Converting Revacycle to Coniflex

Dr. Hermann J. Stadtfeld

(The following is another chapter from Dr. Hermann J. Stadtfeld's new book, Practical Gear Technology, part of an ongoing series of installments excerpted from the book. Designed for easy understanding and supported with helpful illustrations and graphic material, the e-book can be accessed for free at Gleason.com.)

Traditional Cutting of Differential Gears with Revacycle

Automotive differential gears are generally Gleason Revacycle designs. Revacycle gears are cut by a large circular broach which is extremely productive (Fig. 1). Differential gears require the highest power density of all bevel gear types. Typical features of differential gears related to the high power density are the high pressure angle of 25° and even more and course pitch teeth with near miter ratios. The wide root fillets of the Revacycle gears have a fully rounded radius for maximal root bending strength. The Revacycle process performs a non-generated form cutting of the tooth profiles. The broach cutter moves from toe to heel during the roughing portion of the cycle and then back to the toe in a climb cutting mode in order to finish the flank surfaces and generate a straight root line. However, the flank profiles of Revacycle cut gears have no involute profile. Revacycle blades have a radius which approximates an involute while simultaneously creating some profile crowning.

A Revacycle cutter requires a large number of relief ground blades and the part geometry depends on an experimental trial-and-error optimization loop. Both — the blades and the development process — are expensive, which is only justified for large quantities of produced differential gears.

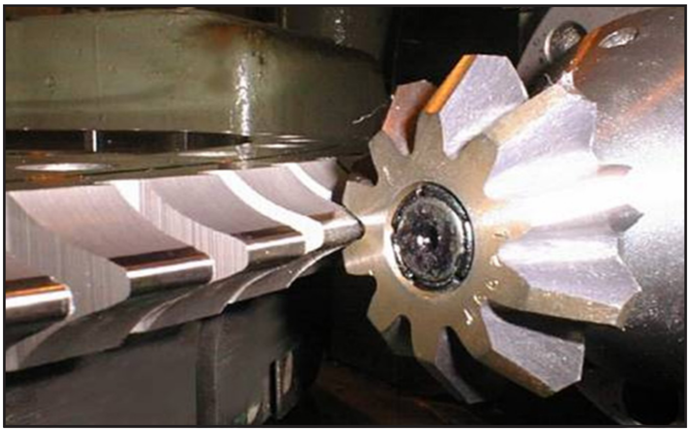


Figure 1 Broaching of a differential gear with Revacycle.

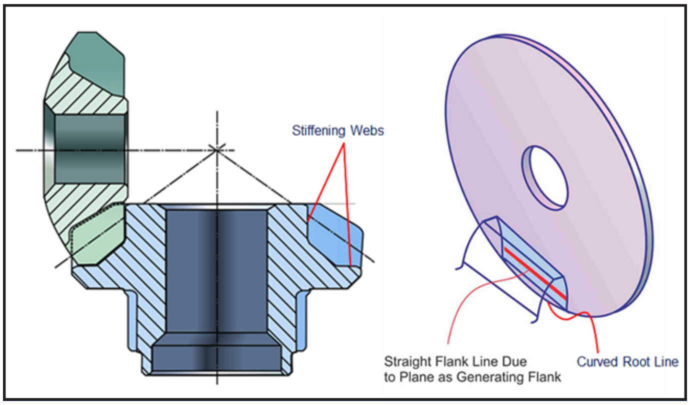


Figure 2 Root form of forged (left) and Coniflex (right) differential gear teeth.

Figure 3 Forged differential gear with pittings.

Forging of Differential Gears

The large quantities in connection with the high power density led the forging companies to promote forging of differential gears. They promoted the advantages of the grain flow of forged teeth in connection with the possibility of improving the profile from the Revacycle radius to a spherical involute. Additionally, it is possible with forging to create a web as shown (Fig. 2, left) at toe and heel in order to increase the tooth stiffness.

Preparation and setup cost for forging are extremely high and only justified for large size mass production. After the design of the gear geometry, a copper electrode is manufactured, either by a gear cutting process or with a machining center using ball nose end-mills. In case of the machining center, surface point clouds are processed rather than basic machine settings. This makes it possible to modify the root geometry of the electrode as shown (Fig. 2, left). The electrode is used to create the forging die as the negative form of the final differential gear with a spark erosion process (EDM). Certain corrections have to be made because of the forging billet temperature of about 1,000°C.

The corrections consider the proportional shrinking and the systematic tooth form distortion after cooling down to ambient temperature. An additional die is manufactured which has the gear tooth shape at the tempering temperature. This is the calibration die used to eliminate the random tooth distortions of each forged bevel gear and to improve the surface finish of the tooth flanks.

The webs of the forged differential gears (Fig. 2, left) are overrated because they prevent the free bending which can cause cracks in the web transition to the teeth; it also promotes early pitting due to the elimination of a "free contact breathing" under varying loads. Figure 3 shows a forged differential gear with pittings on the left flank. Although there are geometry freedoms like the webs which can be applied in forging, but not in cutting, the forged differential gears with the highest strength are the ones that just duplicate the Revacycle geometry (Ref. 1).

The Coniflex Process

Many truck and off-road vehicle applications do not require very large quantities of differential gears. Low-quantity differential gears are often manufactured using the Coniflex cutting method instead of Revacycle or forging.

Coniflex is a bevel gear cutting process developed for industrial straight bevel gears. In the past, mechanical cradle-style machines with many setup axes were used to cut Coniflex gears with an interlocking HSS dual cutter arrangement (Fig. 4). Although Coniflex is slow compared to Revacycle, it is the fastest-generating straight bevel gear manufacturing process available. Coniflex replicates in the root (in face width direction) the radii of the Coniflex cutter disks, as indicated (Fig. 2, right). The curved root line has no negative effect on the strength of a Coniflex straight bevel gear (within the recommended limits of face width/cutter radius < 0.4).

With Coniflex it is possible to approximate the Revacycle geometry. Common differences of Revacycle versus Coniflex gears are the blank geometry, the slot root geometry, the curved non-generated profiles and the larger pressure angles.

