GEAR GRINDING

Grinding wheels are used to generate the profile of the gear teeth. The machine and gear type determine the shape of the grinding wheel. Continuous gear generation, profile grinding and bevel gear grinding are the most common grinding processes.
Increasingly stringent requirements for gears result in tighter tolerances, higher profile accuracy and improved surface finish. The choice of abrasive is key in the production of high quality gears. In order to select the right abrasive, it is important to understand the terminology and technical criteria.

**DEFINITIONS:**

- **Line of action:** line along which the force between two meshing gear teeth is directed.
- **Pitch point:** the point where the line of action crosses a line joining the two gear centers.
- **Pitch circle:** the circle centered on the gear axis and passing through the pitch point.
- **Circular pitch (P):** the distance from one face of a tooth to the corresponding face of an adjacent tooth on the same gear, measured along the pitch circle.
- **Pitch diameter or reference diameter (D):** diameter of a pitch circle.
- **Modulus or “size coefficient” (M):** the module of a gear is equal to the pitch diameter divided by the number of teeth (Z).
- **Pressure angle (α):** the angle at a pitch point between the line of action which is normal to the tooth surface, and the plane tangent to the pitch surface.
- **Profile angle (V):** the angle at a specified pitch point between a line tangent to a tooth surface and the line normal to the pitch surface (which is a radial line of a pitch circle).

**Example calculation:**

1. Gear with Z = 30
2. Max PS = 600 RPM
3. Max WS = 4000 RPM

Based on (1) 
\[ E = \frac{PS \times Z}{Ws} \]

In this example, the general rule suggests 5 should be selected as the number of entries. However, 5 is a multiple of 30 so 4 should be chosen to optimize wheel speed.

**Part speed (PS):** PS (RPM) or (m/s)

**Wheel speed (WS):** WS (RPM) or (m/s)

**Number of entries (E):**

**Number of teeth (Z):**

Example calculation:

- Gear with Z = 30
- Max PS = 600 RPM
- Max WS = 4000 RPM

Based on (1) 
\[ E = \frac{PS \times Z}{Ws} \]

In this example, the general rule suggests 5 should be selected as the number of entries. However, 5 is a multiple of 30 so 4 should be chosen to optimize wheel speed.

The part speed is calculated by:

\[ PS = \frac{WS \times E}{Z} \]

Choice of E (depends on Z, see example below)
GEAR MANUFACTURING

Prior to grinding, a number of stages are involved in gear manufacturing:

**Hobbing** is a roughing operation which produces a gear profile with stock remaining for a final grinding process (see figure 1).

**Hardening/Heat-Treating** is a group of processes used to alter the physical, and sometimes chemical, properties of a material. Treatment involves the use of heating or chilling, normally to extreme temperatures, to achieve the desired result such as hardening or softening of a material. Heat-treatment techniques include annealing, case hardening, precipitation strengthening (age hardening), tempering and quenching.

**Grinding** produces a high-quality surface finish, correcting any distortion following heat treating, establishes profile dimensional accuracy. In some cases, grinding can be utilized to grind gears from solid eliminating the hobbing process.

The process is determined by the production lot size. High production gears follow:

- **Hobbing**
- **Hardenig**
- **Grinding**

**MAIN GEAR GRINDING METHODS**

**Continuous gear generation** Profiles an exact gear form into the workspace. With multiple passes, the wheel grinds the gear teeth to produce the desired gear geometry.

**Profile grinding** Profiles the exact shape of the gear teeth. The wheel runs between two opposing teeth to grind both surfaces at the same time.

**Bevel grinding** Bevel gears are conically shaped gears often used in differentials. Grinding of spiral bevel gears is performed with cup wheels following a profile grinding process.

Utilizing grinding over hobbing for small lot quantities is common with the advanced grinding wheel technology of today.

---

**PRODUCT DESCRIPTION**

Use the following example as a guide when selecting wheel shape, profile and grit quality.

