Advances in Gear Manufacturing

T.J. Buzz Maiuri
The Gleason Works
Presentation Topics

- Advances in Gear Manufacturing
  - Some Gear History
  - Types of Gears – Cylindrical & Bevel
  - Manufacturing Flow
  - Tool Materials & Coatings
  - Bevel & Cylindrical Advances
  - Software and Networking
  - Industry 4.0
History of Gears

- Gear Manufacturing was an Art until the 19th Century
- Almost All Gears were Made by Hand
- The First Gears were Cut With Form Cutters Shaped to the Tooth Space
History of Gears

- Gears are one of man’s oldest mechanical devices.

- The toothed wheel takes its place with the lever, the inclined plane, the screw and the pulley as one of man’s earliest devices to increase the force that could be applied to an object.

- Most writers trace gears back to the writings of Aristotle (around 330 BC)

- The earliest know relic of gearing from ancient times is the “South Pointing Chariot” from about 2600 BC.

From “The Evolution of the Gear Art” Written by Darle W. Dudley Published in 1969 by the American Gear Manufacturers Association
The “South Pointing Chariot” was not only geared but it contained a very complex differential gear train made with wooden pins that is hard for even a modern gear engineer to analyze!

The ancient Chinese apparently used this chariot to keep from getting lost while traveling through the Gobi Desert.

It can be set so that the figure points south and continues to point south regardless of which direction the chariot is going.

In view of the intricacy of the South Pointing Chariot, it seems obvious that there must have been earlier use of gearing going back to at least 3000 BC.

From “The Evolution of the Gear Art” Written by Darle W. Dudley Published in 1969 by the American Gear Manufacturers Association
South Pointing Chariot - circa 2600 BC

• Gleason has several working models on display
• Kits to build South Pointing Chariots can be purchased on the internet
Bevel & Cylindrical Gears

✓ Bevel Gears Transmit Motion at an Angle
  - Usually 90°, but may higher or lower than 90°
  - Bevel Gears have a Conical Shape
  - Bevel Gears have Intersecting or Offset Axes

✓ Cylindrical Gears Transmit Motion Between Parallel Shafts
  - Worm Gears are Cylindrical Gears, but Transmit Motion at an Angle
Types of Cylindrical Gears

Spur
Types of Cylindrical Gears

Helical
Hand of Helix – External Gears

Left Hand

Right Hand
Types of Cylindrical Gears

Internal

“Train planetaire” by Jmtrivial, available under a Creative Commons Attribution-Share Alike 3.0 license at:
Left Hand Internal meshes with Left Hand External

Right Hand Internal meshes with Right Hand External
Worm
Splines

- Splines provide positive rotational connection between shafts
- Splines DO NOT roll together
Types of Cylindrical Gears

Sprockets
Straight Bevel Gear

✓ Oldest Type of Bevel Gear
✓ Non Parallel – Intersecting Axes
✓ Teeth are Straight and Tapered
✓ Extensions of the Straight Teeth Intersect at the Axis of the Gear
✓ Applications
  ▪ Machine Tools
  ▪ Marine
  ▪ Aircraft Actuators
✓ Non Parallel – Intersecting Axes
✓ Similar to a Straight Bevel Gear, But the Teeth are Curved Along Their Axis
✓ The Mean Spiral Angle is Zero
  ▪ [or Less Than 10°]
✓ Applications
  ▪ Aircraft
Spiral Bevel Gear

- Non Parallel – Intersecting Axes
- Teeth are Curved and Oblique
- Higher Operating Speeds & Load Capacity over Straights & Zerols

Applications
- Machine Tools
- Trucks
- Farm Equipment
Hypoid Bevel Gear

- Non Parallel – Non-Intersecting Axes
- Teeth are Curved and Oblique
- Pinion is Offset
- High Sliding – Less Efficient
- Smoother and Quieter than Spiral Bevel Gears

Applications
  - Automotive
✓ Spiral Angle is Determined by the Direction of Inclination from the Axial Plane Through the Midpoint of the Tooth Looking at the Gear Face

✓ Right Hand – Outer Half of Tooth is Inclined in the Clockwise Direction

✓ Left Hand – Outer Half of Tooth is Inclined in the Counterclockwise Direction
SRH™ – Super Reduction Hypoids