The Coniflex-Plus Process

The latest development in the manufacturing of straight bevel gears is the Coniflex-Plus technology. A single carbide stick blade cutter is used in a high-speed dry cutting process on free-form Phoenix machines (Fig. 5). The same machines are used for spiral bevel and hypoid gear cutting. At first view it appears that a single cutter, compared to the dual interlocking cutter arrangement in Figure 4, produces the straight bevel gears much slower. In reality, the facts that the cutting speed is 4 times higher with the Coniflex-Plus cutter head and the indexing motion of the gearless direct drive work spindle of the Phoenix II is significantly faster than the indexing of a mechanical machine (Fig. 4) make this new process more than twice as fast compared to the traditional Coniflex process using HSS blades. The new Coniflex process also has a higher flexibility because of the stick blades, which can be re-ground with optimized blade geometry rather quickly. The Phoenix machine kinematic allows applying a first-order modified roll which increases or reduces the profile crowning without the requirement of blade re-grinding. Three section universal motions (UMC) can be used in order to create a tip relief which eliminates rolling noise in cases of high-load-affected deflections.

Coniflex-Plus optimizations and summary calculations are supported in the *UNICAL* software. TCAs and CMM download files can be generated, and closed loop corrections via *GAGE* are a standard today.

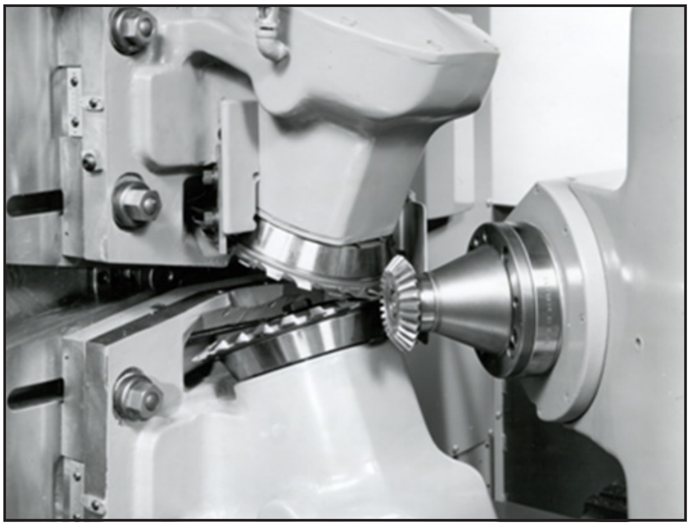


Figure 4 Coniflex cutting with an interlocking HSS dual cutter arrangement.

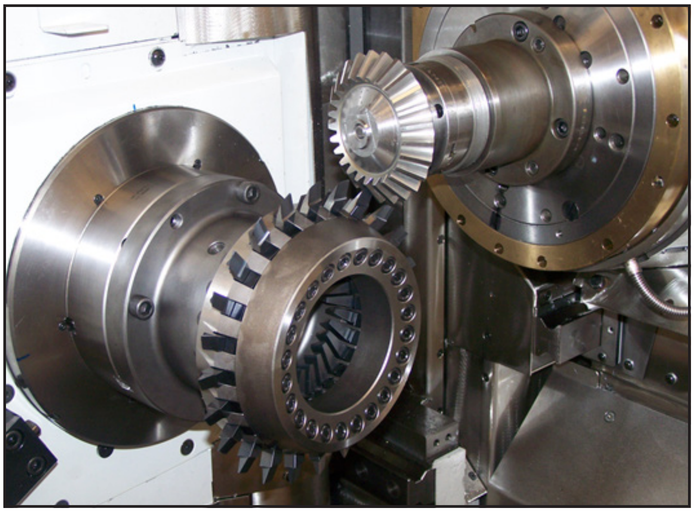


Figure 5: Coniflex-Plus high-speed dry cutting on a PhoenixII 275HC machine.

Conversion of Revacycle to Coniflex-Plus

Revacycle design calculations are performed with the Gleason T6000 program; a dimension sheet of a typical Revacycle differential gearset is printed here (Fig. 6).

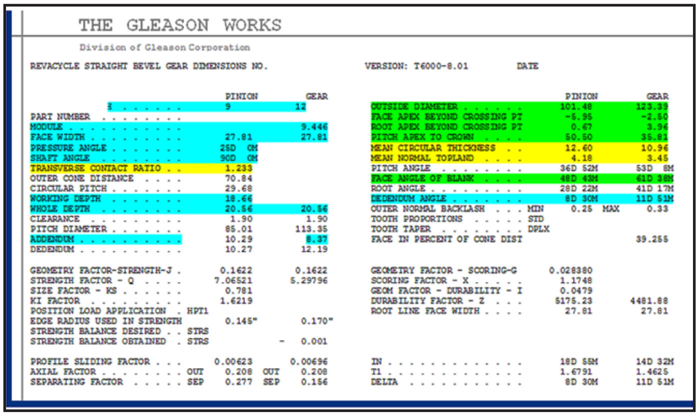
The blue-highlighted items (Fig. 6) mark the items used as input for the straight bevel mechanical program; the yellow-highlighted items are strength-relevant parameters; the green-highlighted items are the specifications of the blank dimensions.

The initial goal of a complete duplication of the Revacycle dimension sheet with a Coniflex design will not be entirely possible due to the different gear theory-related assumptions and rules between Revacycle and Coniflex. However, the approximation of the original Revacycle dimensions is generally very close.

Coniflex design calculations are conducted in the Gleason *Straight Bevel Mechanical* program. The blue-highlighted items are used to fill out the basic data screen and the tooth proportions screen as shown (Figs. 7 and 8). In order to achieve the closest possible duplication in the second screen (Fig. 8) as "tooth taper" the option "given proportions" is chosen in the drop-down tab. After complete input of the data the dimension sheet calculation is started by clicking "execute."

The resulting dimension sheet is shown (Fig. 9). All the blank design relevant data (highlighted in green) duplicate the original Revacycle blank precisely. Missing is the dimension "face apex beyond crossing point;" this dimension is not shown in the Coniflex dimension sheet because it is zero in all standard Coniflex cases. However, in cases that the Coniflex program is forced to accommodate given proportions, there is the possibility of a face apex beyond crossing point of not equal to zero. This dimension will only become visible after the *SBF* output file from the *Straight Bevel Mechanical* program is imported into the Coniflex conversion module of *UNICAL*.

If the dimension sheet data indicates a good duplication of an existing differential gear job, the basic data file (*SBF*-file) is imported to the *UNICAL*-Coniflex software program which features analysis tools like tooth contact calculation, undercut check, calculation of backlash, clearance and more. All optimizations required to duplicate in addition to the dimension sheet data also the tooth contact and fine tune the tooth thicknesses of pinion and gear of the given Revacycle design can be done in *UNICAL*.