**GRI T SIZE SELECTION**

The larger the gear module, the coarser the grit.

<table>
<thead>
<tr>
<th>MODULE</th>
<th>80</th>
<th>90</th>
<th>100</th>
<th>120</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 3.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5 - 3.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 1.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The grit sizes highlighted with are recommended.

**Gear example:** 120mm diameter, 36 teeth, pressure angle 20°, module “M” = 3mm

**Tip:** When designing a worm wheel, be sure to check the wheel construction parameters: module, pitch, number of starts, pressure angle, and thread direction.
WORM WHEEL FOR CONTINUOUS GEAR GENERATION

RS Profile

Key:
D1 = Type
D = Diameter
T = Thickness
H = Hole
R = Thread depth, optional field

STRAIGHT WHEEL FOR PROFILE GRINDING

S Profile

Key:
D1 = Type
D = Diameter
T = Thickness
H = Hole
V = Angle, face point to side
U = Flat face width

CUP WHEEL FOR BEVEL GRINDING

YM Profile

Key:
D1 = Type
D = Diameter
T = Thickness
W = Rim thickness
V1 = Face angle side 1
V2 = Face angle side 2
D1 = Distance to point from side 1
D2 = Distance to point from side 2

CONTINUOUS GEAR GENERATION

Continuous gear generation profiles an exact gear form into the workpiece. With multiple passes, the wheel then works on the gear teeth to produce the desired gear geometry. This is known as continuous grinding and is mainly used on small contact areas, but can also be used on large contact areas.

WORM GRINDING WHEEL DESIGN WORK SHEET

<table>
<thead>
<tr>
<th>TIER</th>
<th>GRIT TYPE</th>
<th>FEATURES</th>
<th>BENEFITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>BEST</td>
<td>3NQM</td>
<td>Engineered microstructure ceramic grain</td>
<td>Free cutting action</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sharp, friable ceramic technology</td>
<td>Long life</td>
</tr>
<tr>
<td></td>
<td></td>
<td>For low, medium and high force</td>
<td></td>
</tr>
<tr>
<td>BETTER</td>
<td>25A</td>
<td>High purity friable abrasive</td>
<td>Cool cutting</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Suitable for light to moderate feed rates</td>
<td></td>
</tr>
</tbody>
</table>

BOND DESCRIPTION

<table>
<thead>
<tr>
<th>TIER</th>
<th>BOND TYPE</th>
<th>FEATURES</th>
<th>BENEFITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>BEST</td>
<td>VS3G</td>
<td>Vitrified durable bond</td>
<td>Form holding</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Latest generation bond</td>
<td>Well suited for high-speed operations (80m/s)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Long life</td>
</tr>
</tbody>
</table>
**DRESSING TOOLS FOR CONTINUOUS GEAR GENERATION GRINDING WHEELS**

**SINGLE-TAPER DRESSING DISCS**
- Highly flexible tool concept for different module ranges
- Discs are mounted on separate spindles

**DOUBLE-TAPER DRESSING DISCS**
- Very good when tooth root machining is required
- Tool design is dependent on the workpiece

<table>
<thead>
<tr>
<th>Module</th>
<th>Tool design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small ≤1.5</td>
<td>Reverse electroplated</td>
</tr>
<tr>
<td>Large &gt;1.5</td>
<td>Positive electroplated</td>
</tr>
</tbody>
</table>

**ROLLER DRESSER SETS FOR SINGLE-PASS DRESSING**
- High pitch adjustment
- Very good when tooth root grinding is required
- Tool design is dependent on the workpiece

**FULL PROFILE ROLLER DRESSERS**
- Particularly suitable for modules ranges ≤ 1.5
- Excellent tool design with low setup requirements
- Specific design to each workpiece

**WHEEL SELECTION GUIDE**

**SINGLE RIB GRINDING**
Single rib grinding forms the exact shape of the gear teeth. The wheel runs between two opposing teeth to grind both surfaces at the same time. This is known as discontinuous grinding and is used on large contact areas.