- SRH™ (Super Reduction Hypoids) are gear drives with ratios of 1x5 up to 1x100
- Non Parallel – Non-Intersecting Axes
- Teeth are Curved and Oblique
- Pinion is Offset
- The Lowest Number of Pinion Teeth of a SRH Pair is 1
- Applications
  - Replacement for Worm Gear Drives
✓ Hypoloid™ Gears are Slightly Conical Bevel Gears with Curved Flank Lines
✓ Small Shaft Angles (2°-16°)
✓ Can Have an Offset
✓ Face Width is Significantly Larger than Comparable Bevel Gears
✓ Very Forgiving Displacement Behavior under High Loads in Aluminum Gear Box Housings
✓ Applications
  - Automotive Transfer Case
Beveloid Gears are Slightly Tapered Helical Gears with Non-Parallel Shafts

- Shaft Angles Can be Between 2°-12°
- The Axes Always Intersect
- No Offset

Applications
- Marine
Cylindrical Gear Tooth Nomenclature
Bevel Gear Tooth Nomenclature

Terms Used to Define the Sides of the Gear Tooth:

- Concave – Convex
- O.B. Side – I.B. Side
- Drive Side – Coast Side
- Forward Side – Reverse Side
- Top Side – Bottom Side
Shaft Angles – from 10° to 170°

- **Automotive Rear Axle**
- **Heavy Duty Right Angle Drive**
- **Marine Drive – Less Than 90°**
- **Helicopter Greater Than 90°**
Cylindrical Gear Process Flow

1. Design Gear Set
2. Manufacture Blanks
3. Cut Teeth
4. Inspect Gear Set
5. Soft Finish Gear Set?
6. Inspect Gear Set
7. Heat Treat
8. Process Grind Blank
9. Hard Finish Teeth?
10. Final Inspection
11. Assemble Gear Set
12. Evaluate Gear Set
Bevel Gear Process Flow

1. Design Gear Set
2. Manufacture Blanks
3. Cut Teeth
4. Inspect Gear Set
5. Develop Contact Pattern
6. Inspect Gear Set
7. Heat Treat
8. Process Grind Blank
9. Hard Finish Teeth
10. Final Inspection
11. Assemble Gear Set
12. Evaluate Gear Set
Bevel Gear Manufacturing

✓ Bevel Gear Cutting (Before Heat Treat)
  ▪ Face Milling
  ▪ Face Hobbing
  ▪ UNIMILL™
✓ Bevel Gear Hard Cutting (After Heat Treat)
  ▪ Skiving
✓ Bevel Gear Grinding (After Heat Treat)
✓ Bevel Gear Lapping (After Heat Treat)
✓ Elemental Inspection
  ▪ Index and Runout
  ▪ Flank Form
  ▪ Size
✓ Objective Quality Measurement
  ▪ Single Flank Testing
  ▪ Structure Borne Noise Testing
  ▪ Contact Pattern Testing
Cylindrical Gear Manufacturing

- Cylindrical Gear Cutting (Before Heat Treat)
  - Hobbing
  - Shaping
  - Milling
  - Broaching
  - Soft Power Skiving
- Cylindrical Gear Soft Finishing (Before Heat Treat)
  - Shaving : Rolling
- Cylindrical Gear Hard Cutting (After Heat Treat)
  - Hard Skiving : Hard Power Skiving
- Cylindrical Gear Grinding (After Heat Treat)
  - Threaded Wheel Grinding : Profile Grinding
- Cylindrical Gear Honing (After Heat Treat)
- Inspection
  - Elemental Inspection: Tooth Spacing : Lead : Involute : Size
- Objective Quality Measurement
### High Speed Steels for Cylindrical Gear Cutting Tools

<table>
<thead>
<tr>
<th>Designation</th>
<th>Industry Equivalents</th>
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<tbody>
<tr>
<td>G10</td>
<td>M35 Conventional</td>
</tr>
<tr>
<td>G20</td>
<td>CPM M4, ASP2004, S690, AISI M4</td>
</tr>
<tr>
<td>G30</td>
<td>CPM REX45, ASP2030, S592</td>
</tr>
<tr>
<td>G40</td>
<td>CPM T15, ASP2015, AISI T15</td>
</tr>
<tr>
<td>G50</td>
<td>CPM REX 76, ASP2048, S376, AISI M48</td>
</tr>
<tr>
<td>G60</td>
<td>CPM REX86, ASP2060</td>
</tr>
<tr>
<td>G90</td>
<td>MC90</td>
</tr>
</tbody>
</table>
G90 - Intermetallic Alloy