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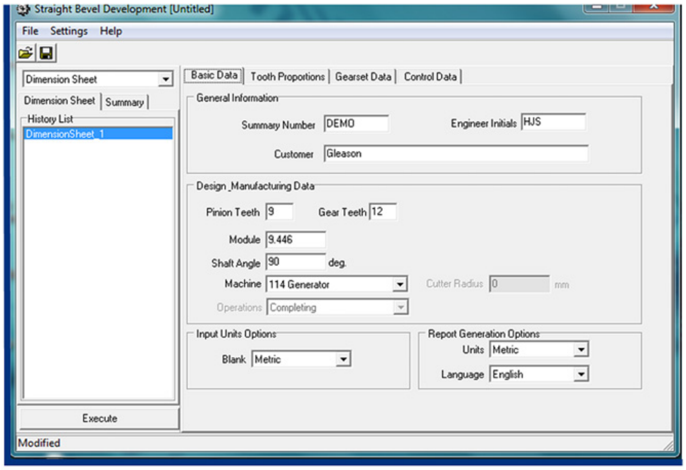
        THE  GLEASON  WORKS
        Division of Gleason Corporation
REVACYCLE STRAIGHT BEVEL GEAR DIMENSIONS NO.             VERSION: T6000-8.01        DATE

                                PINION      GEAR                                            PINION      GEAR
          # . . . . . . .       9           12        OUTSIDE DIAMETER . . . . . . .        101.48      123.39
PART NUMBER  . . . . . . . . .                         FACE APEX BEYOND CROSSING PT          -5.95       -2.50
MODULE . . . . . . . . . . . .              9.446     ROOT APEX BEYOND CROSSING PT           0.67        3.96
FACE WIDTH . . . . . . . . . .  27.81       27.81     PITCH APEX TO CROWN  . . . .          50.50       35.81
PRESSURE ANGLE . . . . . . . .  25D  0M               MEAN CIRCULAR THICKNESS  . .          12.60       10.96
SHAFT ANGLE  . . . . . . . . .  90D  0M               MEAN NORMAL TOPLAND  . . . .           4.18        3.45
TRANSVERSE CONTACT RATIO . .    1.233                 PITCH ANGLE  . . . . . . . . .        36D 52M     53D  8M
OUTER CONE DISTANCE  . . . .    70.84                 FACE ANGLE OF BLANK  . . . .          48D 43M     61D 38M
CIRCULAR PITCH . . . . . . . .  29.68                 ROOT ANGLE . . . . . . . . . .        28D 22M     41D 17M
WORKING DEPTH  . . . . . . . .  18.66                 DEDENDUM ANGLE . . . . . . . .         8D 30M     11D 51M
WHOLE DEPTH  . . . . . . . . .  20.56       20.56     OUTER NORMAL BACKLASH  . . . MIN       0.25  MAX   0.33
CLEARANCE  . . . . . . . . . .   1.90        1.90     TOOTH PROPORTIONS  . . . . . . STD
PITCH DIAMETER . . . . . . . .  85.01      113.35     TOOTH TAPER  . . . . . . . . . DPLX
ADDENDUM . . . . . . . . . . .  10.29        8.37     FACE IN PERCENT OF CONE DIST                      39.255
DEDENDUM . . . . . . . . . . .  10.27       12.19

GEOMETRY FACTOR-STRENGTH-J .    0.1622      0.1622    GEOMETRY FACTOR - SCORING-G       0.028380
STRENGTH FACTOR - Q  . . . .   7.06521     5.29796    SCORING FACTOR - X . . . . . .      1.1748
SIZE FACTOR - KS . . . . . . .  0.781                 GEOM FACTOR - DURABILITY - I      0.0479
KI FACTOR  . . . . . . . . . . 1.6219                 DURABILITY FACTOR - Z  . . .     5175.23     4481.88
POSITION LOAD APPLICATION  . HPT1                     ROOT LINE FACE WIDTH . . . .        27.81       27.81
EDGE RADIUS USED IN STRENGTH    0.145"      0.170"
STRENGTH BALANCE DESIRED . . STRS
STRENGTH BALANCE OBTAINED  . STRS         -  0.001