**WHEEL SELECTION GUIDE**

Key:
- 01 = Type
- D = Diameter
- T = Thickness
- H = Hole
- V = Angle, face point to side
- U = Flat face width

Norton rotary dressing discs provide excellent results on single profile wheels:
- Contour controlled CNC dressing
- Very flexible
- One tool for several profiles
SINGLE RIB GRINDING

SINGLE RIB GRINDING WHEEL DESIGN WORK SHEET

FILL IN ALL BOXES

OUTSIDE DIAMETER

BEVEL ANGLE

RECESS Dia.,

RECESS DEPTH

WIDTH

FLAT

BEVEL ANGLE

RECESS Dia.,

RECESS DEPTH

HOLE

REQUEST NORTON PRINT ME161178

WHEEL MAY OR MAY NOT BE RECESSED

GRIT DESCRIPTION

<table>
<thead>
<tr>
<th>Tier</th>
<th>Grit Type</th>
<th>Features</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>BEST</td>
<td>3TGP</td>
<td>Blend of ceramic with pink aluminum oxide</td>
<td>Free cutting</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Long, sharp ceramic grain</td>
<td>Self sharpening</td>
</tr>
<tr>
<td>BETTER</td>
<td>25A</td>
<td>High purity friable abrasive</td>
<td>Cool cutting</td>
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SPIRAL BEVEL GEAR GRINDING WHEELS

Bevel gears are conically shaped and used for differentials. Grinding of spiral bevel gears is performed with cup wheels in a specific profile grinding process.

WHEEL SELECTION GUIDE

CUP GRINDING WHEEL DESIGN WORK SHEET

FILL IN ALL BOXES

PLATE DATA (DESIGN INFO)

PLATE DIAM

PLATE THICKNESS

PLATE THICKNESS (CONC.)

PLATE THICKNESS (CONC.)

HOLE SIZE

HOLE SIZE

HOLE SIZE

HOLE SIZE
**GRIT DESCRIPTION**

<table>
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</tr>
</tbody>
</table>

**DRESSING TOOLS**

Norton offers a dressing solution for all spiral bevel gear grinding wheels:

- Contour controlled CNC dressing
- Very flexible
- One tool for several profiles

**MACHINING TO GRINDING FOR SMALL LOT SIZE GEAR PRODUCTION**

- Machining to grinding eliminates rough cutting the gears (through the use of formed cutters, broaching or hobbing)
- Grinding from solid eliminates the need for a cutting machine and all the complementary tooling and equipment required to start and maintain the rough cutting operation
- Typically a rough-ground gear will be of higher quality than a hobbed, near-net, or cut gear – particularly larger spur gears and gear sets
- Norton machining to grinding (MTG) wheel specifications create the flexibility to combine grinding in the soft state from solid, to hard finishing – with only 1 grinder

**MTG CASE HISTORY**

**Spar and Helix Gear Sets**

Grinding spur and helix gear sets from solid at a large gear manufacturer.

**Customer Assessment**

- Norton engineers were approached by a customer interested in improving grind cycle times on large gears
- This customer typically manufactures and repairs 2,500+ large gears and gear boxes per year
- A large backlog at the customer’s cutting machine was creating late ship dates and preventing the customer from accepting new orders
- Customer contacted OEM and Norton for assistance in speeding up grind cycle and to explore the possibility of grinding gears from a solid.
- Development work by OEM and Norton application engineer proved that gears could be efficiently ground from solid, and then finish-ground on the same machine after heat treat as required.
Test Data
Wheel Size: 457mm X 127mm
Wheel Type: 01, face bevel 2 sides 30 degrees
Wheel Specification: TGX-VTX2
Workpiece Material: 4340, Hardness: 38-42 Rc
Spur/Helix Gear: 115 teeth
58.370” OD, 8” face width
30” helix angle, whole depth .990”
D.P. 2.3, 25 degree PA, AGMA 12
Machine Model: Hofler Grinder, 32 hp