G90:

- Carbon-free alloy of iron, cobalt, and molybdenum
- Exceptional red hardness beyond that of any PM high speed steel (HSS)
- Ability to increase cuttings speeds by more than 30% with same or better tool life

Chemical Composition (average mass %)

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>Cr</th>
<th>Mo</th>
<th>V</th>
<th>W</th>
<th>Co</th>
<th>Fe</th>
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<tbody>
<tr>
<td>G90</td>
<td>0</td>
<td>0.6</td>
<td>0.2</td>
<td>0</td>
<td>15</td>
<td>0</td>
<td>0</td>
<td>25</td>
<td>Bal.</td>
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<td>G30</td>
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<td>0.3</td>
<td>4.2</td>
<td>5</td>
<td>3</td>
<td>6.3</td>
<td>8.4</td>
<td>Bal.</td>
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</tbody>
</table>
## Carbide Stick Blade Material

<table>
<thead>
<tr>
<th>ISO “P” Grades - Alloyed Carbide</th>
<th>ISO “K” Grades - Straight Carbide</th>
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<tbody>
<tr>
<td>Three-Phase Composition</td>
<td>Simple Two-Phase Composition</td>
</tr>
<tr>
<td>WC (Tungsten) + Co (Cobalt) + Cubic Carbides</td>
<td>WC (Tungsten) + Co (Cobalt) Only</td>
</tr>
<tr>
<td>TiC - Titanium Carbide</td>
<td>90%WC, 10%Co Typical</td>
</tr>
<tr>
<td>TaC - Tantalum Carbide</td>
<td>Grain Size Less than 0.8 µm</td>
</tr>
<tr>
<td>NbC - Niobium Carbide</td>
<td>Good Abrasion Resistance</td>
</tr>
<tr>
<td>Grain Size Larger Than 1.5 µm</td>
<td>Good Edge Stability</td>
</tr>
<tr>
<td>73.5%WC, 8.5%TiC, 8%TaC, 10%Co</td>
<td>Most Appropriate Grade for Bevel</td>
</tr>
<tr>
<td>Typical Composition by Weight</td>
<td>Gear Cutting</td>
</tr>
<tr>
<td>Good High Temperature Stability</td>
<td></td>
</tr>
<tr>
<td>Good Wear Resistance</td>
<td></td>
</tr>
<tr>
<td>Not as Tough as K-Grades</td>
<td></td>
</tr>
</tbody>
</table>

- ISO “K” Grades - Straight Carbide
  - Simple Two-Phase Composition
  - WC (Tungsten) + Co (Cobalt) Only
  - 90%WC, 10%Co Typical
  - Grain Size Less than 0.8 µm
  - Good Abrasion Resistance
  - Good Edge Stability
  - Most Appropriate Grade for Bevel Gear Cutting
AlCroNite®Pro is a top-tier all-around coating in cutting applications, in punching and forming as well as in aluminum pressure die casting. Excellent wear resistance, thermal shock stability and hot hardness are the properties that are modified to enhance the proven AlCroNite® coating.

**Recommended applications:**
- Solid carbide end mills and carbide indexable inserts for roughing and finishing
- Carbide and HSS hobs
- Primarily used for HSS and PM-HSS materials
- Used for wet machining and dry machining

### Coating Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
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<tbody>
<tr>
<td>Coating Material</td>
<td>AlCrN</td>
</tr>
<tr>
<td>Microhardness (HV 0.05)</td>
<td>3,200</td>
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<tr>
<td>Friction coefficient against steel (dry)</td>
<td>0.35</td>
</tr>
<tr>
<td>Max. service temperature (Celsius)</td>
<td>1,100°</td>
</tr>
<tr>
<td>Coating color</td>
<td>bluish-grey</td>
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</tbody>
</table>
Continous Improvements in coating is an ongoing process
Universal coatings allow dry and wet applications
Stripping capabilities of the coating is an important factor
Tailored coatings will become gain more attention (specially for solid carbide hobs)
Bevel Cutting Videos