PROFILE SLIDING FACTOR . . .   0.00623     0.00696    IN . . . . . . . . . . . . . .        18D 55M     14D 32M
AXIAL FACTOR . . . . . . . . . OUT  0.208  OUT  0.208 T1 . . . . . . . . . . . . . .        1.6791      1.4625
SEPARATING FACTOR  . . . . . . SEP  0.277  SEP  0.156 DELTA  . . . . . . . . . . . .         8D 30M     11D 51M
```

Figure 6 **Revacycle dimension sheet.**



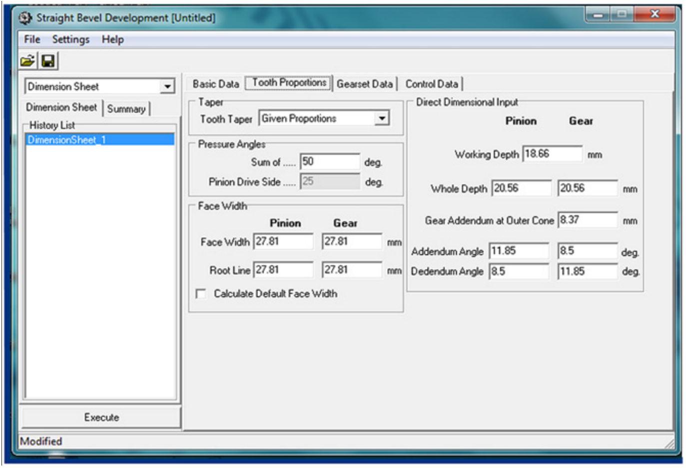
General Information
Summary Number: DEMO
Engineer Initials: HJS
Customer: Gleason

Design_Manufacturing Data
Pinion Teeth: 9
Gear Teeth: 12
Module: 9.446
Shaft Angle: 90 deg.
Machine: 114 Generator
Cutter Radius: 0 mm
Operations: Completing

Input Units Options
Blank: Metric

Report Generation Options
Units: Metric
Language: English

Figure 7 **Basic data input screen.**



Taper
Tooth Taper: Given Proportions

Pressure Angles
Sum of ..... 50 deg.
Pinion Drive Side ..... 25 deg.

Face Width

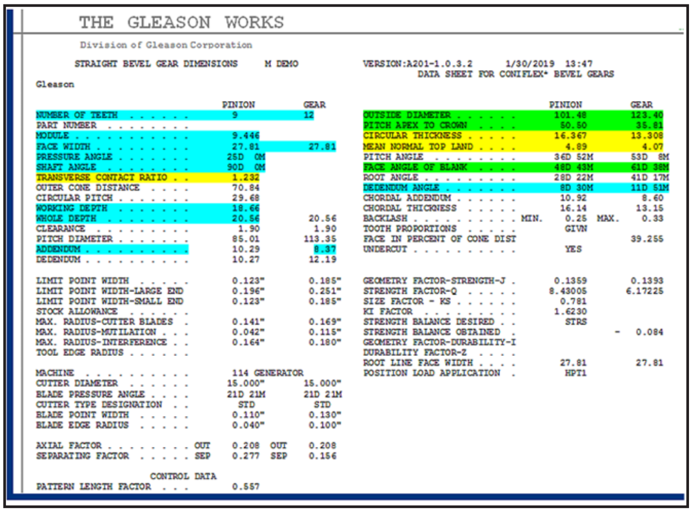
	Pinion	Gear	
Face Width	27.81	27.81	mm
Root Line	27.81	27.81	mm

☐ Calculate Default Face Width

Direct Dimensional Input

	Pinion	Gear	
Working Depth	18.66		mm
Whole Depth	20.56	20.56	mm
Gear Addendum at Outer Cone		8.37	mm
Addendum Angle	11.85	8.5	deg.
Dedendum Angle	8.5	11.85	deg.

Figure 8 **Tooth proportions screen.**



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        THE  GLEASON  WORKS
        Division of Gleason Corporation
     STRAIGHT BEVEL GEAR DIMENSIONS     M DEMO          VERSION:A201-1.0.3.2      1/30/2019  13:47
                                                                 DATA SHEET FOR CONIFLEX* BEVEL GEARS
Gleason

                                 PINION        GEAR                                             PINION       GEAR
NUMBER OF TEETH  . . . . . .     9             12        OUTSIDE DIAMETER . . . . . . .        101.48       123.40
PART NUMBER  . . . . . . . . .                            PITCH APEX TO CROWN  . . . .          50.50        35.81
MODULE . . . . . . . . . . . .   9.446                    CIRCULAR THICKNESS . . . . . .        16.367       13.308
FACE WIDTH . . . . . . . . . .   27.81         27.81     MEAN NORMAL TOP LAND . . . .           4.89         4.07
PRESSURE ANGLE . . . . . . . .   25D  0M                  PITCH ANGLE  . . . . . . . . .        36D 52M      53D  8M
SHAFT ANGLE  . . . . . . . . .   90D  0M                  FACE ANGLE OF BLANK  . . . .          48D 43M      61D 38M
TRANSVERSE CONTACT RATIO . .     1.232                    ROOT ANGLE . . . . . . . . . .        28D 22M      41D 17M
OUTER CONE DISTANCE  . . . .     70.84                    DEDENDUM ANGLE . . . . . . . .         8D 30M      11D 51M
CIRCULAR PITCH . . . . . . . .   29.68                    CHORDAL ADDENDUM . . . . . . .        10.92         8.60
WORKING DEPTH  . . . . . . . .   18.66                    CHORDAL THICKNESS  . . . . . .        16.14        13.15
WHOLE DEPTH  . . . . . . . . .   20.56         20.56     BACKLASH . . . . . . . . . . . MIN.    0.25  MAX.   0.33
CLEARANCE  . . . . . . . . . .    1.90          1.90     TOOTH PROPORTIONS  . . . . . .         GIVN
PITCH DIAMETER . . . . . . . .   85.01        113.35     FACE IN PERCENT OF CONE DIST                       39.255
ADDENDUM . . . . . . . . . . .   10.29          8.37     UNDERCUT . . . . . . . . . . .          YES
DEDENDUM . . . . . . . . . . .   10.27         12.19

LIMIT POINT WIDTH  . . . . . .   0.123"        0.185"    GEOMETRY FACTOR-STRENGTH-J .          0.1359       0.1393
LIMIT POINT WIDTH-LARGE END      0.196"        0.251"    STRENGTH FACTOR-Q  . . . . . .        8.43005      6.17225
LIMIT POINT WIDTH-SMALL END      0.123"        0.185"    SIZE FACTOR - KS . . . . . . .         0.781
STOCK ALLOWANCE  . . . . . . .                            KI FACTOR  . . . . . . . . . .        1.6230
MAX. RADIUS-CUTTER BLADES  .     0.141"        0.169"    STRENGTH BALANCE DESIRED . .          STRS
MAX. RADIUS-MUTILATION . . .     0.042"        0.115"    STRENGTH BALANCE OBTAINED  .                   -   0.084
MAX. RADIUS-INTERFERENCE . .     0.164"        0.180"    GEOMETRY FACTOR-DURABILITY-I
TOOL EDGE RADIUS . . . . . . .                            DURABILITY FACTOR-Z  . . . .
                                                          ROOT LINE FACE WIDTH . . . .          27.81        27.81
MACHINE  . . . . . . . . . . .   114 GENERATOR            POSITION LOAD APPLICATION  .          HPT1
CUTTER DIAMETER  . . . . . . .  15.000"       15.000"
BLADE PRESSURE ANGLE . . . . .  21D 21M       21D 21M
CUTTER TYPE DESIGNATION  . .      STD           STD
BLADE POINT WIDTH  . . . . . .   0.110"        0.130"
BLADE EDGE RADIUS  . . . . . .   0.040"        0.100"

AXIAL FACTOR . . . . . . . . . OUT   0.208  OUT   0.208
SEPARATING FACTOR  . . . . . . SEP   0.277  SEP   0.156

                 CONTROL DATA
PATTERN LENGTH FACTOR  . . .     0.557
```
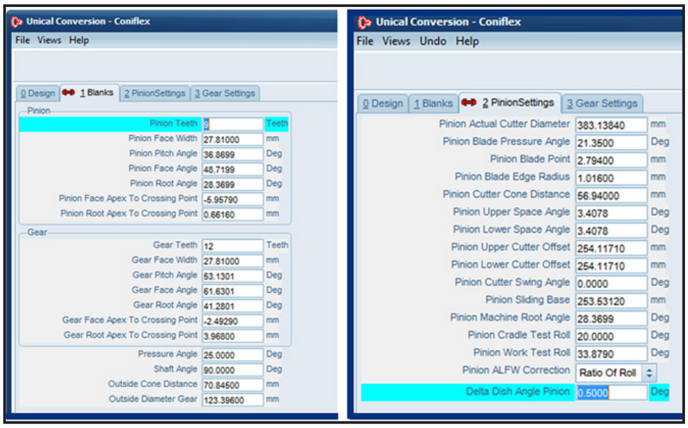

