of experiment" (DOE) method.

The blue color in the root is the remaining witness marks of the side grinding technique, which was applied in order to keep the cost of the parameter study down and allow for grinding up to six different MicroPulse parameter sets on one single pinion. Although this procedure changes the backlash, the results of the single flank testing are identical to the results of the original parts with correct tooth thickness and backlash.

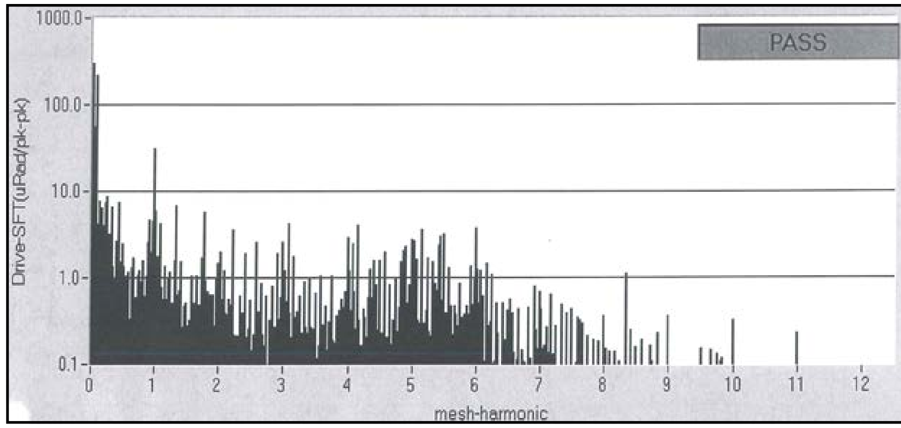


**Figure 17 Single flank test Fourier analysis results of gearset with MicroPulse-processed pinion (Ref. 5).**

Figure 17 shows the results of a Fourier analysis after a single flank test of the pinion from Figure 15, rolled with the same Formate ring gear from the test shown in Figure 14. The single flank test was again conducted with a pinion speed of 60 rpm and a torque of 12 Nm. At the low frequency the pinion and gear runout bars are identical to the bars in the analysis of the gearset without MicroPulse. The bars of all harmonic frequencies across the chart in Figure 17 are less than 50% of the values in case without MicroPulse. While the first harmonic is lower but still pronounced, the higher harmonic frequency bars are low and imbedded within many raised side bands.

Already the results of the single flank test and the Fourier analysis indicate the highly reduced excitation potential of this MicroPulse-processed gearset. All gearsets with the amplitude frequency characteristic (dominated by side bands) resulted in quieter operating performance during vehicle noise analysis. Presently the evaluated gearset might benefit from a reduction of the fist harmonic excitation bar that has an amplitude of 13 mμrad. Although this is already a low value, compared with the higher harmonics and the side bands, 8 to 10 μrad would give an optimally balanced amplitude frequency plot.

## Summary

- This paper described the combination of the existing MicoPulse with a controlled structure shift. The structure shift is calculated, such that a complete sine function around the circumference of a pinion is established that changes the start roll positions of the individual teeth by the ordinate value of the sine function, which is split in a number of sections, equal to the number of teeth. The combination of a surface texture generation and the controlled shift of this texture from one tooth surface to the next is a new technology, which finds many physical analogies in unrelated fields, but a technique to apply this physical principle to gears had not been discovered until now.
- In production grinding with rather aggressive roll rates, it can be noticed that some structure or texture related to generating flats is created. Such a generating flat structure on a ground gear flank is undesirable, which prompts a gear manufacturer to find ways to eliminate this effect. Besides the obvious possibility of a slower roll rate or a dual rotation cycle, some manufacturers have chosen to short time structure lap after grinding. Lapping after grinding might not present the most cost effective solution to achieve flank surfaces with a precise flank form and a desirable surface structure, but this process combination guarantees in nearly each case quiet performing bevel and hypoid gearsets.
- The structure shift principle can be applied to initially undesirable surface textures, generated with fast roll rates and reduce or eliminate the dynamically negative effect of the generating flats. In this case, it is no longer required to use the MicroPulse surface texture generation, because the naturally existing texture is utilized to cancel its own excitation and produce in addition desirable side bands which result in an acoustic gearset quality similar to gearsets manufactured with the combination of MicroPulse and MicroShift. The latter turns a disadvantage to an advantage because it delivers the benefit of a highly productive grinding combined with high quality and quiet gearsets.

## References

1. Stadtfeld, H.J. "MicroPulse-Structure Grinding," Company Publication, The Gleason Works, Rochester, New York, Feb. 2007.
2. Stadtfeld, H.J. "Psycho-Acoustic Methodology for Noise Reduction of Bevel Gears," *AGMA, Fall Technical Meeting*, Columbus, OH, October 2017.
3. Strunk, S. "Targeted Generation of Surface Structure and use of Modulation Principles for the Roll performance Optimization of Ground Bevel Gears," Master Thesis, Technical University of Ilmenau August 2014.
4. Bollinger, J.G., D. Ewald and A. Pavlovic. "Noise Reduction by Applying Modulation Principles," *The Journal of the Acoustical Society of America*, Vol. 49, No. 5 (Part 1), May 1971.
5. Strunk, S. "Surface Structure Shift for Ground Bevel Gears," *AGMA Fall Technical Meeting*, Pittsburg, PA, October 2016.

**Dr. Hermann J. Stadtfeld** received in 1978 his B.S. and in 1982 his M.S. in mechanical engineering at the Technical University in Aachen, Germany; upon receiving his Doctorate, he remained as a research scientist at the University's Machine Tool Laboratory. In 1987, he accepted the position of head of engineering and R&D of the Bevel Gear Machine Tool Division of Oerlikon Buehrle AG in Zurich and, in 1992, returned to academia as visiting professor at the Rochester Institute of Technology. Dr. Stadtfeld returned to the commercial workplace in 1994 — joining The Gleason Works — also in Rochester — first as director of R&D, and, in 1996, as vice president R&D. During a three-year hiatus (2002-2005) from Gleason, he established a gear research company in Germany while simultaneously accepting a professorship to teach gear technology courses at the University of Ilmenau. Stadtfeld subsequently returned to the Gleason Corporation in 2005, where he currently holds the position of vice president, bevel gear technology and R&D. A prolific author (and frequent contributor to Gear Technology), Dr. Stadtfeld has published more than 200 technical papers and 10 books on bevel gear technology; he also controls more than 50 international patents on gear design, gear process, tools and machinery.