Face Milling - Gear: fmgear2.mpg
Face Milling - Pinion: fmpin.mpg
Face Hobbing - Gear: fhgear.mpg
Face Hobbing - Pinion: fhpin.mpg
Non Traditional Cutting on Spiral Bevel Machines

UNIMILL™ End Mill

UNIMILL™ Disc Cutter

Power Skiving

280CX Cutting Machine

Video
Unimill end mill.mp4

Video
Unimill disk.mp4

Video
Powerskiving.mp4

Video
280C Clips.mp4
Cutting Technology – Fast Changeover

- Tool-less arbor change
- Tool-less cutter change
- Tool-less loader jaw change

Tool-less Cutter Change Adaptor

Tool-less Workholding Change

Tool-less Loader Jaw Change

Time Savings

Video
280C Clips.mpg
Calculate Machine Path as Opposed to Teaching

Process inputs:

- chamfer definition, cutter selection, cutter edge utilization, clearances
- The combination of process inputs must provide for acceptable chamfer aesthetics, good tool life, minimal secondary burr, fast cycle times, etc…

Discovery Probing

Toe

Heel

Probing of Gear or Pinion Blank to Calculate Edge Coordinates and Normals
Phoenix® 280CX – Parallel Chamfering

- Chamfering while Cutting
- Chamfering of Heel and Toe, one or both flanks
- Chamfer Gears & Pinions

**Video**

***GearChamfer.wmv

**Video**

***PinionChamfer.wmv

Locate Part Position
Chamfering Heel & Toe
Phoenix® 280CX – Rotary Deburring

✓ Brush Deburring Option
✓ File Option also Available
- Check Cut Part after cutter change
- Inspect Part against Master Data
- Correction algorithms in development
- No need to wait for measurement machine to continue production
- Measurement in 5 min vs. 30 min or more depending on CMM availability.
Two Tool Generator

No. 14 (429) Straight Bevel Coniflex® Generator

Video 2-tool.mpg
Interlocking Cutters

No. 104 (439) Straight Bevel Coniflex® Generator
Circular Broach Cutters
One Cutter Rev Finishes One Tooth Slot

Video
Revacycle.mpg

November 9, 2015
✓ Coniflex® Cutting on a Phoenix® CNC Bevel Machine

9” Coniflex®Plus Cutter
Roll Only

9” Coniflex®Plus Cutter
Plunge Only - Formate®

Video ConiflexPlus-RollOnly.avi

Video ConiflexPlus-Formate.avi
Bevel Gear Cutting Tools and Grinding Wheels

Pentac Plus Cutter
Pentac RT Cutter
Tri-Ac Face Hobbing
Hardac III
Pentac Aero
Cyclocut

Carbide Coniflex Plus Cutter
Coniflex Cutters
Revacycle Flo-Cut
Solid Cutters
Bevel Grinding Wheels
Stick Blade Sharpening & Blade Inspection

Stick Blade Sharpener with Loader

Stick Blade Measurement Machine
Closed-Loop Measurement & Correction
Blade Measurement - Inspection with Laser Beam

- Two & three-face blade measurement and correction
- Complete blade geometry acquisition in one minute
- Advantage of non-contacting cutting edge measurement
- Fully automated version available
- Use for development and as comparison checker
- Closed-Loop between BIM and BPG Available
Automated Cutter Build, Truing and Inspection

- Automated cutter build
- Closed Loop blade positioning
- Automated truing on Gleason RT heads
- Intuitive operator interface
- Software “Wizards” to assist less experienced users
- Intelligent process diagnostics
- Consistent build quality
- 60% Reduction in operator interaction
- Less dependence on operator Skill
- Adaptive process “Learns” from previous build data

New Cutter Build Machine - 500CB

Automated Blade Positioning / Measurement / Clamping
Cutting Technology – 5-Axis Gear Production

- Gleason design expertise and software for process simulation via 3D CAM
- Productivity gains due to stiff machine design and innovative tool concepts
- Spiral and straight bevel gears, cylindrical gears, double helical gears
- Complete machining
Conventional Roll Testing
- Contact Pattern Observation