Figure 9 **Straight bevel dimensiond sheet.**



Pinion
Pinion Teeth 9 Teeth
Pinion Face Width 27.81000 mm
Pinion Pitch Angle 36.8699 Deg
Pinion Face Angle 48.7199 Deg
Pinion Root Angle 28.3699 Deg
Pinion Face Apex To Crossing Point -5.95790 mm
Pinion Root Apex To Crossing Point 0.66160 mm

Gear
Gear Teeth 12 Teeth
Gear Face Width 27.81000 mm
Gear Pitch Angle 53.1301 Deg
Gear Face Angle 61.6301 Deg
Gear Root Angle 41.2801 Deg
Gear Face Apex To Crossing Point -2.49290 mm
Gear Root Apex To Crossing Point 3.96800 mm

Pressure Angle 25.0000 Deg
Shaft Angle 90.0000 Deg
Outside Cone Distance 70.84500 mm
Outside Diameter Gear 123.39600 mm

Pinion Actual Cutter Diameter 383.13840 mm
Pinion Blade Pressure Angle 21.3500 Deg
Pinion Blade Point 2.79400 mm
Pinion Blade Edge Radius 1.01600 mm
Pinion Cutter Cone Distance 56.94000 mm
Pinion Upper Space Angle 3.4078 Deg
Pinion Lower Space Angle 3.4078 Deg
Pinion Upper Cutter Offset 254.11710 mm
Pinion Lower Cutter Offset 254.11710 mm
Pinion Cutter Swing Angle 0.0000 Deg
Pinion Sliding Base 253.53120 mm
Pinion Machine Root Angle 28.3699 Deg
Pinion Cradle Test Roll 20.0000 Deg
Pinion Work Test Roll 33.8790 Deg
Pinion ALFW Correction Ratio Of Roll
Delta Dish Angle Pinion 0.5000 Deg

Figure 10 ***UNICAL* conversion input for Coniflex.**

The *SBF* file created by the *Straight Bevel Mechanical Program* is now loaded into the *UNICAL Conversion Module* "CONIFLEX." The screen "1 Blanks" (Fig. 10, left) shows in addition to the data of the dimension sheet also the pinion and gear face and root apex distances.

The screen "2 Pinion settings" (Fig. 10, right) and "3 Gear Settings" allow in the last input tab to enter a delta dish angle. For the present Revacycle conversion, a 0.5° delta dish angle was entered to the pinion and the gear settings in order to achieve sufficient length crowning. Before a delta dish angle is entered, the Coniflex data have to be converted to *UNICAL* followed by a TCA run. If the length crowning is found too small, then a change back to the Coniflex conversion module has to happen. Now an approximated amount of delta dish angle is entered (same amount for pinion and gear to keep pinion and gear cutter blades equal). After this, the conversion is repeated and the next TCA run will reveal if an additional fine tuning of the delta dish angle is necessary.

The first TCA after the conversion is shown (Fig. 11). The Ease-Off shows too much profile crowning, very small length crowning and a large spiral angle error. In case of a Revacycle conversion, the flank geometry is rather exotic compared to regular straight bevel gears, which explains the bad initial Coniflex TCAs. The length crowning correction is done in the conversion module under pinion and gear setting with a 0.5° delta dish angle for pinion and gear cutter. Profile crowning and spiral angle can be corrected in the *UNICAL* optimization module. Because of the large amounts of spiral angle and profile crowning errors, 50% of the required corrections were applied to the pinion and 50% to the gear. The resulting TCA for the present conversion is shown (Fig. 12).

The Ease-Offs (Fig. 12) reflect the original Revacycle crowning very well. The contact pattern on coast- and drive-side are identical and look good from location and size. The fuzzy contact boundaries are a phenomenon which is often seen in Revacycle conversions. The explanation is a numeric instability of the TCA applet, which is a result of the large amounts of modified roll required to reduce the large profile crowning from the original Revacycle-Coniflex conversion. Revacycle geometries have very tall teeth, which appear to create a large profile crowning when converted to a generated involute geometry. The fuzzy boundaries will not exist in the real manufactured parts.