Wheel Speed: 5,500 SFPM
Coolant: Straight oil, high pressure system - chilled and filtered 70 GPM @ 75-80 PSI
MTG Rate of Cut: 3.0 cubic inches per minute
Dresser Type: Rotary
Dressing: Dress every 5 teeth; dress .0009” x 4 passes
Peak Power
Steady State: 11hp

Test Results

<table>
<thead>
<tr>
<th>Process Time: 1,200 minutes</th>
<th>949 minutes</th>
<th>Savings: 21%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tooling Cost: $568.25</td>
<td>$244.76</td>
<td>57%</td>
</tr>
<tr>
<td>Total Cost: $2,968.25</td>
<td>$2,618.79</td>
<td>12%</td>
</tr>
</tbody>
</table>

The table below is a guide to selecting the best product solution for the machine brand and type. Contact your local sales representative for more information.

<table>
<thead>
<tr>
<th>WHEEL DESIGN</th>
<th>WHEEL DIMENSION</th>
<th>SPECIFICATION</th>
<th>PART #</th>
</tr>
</thead>
<tbody>
<tr>
<td>Worm Wheel</td>
<td>280 x 160 x 115</td>
<td>NG80-H8V3S3G</td>
<td>0031048492</td>
</tr>
<tr>
<td></td>
<td>280 x 160 x 115</td>
<td>25A80-H8V3S3G</td>
<td>0031048494</td>
</tr>
<tr>
<td></td>
<td>350 x 125 x 160</td>
<td>3N080-H10V3S3G</td>
<td>310448495</td>
</tr>
<tr>
<td></td>
<td>350 x 125 x 160</td>
<td>25A80-H10V3S3G</td>
<td>310448496</td>
</tr>
<tr>
<td>Single Rib Wheels</td>
<td>450 x 150 x 127</td>
<td>3TGP80/3-G12V3S3G</td>
<td>0031048497</td>
</tr>
<tr>
<td></td>
<td>450 x 100 x 127</td>
<td>3TGP80/3-G12V3S3G</td>
<td>0031048498</td>
</tr>
<tr>
<td></td>
<td>450 x 50 x 127</td>
<td>3TGP80/3-G12V3S3G</td>
<td>0031048499</td>
</tr>
<tr>
<td></td>
<td>300 x 60 x 59.8</td>
<td>3TGP80/3-G12V3S3G</td>
<td>0031048500</td>
</tr>
<tr>
<td></td>
<td>300 x 30 x 59.8</td>
<td>3TGP80/3-G12V3S3G</td>
<td>0031048501</td>
</tr>
<tr>
<td></td>
<td>120 x 30 x 20</td>
<td>3TGP80/3-G12V3S3G</td>
<td>0031048502</td>
</tr>
</tbody>
</table>
TYPICAL COST REDUCTIONS

On average, abrasives and cutting tools only account for about 3% of total manufacturing budgets. Norton Vitrium³ products optimized with Norton’s proprietary PSP (process solutions program) helps to optimize your total cost and improve your productivity.

For information on how to achieve the greatest overall cost savings, see the example below or go to www.nortonindustrial.com/psp.aspx.

Increasing the life of abrasives
Even a 50% increase in product life will only reduce costs per part by 1%.

Decreasing the price of abrasives
A 30% price reduction will only reduce costs per part by 1%.

Increase overall productivity through PSP
With a 20% decrease in cycle time per part, there will be a reduced total cost per part of more than 15%.

ENVIRONMENTAL BENEFITS

IMPROVING OUR CARBON FOOTPRINT
Increased productivity with existing customer machine capacity. Able to work with higher feed rates, speed and pressure, to significantly increase production while using fewer wheels.
Reduced energy consumption with optimal firing temperatures during manufacturing of Norton Vitrium3 wheels.

By choosing Norton Vitrium3 technology for your grinding operation, you help to preserve the environment. In addition, Norton Vitrium3 eliminates costly re-validation of processes associated with using certain chemicals.