Elemental Inspection
- Index and Runout
- Flank Form
- Size

Objective Quality Measurement
- Single Flank Testing
- Structure Borne Noise Testing
- Contact Pattern Testing

Various Standards are available to define gear quality:
- ANSI / AGMA (Old 390.03 : Old 2009 A98 : ANSI/AGMA/ISO 17485 A08)
- DIN (Deutsches Institut für Normung - German Institute for Standardization)
- JIS (Japanese Industrial Standards)
- ISO (International Organization for Standardization)
- Other Countries have Standards
- Individual Companies have their own Standards
Inspection of Bevel & Hypoid Gears

- Comparison of actual tooth surface measurement to theoretical surface as identified by G-AGE™ (Gleason Analytical Gear Inspection) Software
- Surface Coordinates Use a Coordinate Measuring Machine
Flank Form Measurement

<table>
<thead>
<tr>
<th>Job Number</th>
<th>Number Of Teeth</th>
<th>Process</th>
<th>Mounting Distance</th>
<th>Measurement ID</th>
<th>Serial Number</th>
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<tr>
<td>269.445</td>
<td>7</td>
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<table>
<thead>
<tr>
<th>Part Number</th>
<th>Teeth Measured</th>
<th>Index Location</th>
<th>Gear/Cam Version</th>
<th>Measuring Direction</th>
<th>Deviation Measurement</th>
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<tr>
<td>5207056</td>
<td>10</td>
<td>5-3</td>
<td>2.36.02.0.00</td>
<td>Counterclockwise</td>
<td>transverse</td>
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</tbody>
</table>

Flank Point Mode sample dwell 100.3 Used new Fall 2015, Scan along Pressure Angle, Tooth Thickness by Index, Normal to Flank 2 (Gleason) | S20756 Pinion plate |

**Average Tooth**

Nom. Diff. Angle: 22.4697°

DIN 3965/366 (4)

Index FI 1 Cotswa

Index FI 2 Cotswa

**Total Gear Solutions**

November 9, 2015
Precision Index

Gleason Metrology Systems

Scan along Pressure Angle, Tooth Thickness by Index, Normal to Flank 2 (Gleason), Tooth Thickness = 16.7 mm, Nom. Diff. Angle = 22.459°, Act. Diff. Angle = 22.5004°

Pinion

Index Variation

DIN 3965/86(6)

<table>
<thead>
<tr>
<th>Flank 1</th>
<th>Dev</th>
<th>≠Q</th>
<th>=Q</th>
<th>Tol</th>
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<tbody>
<tr>
<td>Fp</td>
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<td>6</td>
<td>47</td>
</tr>
<tr>
<td>fp</td>
<td>2.3</td>
<td>1</td>
<td>6</td>
<td>17</td>
</tr>
<tr>
<td>fü</td>
<td>2.2</td>
<td>1</td>
<td>6</td>
<td>21</td>
</tr>
<tr>
<td>Frs</td>
<td>4.5</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Fr</td>
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Index Variation Runout Removed

Flank 2

<table>
<thead>
<tr>
<th>Flank 2</th>
<th>Dev</th>
<th>≠Q</th>
<th>=Q</th>
<th>Tol</th>
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<td>Fp</td>
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<td>6</td>
<td>17</td>
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<tr>
<td>fü</td>
<td>6.6</td>
<td>3</td>
<td>6</td>
<td>21</td>
</tr>
<tr>
<td>Frs</td>
<td>8.2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Gleason Metrology Systems Corporation

Data | Time | Operator | Customer | Machine ID | Probe Tip
---|------|----------|----------|------------|------------
24/11/2015 9:22:00 AM | Mark May | 7001 | 4F0-4, fPlus 0.0 mm
Bevel Gear Inspection - Corrections

Gleason Machine Corrections

Gear Name: S020718 Pinion
Operator: Mark May
Date/Time: 2/18/2015 1:59:27 PM
Download Date: 5/5/2014

Summary No.: S020718
Measurement ID: s/n 1031201
CMM ID: 7001
Difference Angle: -22.4697