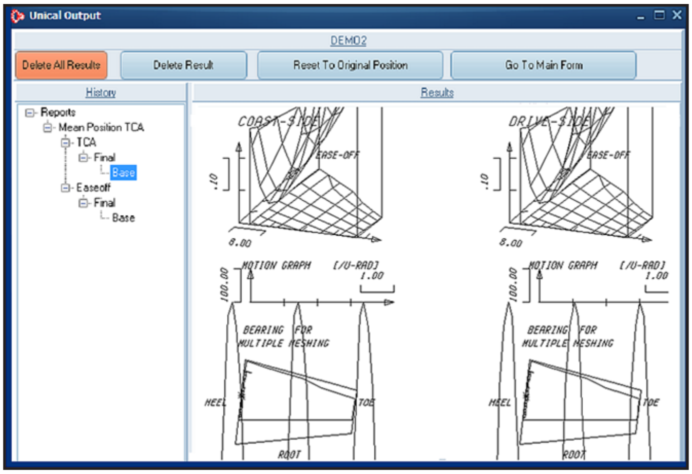


Figure 11 **Coniflex TCA after conversion.**

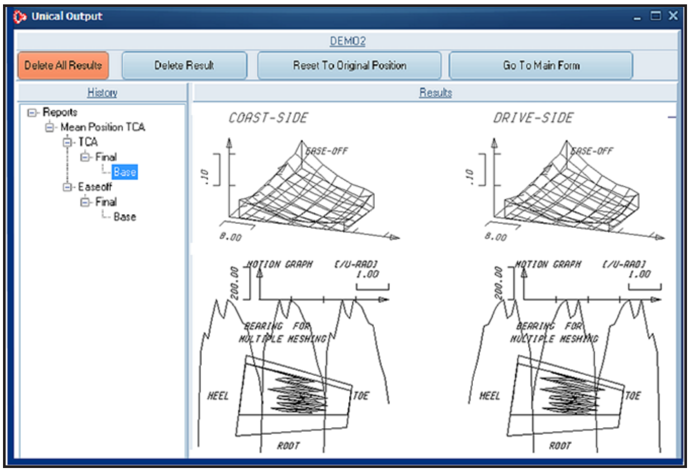
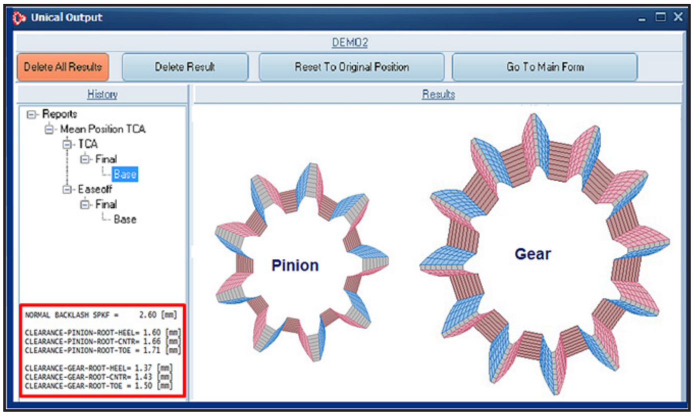


Figure 12 **Revacycle-Coniflex TCA after optimization.**



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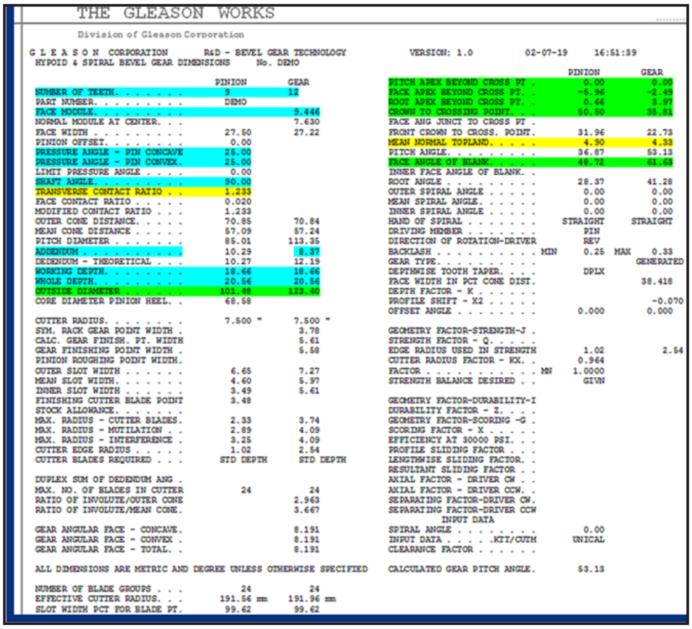
NORMAL BACKLASH SPKF =    2.60 [mm]

CLEARANCE-PINION-ROOT-HEEL= 1.60 [mm]
CLEARANCE-PINION-ROOT-CNTR= 1.66 [mm]
CLEARANCE-PINION-ROOT-TOE = 1.71 [mm]