Flankform measurement references unmodified nominal data.
600G Machine Setting Changes (1019002)
Asset No.: runoff / Description: runoff
Zero Order
First Order: Cross Toe/Heel I.B. O.B.
Pinion - Spread Blade

Radial Distance: 0.0351 mm
Tilt Angle: -0.0004°
Swivel Angle: -0.0071°
Machine Root Angle: 0.0018°
Sliding Base: -0.0205 mm
Ratio of Roll: 0.000000
Center Roll Position: -0.0038°
Pressure Angle - OB: 0.0097°
Pressure Angle - IB: 0.0107°

Tooth Thickness Error: 0.0187 mm
Sum of the Errors Squared (original): 0.00000162 inch²
Sum of the Errors Squared (after 1st): 0.0000023 inch²

Average Errors
Concave Flank
Pressure Angle: -0.18°
Spiral Angle: 0.43°
Warp Factor: 0.04/10 mm
RMS Error (Original): 0.0026 mm
Minimum Flankform Error: -0.0060 mm
Maximum Flankform Error: 0.0050 mm

Convex Flank
Pressure Angle: -0.41°
Spiral Angle: 0.61°
Warp Factor: -0.02/10 mm
RMS Error (Original): 0.0040 mm
Minimum Flankform Error: -0.0073 mm
Maximum Flankform Error: 0.0064 mm

RMS Flank 1: 0.0026
RMS Flank 2: 0.0040, Sum of Errors Squared: 0.00000162
RMS Flank 2: 0.0017, Sum of Errors Squared: 0.0000023
Gear Quenching Machines

✓ Die Quenching to Minimize Distortion
Lapping
  - Surface Refinement Process
Grinding
  - Corrective Machining Process
Carbide Hard Finishing - Skiving
  - Corrective Machining Process
Lapping Bevel Gears – Why Lap?

- One Machine to Complete Gear and Pinion in One Operation
- Fast Cycle Times
  - 1.5 min to 3 min for Typical for Automotive
- Noise Reduction

Video
LappingClip.mpg
Lapping - Active Torque-Controlled Lapping

- Higher QUALITY from Intelligent Active Torque
- Higher PRODUCTIVITY from Higher Speed and Torque Settings
- 1-2 Gear Class Improvement in Run-Out and Spacing
- 30% Cycle-Time Reduction
- Tester-like MTE Measurements
Grinding Bevel Gears – Why Grind?

✔ Strength
  - Root Blend
  - Tooth Spacing
✔ Longevity
  - Compressive Residual Stresses
  - Lack of Lapping Compound in Tooth Surface
✔ Economy
  - Eliminate Lapping
  - Interchangeable Pinions / Gears
✔ Noise
  - UMC – Universal Motion Concept
  - Transmission Error Control
Chamber Design

- Clean work chamber - minimizes swarf buildup
- Simple structure and movement
- No rails visible in work chamber
- More robust clamshell pivot
- No flat surfaces
- Wide coolant and swarf exit

![Image of chamber design](image-url)
Coolant Header

- Simplified design - less opportunity for swarf build up
- Increased travel - 175 mm
- Higher pressure wheel cleaning
- New coolant nozzle design
Better coolant adhesion to wheel
- Reduced risk of burning
- Cleaner line arrangement
- Less swarf buildup

Hard Pipes or Swivel Jets

Laser Pointer Assisted Set-up
Dresser

- Mounted to work spindle for maximum accuracy
- Advance and retract axial with spindle for ideal stiffness
- All services and mechanism internal to dresser results in high reliability and repeatability.
Stock Divider

- Fully retracts out of grind chamber
- Full CNC works on gears or pinions
- Stock divide can be done in parallel to dressing
- Higher speed than previous designs
Part Checking & Arbor Runout Compensation

- Removable Probe Measures:
  - Flank Form
  - Tooth Size
  - Pitch Error
- Stock mapping
- Stock balancing
- Corrections
  - Final corrections should be performed on a CMM machine

- Runout Compensation of Arbor
  - Measure Runout of Arbor
  - Software Compensates

Runout Compensation of Arbor
Grind From Solid - Adaptive Control Feature

✓ Teaching Cycle Grinding One Slot
CONIFLEX Grinding with CBN Wheel

Video
Coniflex Grinding.wmv
Continuous Search with Interpolation

- High productivity on the floor
- “Sliding” search parameters
- Faster measurements
- Interpolation by overlapping time records
- 9 positions in the time of 5
- 5 positions in the time of 3

Multi-Dimensional Searches

- Complete gear-set characterization in the lab
- Searches a multi-dimensional space of conditions
- Fully flexible and configurable from 2 to 6 dimensions
- V, H, G/BL, $\alpha$, Torque and Speed search variables
- Extended SFT data-collection cycles
- Hands-off operation
Carrier Deflection Simulation
- CNC angular machine can duplicate any deflected position
- Both thermal and load-induced
- External FEA utilized

Machine Deflection Compensation
- The infinitely stiff machine!
- Self-compensated for high load deflection
- Calculates gear-set forces in real time
- Standard and ultra-stiff spindles available

FEA Load Simulation ➔ Carrier Deflections ➔ Simulation Positioning
Gearset Forces from Applied Torque ➔ Calculated Machine Deflections ➔ Compensation Positioning
Takes Advantage of the Available Free Form CNC Machine Motions
Control Each Flank Independently
More Freedom to Modify Tooth Flank Form

Results:
- Improves Motion Transmission Error
- Reduces Noise
- Possible Strength Improvement

Complete Bevel Design, Analysis and Manufacturing Software

✓ CAGE™
  • Computer Aided Gear Engineering
✓ G-AGE™
  • Gleason Automated Gear Evaluation
✓ FEA
  • Finite Element Analysis
✓ UNICAL
  • Universal Gear Calculation & Analysis
✓ GABE™
  • Gleason Automated Blade Evaluation
Bevel Software Technology

- Gentle learning curve for new and existing gear engineers
- Easy and advanced base gear design and analysis capabilities
- Interactive 2D/3D TCA including V+H with exceptional default
- Graphical interactive tooth surface modifications for pinion & gear
- Seamless integration and data sharing with Gleason CAGE™
Bevel Software Technology - Closed-Loop Networking

GEMS™ Gleason Expert Manufacturing System

- Transmission of summaries and nominal gear data to proxy server
- Automatic creation of job “Fingerprint” by GEMS™ software
- Wireless or network transmission from server to machines
- Network transmission of nominal surfaces to CMM’s
- Corrective data calculated by G-AGE™ and send to server
- Automatic or operator approved application of corrections
System Design Loop - SMT and GAGE™ and Machines

System Design & Simulation

Gear Design & Analysis

Manufacturing

System Testing

Gear Testing

Gear Optimization
• Strength
• NVH
• Efficiency

Cutting
Grinding
Internal Chamfering & Deburring
Cylindrical Gear Polish Grinding
Grey zone
Resin bonding
very fine grit size
Polishing

Blue zone
Ceramic bonding
Medium grit size
Roughing & Finishing

Sandwich wheel for Polish Grinding
Rz < 1 µm

Grinding Wheels to Achieve Excellent Surface Finish
Wobble Compensation

Video: V_EN_Wobble_Compensation_Principle_2013_02_AT.wmv
From Industry 1.0 to Industry 4.0

**First Industrial Revolution**
- Based on the introduction of mechanical production equipment driven by water and steam power.
- First mechanical loom, 1784

**Second Industrial Revolution**
- Based on mass production achieved by division of labor concept and the use of electrical energy.
- First conveyor belt, Cincinnati slaughterhouse, 1870

**Third Industrial Revolution**
- Based on the use of electronics and IT to further automate production.
- First programmable logic controller (PLC) Modicon 084, 1969

**Fourth Industrial Revolution**
- Based on the use of cyber-physical systems.

Source: http://rtcmagazine.com/articles/view/115293
GLEASON 4.0

Gleason provides to customers a suite of solutions employing sensors, the internet, digital cloud data, mobile devices, in-depth gear process technology know-how, big data handling and advanced analytics to optimize the design and production of gears.

- gTools – Solutions to extract maximum value from Gleason Tools
- gUptime – Keep your machines running fault free
- gProcess – Solutions to use Gear Process Technology knowledge to optimize gear fabrication TCO
- gProduction – Use real time data to streamline your smart gear factory