CLEARANCE-GEAR-ROOT-HEEL= 1.37 [mm]
CLEARANCE-GEAR-ROOT-CNTR= 1.43 [mm]
CLEARANCE-GEAR-ROOT-TOE = 1.50 [mm]
```

Figure 13 **Converted pinion and gear geometry (initial).**

In addition to the analysis and optimizations discussed above, the top-root clearance, the backlash as well as the tooth thicknesses have to be checked and corrected in *UNICAL* if necessary. Figure 13 shows in the graphic a healthy looking pinion and a gear with thin teeth and thin toplands. At the bottom-left the normal backlash shows 2.60 mm. A gear tooth thickness correction of 2.30 mm is required to achieve the correct tooth thicknesses and a backlash of 0.25 mm.



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     THE  GLEASON  WORKS

     Division of Gleason Corporation

G L E A S O N  CORPORATION     R&D - BEVEL GEAR TECHNOLOGY      VERSION: 1.0          02-07-19      16:51:39
 HYPOID & SPIRAL BEVEL GEAR DIMENSIONS      No. DEMO
                                                                                                PINION        GEAR
                                   PINION       GEAR           PITCH APEX BEYOND CROSS PT .        0.00         0.00
 NUMBER OF TEETH. . . . . . .        9           12            FACE APEX BEYOND CROSS PT. .       -5.96        -2.49
 PART NUMBER. . . . . . . . .      DEMO                        ROOT APEX BEYOND CROSS PT. .        0.66         3.97
 FACE MODULE. . . . . . . . .                  9.446           CROWN TO CROSSING POINT. . .       50.50        35.81
 NORMAL MODULE AT CENTER. . .                  7.630           FACE ANG JUNCT TO CROSS PT .
 FACE WIDTH . . . . . . . . .      27.50      27.22            FRONT CROWN TO CROSS. POINT.       31.96        22.73
 PINION OFFSET. . . . . . . .       0.00                       MEAN NORMAL TOPLAND. . . . .        4.90         4.33
 PRESSURE ANGLE - PIN CONCAVE      25.00                       PITCH ANGLE. . . . . . . . .       36.87        53.13
 PRESSURE ANGLE - PIN CONVEX.      25.00                       FACE ANGLE OF BLANK. . . . .       48.72        61.63
 LIMIT PRESSURE ANGLE . . . .       0.00                       INNER FACE ANGLE OF BLANK. .
 SHAFT ANGLE. . . . . . . . .      90.00                       ROOT ANGLE . . . . . . . . .       28.37        41.28
 TRANSVERSE CONTACT RATIO . .      1.233                       OUTER SPIRAL ANGLE . . . . .        0.00         0.00
 FACE CONTACT RATIO . . . . .      0.020                       MEAN SPIRAL ANGLE. . . . . .        0.00         0.00
 MODIFIED CONTACT RATIO . . .      1.233                       INNER SPIRAL ANGLE . . . . .        0.00         0.00
 OUTER CONE DISTANCE. . . . .      70.85      70.84            HAND OF SPIRAL . . . . . . .    STRAIGHT     STRAIGHT
 MEAN CONE DISTANCE . . . . .      57.09      57.24            DRIVING MEMBER . . . . . . .        PIN
 PITCH DIAMETER . . . . . . .      85.01     113.35            DIRECTION OF ROTATION-DRIVER        REV
 ADDENDUM . . . . . . . . . .      10.29       8.37            BACKLASH . . . . . . . . . . MIN    0.25  MAX    0.33
 DEDENDUM - THEORETICAL . . .      10.27      12.19            GEAR TYPE. . . . . . . . . .                 GENERATED
 WORKING DEPTH. . . . . . . .      18.66      18.66            DEPTHWISE TOOTH TAPER. . . .        DPLX
 WHOLE DEPTH. . . . . . . . .      20.56      20.56            FACE WIDTH IN PCT CONE DIST.                   38.418
 OUTSIDE DIAMETER . . . . . .     101.48     123.40            DEPTH FACTOR - K . . . . . .
 CORE DIAMETER PINION HEEL. .      68.58                       PROFILE SHIFT - X2 . . . . .                   -0.070
                                                               OFFSET ANGLE . . . . . . . .       0.000        0.000
 CUTTER RADIUS. . . . . . . .      7.500 "    7.500 "
 SYM. RACK GEAR POINT WIDTH .                  3.78            GEOMETRY FACTOR-STRENGTH-J .
 CALC. GEAR FINISH. PT. WIDTH                  5.61            STRENGTH FACTOR - Q. . . . .
 GEAR FINISHING POINT WIDTH .                  5.58            EDGE RADIUS USED IN STRENGTH        1.02          2.54
 PINION ROUGHING POINT WIDTH.                                  CUTTER RADIUS FACTOR - KX. .       0.964
 OUTER SLOT WIDTH . . . . . .       6.65       7.27            FACTOR . . . . . . . . . . . MN   1.0000
 MEAN SLOT WIDTH. . . . . . .       4.60       5.97            STRENGTH BALANCE DESIRED . .        GIVN
 INNER SLOT WIDTH . . . . . .       3.49       5.61
 FINISHING CUTTER BLADE POINT       3.48                       GEOMETRY FACTOR-DURABILITY-I
 STOCK ALLOWANCE. . . . . . .                                  DURABILITY FACTOR - Z. . . .
 MAX. RADIUS - CUTTER BLADES.       2.33       3.74            GEOMETRY FACTOR-SCORING -G .
 MAX. RADIUS - MUTILATION . .       2.89       4.09            SCORING FACTOR - X . . . . .
 MAX. RADIUS - INTERFERENCE .       3.25       4.09            EFFICIENCY AT 30000 PSI. . .
 CUTTER EDGE RADIUS . . . . .       1.02       2.54            PROFILE SLIDING FACTOR . . .
 CUTTER BLADES REQUIRED . . .    STD DEPTH   STD DEPTH         LENGTHWISE SLIDING FACTOR. .
                                                               RESULTANT SLIDING FACTOR . .
 DUPLEX SUM OF DEDENDUM ANG .                                  AXIAL FACTOR - DRIVER CW . .
 MAX. NO. OF BLADES IN CUTTER        24          24            AXIAL FACTOR - DRIVER CCW. .
 RATIO OF INVOLUTE/OUTER CONE                 2.963            SEPARATING FACTOR-DRIVER CW.
 RATIO OF INVOLUTE/MEAN CONE.                 3.667            SEPARATING FACTOR-DRIVER CCW
                                                                         INPUT DATA
 GEAR ANGULAR FACE - CONCAVE.                 8.191            SPIRAL ANGLE . . . . . . . .        0.00
 GEAR ANGULAR FACE - CONVEX .                 8.191            INPUT DATA . . . . .KTT/CUTM      UNICAL
 GEAR ANGULAR FACE - TOTAL. .                 8.191            CLEARANCE FACTOR . . . . . .

 ALL DIMENSIONS ARE METRIC AND DEGREE UNLESS OTHERWISE SPECIFIED   CALCULATED GEAR PITCH ANGLE.       53.13

 NUMBER OF BLADE GROUPS . . .        24          24
 EFFECTIVE CUTTER RADIUS. . .    191.56 mm   191.96 mm
 SLOT WIDTH PCT FOR BLADE PT.      99.62       99.62
```
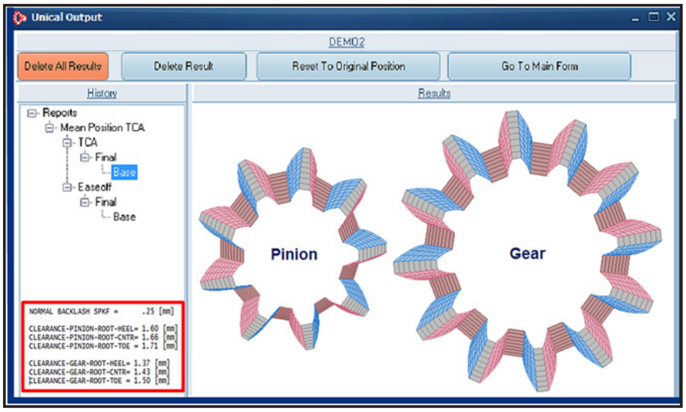

Figure 14 Final dimension Sheet from *UNICAL*.



```
NORMAL BACKLASH SPKF =     .25 [mm]

CLEARANCE-PINION-ROOT-HEEL= 1.60 [mm]
CLEARANCE-PINION-ROOT-CNTR= 1.66 [mm]
CLEARANCE-PINION-ROOT-TOE = 1.71 [mm]

CLEARANCE-GEAR-ROOT-HEEL= 1.37 [mm]
CLEARANCE-GEAR-ROOT-CNTR= 1.43 [mm]
CLEARANCE-GEAR-ROOT-TOE = 1.50 [mm]
```

Figure 15 Converted pinion and gear geometry (final).

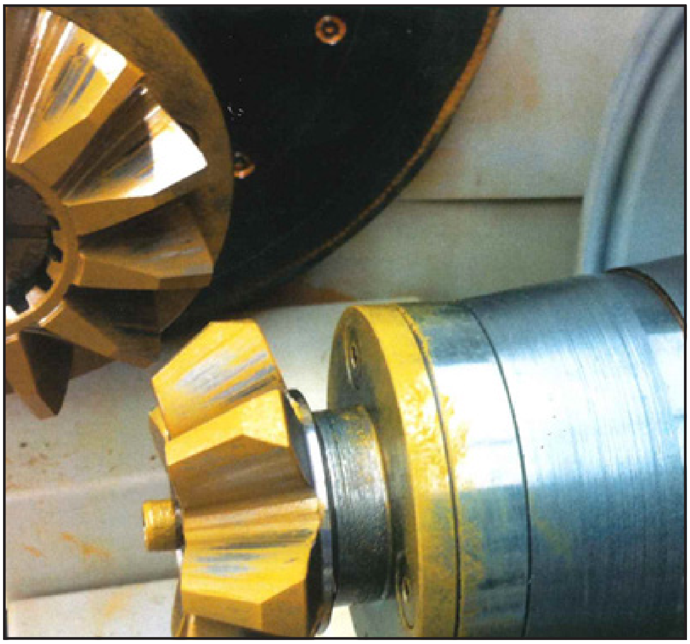


Figure 16 Rolled tooth contact on bevel gear tester.

The final dimension sheet calculation in *UNICAL* (Fig. 14) shows that all values — except the mean normal toplands — are very close to the straight bevel mechanical dimension sheet (Fig. 9).

The gear mean normal topland in the *UNICAL* and *Straight Bevel Mechanical* are different to the original Revacycle. This is a result of the involute profile function of Coniflex, in case of duplicating the Revacycle tooth thicknesses (the latter is an objective).

The pinion and gear graphics, reflecting the final dimension sheet are shown (Fig. 15). Tooth thicknesses and toplands are now balanced, and the teeth as well as the root width look well proportioned. At the bottom-left the box with backlash and clearances shows that all values are in the desirable range.

Tooth thickness, depth and root fillet are next to surface structure and finish the criteria for assuring comparable strength and performance. Except for the tooth thickness, all properties of the new Coniflex dimension sheet are duplicating the Revacycle calculation.

In order to check if the tooth thickness was matched correctly, the CMM inspection (coordinate) file of the newly developed Coniflex differential set should be used for the inspection of the original Revacycle pair. The measured tooth thickness differences (at the 5x9 grid center point) of the new Coniflex pair should be corrected in order to match the pinion and gear tooth thicknesses of the original Revacycle pair. If the correct Revacycle reference gear tooth thicknesses have been established, then the strength of the new Coniflex differential gearset will be comparable to the original Revacycle pair.

Nominal tooth surface grids for a CMM are also a standard of the new software. If the measured flank form deviates from the theoretical target, then corrections can be calculated with the *G-AGE* software, residing on the CMM computer. Thus the latest closed correction loop methods can be applied for Coniflex straight bevel gears and are of course also available for all developments of differential gear designs (Ref. 2).

Manufacturing and Roll Testing of Coniflex Differential Gears

For the example conversion of this chapter, a 15” Coniflex-Plus cutter head with carbide blades was used. *UNICAL* generates all the summaries for the Pentac stick blade grinding and for the cutting of pinions and gears. CMM download files and closed loop *G-AGE* corrections are also available for a straightforward production of Coniflex differential gears.

Roll testing results after soft cutting are displayed (Fig. 16). Tooth contact position and size are close to the theoretical TCA results. The differential pinion in the front has a large chamfer surface at the top-heel. The differential gear (or side gear) in the background has a toe border which is equal to the front face of the gear. Those and similar modifications of the tooth boundaries are very common for differential gears. Those tooth boundary modifications have to be considered at the time of tooth contact development.

It is possible in *UNICAL* to define an arbitrary three-sided heel-top-toe boundary which, however, is rather time-consuming because it would require to enter the L and R coordinates of the corner points directly into the *UNICAL* file.

In the photo in Figure 16 the cutting flats from the generating process can be easily recognized. This was a compromise which the manufacturer of this differential set was willing to make in order to reduce the cutting time to the required minimum. The low number of teeth, as well as the fast generating roll during cutting, resulted in a cutting time of 64 seconds for the pinion. Considered the large whole depth of more than 20mm, this is a good cutting time for a low quantity and flexible differential gear production. Another advantage of Coniflex is the possibility of cutter consolidation. Pinion and gear of the sample design in this chapter had been manufactured with the same 15" diameter Coniflex cutter and with the same blades. Because in Coniflex, the pressure angle is independent from the blade angle and the profile curvature does not require curved blades, it is possible to use one blade geometry for one or several part families.

Summary

Mathematically precise tooth surface definition and contact analysis help to develop state-of- the-art straight bevel gears for many industrial applications. The new Coniflex-Plus manufacturing process utilizes high-speed dry cutting with production times per slot which are about twice compared to the fast Revacycle process.

The Coniflex-Plus innovation inspired many manufacturers of trucks and off-road vehicles to utilize the Coniflex-Plus technology to produce high-quality differential gears in medium and low batch sizes in a modern and flexible manufacturing environment.

For more information.

Questions or comments regarding this paper? Contact Hermann Stadtfeld— *hstadtfeld@gleason.com.*

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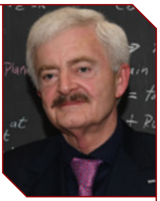
2. Stadtfeld, H.J. "Ask the Expert — "Computerized Differential Gear Development," ***Gear Technology Magazine***, October 2012, Pages 40 to 42.



Dr. Hermann J. Stadtfeld is the Vice President of Bevel Gear Technology and R&D at the Gleason Corporation and Professor of the Technical University of Ilmenau, Germany. As one of the world's most respected experts in bevel gear technology, he has published more than 300 technical papers and 10 books in this field. Likewise, he has filed international patent applications for more than 60 inventions based upon new gearing systems and gear manufacturing methods, as well as cutting tools and gear manufacturing machines. Under his leadership the world of bevel gear cutting has converted to environmentally friendly, dry machining of gears with significantly increased power density due to non-linear machine motions and new processes. Those developments also lower noise emission level and reduce energy consumption.

For 35 years, Dr. Stadtfeld has had a remarkable career within the field of bevel gear technology. Having received his Ph.D. with summa cum laude in 1987 at the Technical University in Aachen, Germany, he became the Head of Development & Engineering at Oerlikon-Bührle in Switzerland. He held a professor position at the Rochester Institute of Technology in Rochester, New York From 1992 to 1994. In 2000 as Vice President R&D he received in the name of The Gleason Works two Automotive Pace Awards — one for his high-speed dry cutting development and one for the successful development and implementation of the Universal Motion Concept (UMC). The UMC brought the conventional bevel gear geometry and its physical properties to a new level. In 2015, the Rochester Intellectual property Law Association elected Dr. Stadtfeld the "Distinguished Inventor of the Year." Between 2015–2016 CNN featured him as "Tech Hero" on a Website dedicated to technical innovators for his accomplishments regarding environmentally friendly gear manufacturing and technical advancements in gear efficiency.

Stadtfeld continues, along with his senior management position at Gleason Corporation, to mentor and advise graduate level Gleason employees, and he supervises Gleason-sponsored Master Thesis programs as professor of the Technical University of Ilmenau — thus helping to shape and ensure the future of gear technology.