Advanced PM Gear Design &
High Pressure Compaction
Overview

• NAH Tech Center and Hoganas Group Prototype Center
• Applications Driven
• Key Advanced Gear Technology Activities
  • Radial Surface Densification
    • NAH/HB experience
    • Status Quo
    • Ref Manheim SIP MIBA, GKN and PMG
    • Other approaches (warm sizing, shot peening etc)
Overview (cont....)

- Alternative Gear Profiles (SMART)
- NAH-WZL Partnership (tougher Application Areas)
- High Pressure Compaction
  - Hipaloy™ (1P1S to 7.40-7.50g/cc
Tech Center Capabilities and offerings
Hoganas Prototype Center

4 Week Lead Time
Application Driven - Motorcycles

<table>
<thead>
<tr>
<th>Engine</th>
<th>Air cooled, 4 stroke single cylinder OHC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displacement</td>
<td>174.7 CC</td>
</tr>
<tr>
<td>Maximum Power</td>
<td>6.72 kW (9 BHP) @ 7000 RPM</td>
</tr>
<tr>
<td>Maximum Torque</td>
<td>10.35 N·m @ 4000 RPM</td>
</tr>
<tr>
<td>Bore x Stroke</td>
<td>52.4 x 57.8 mm</td>
</tr>
<tr>
<td>Compression Ratio</td>
<td>9.1:1</td>
</tr>
<tr>
<td>Carburetor</td>
<td>Side Draft Variable Venturi (Piston)</td>
</tr>
<tr>
<td>Starting</td>
<td>Self Start / Kick Start</td>
</tr>
<tr>
<td>Idle Speed</td>
<td>1400 RPM</td>
</tr>
<tr>
<td>Ignition</td>
<td>A/M - Advanced Microprocessor Ignition System</td>
</tr>
<tr>
<td>Clutch</td>
<td>Multiplate Wet</td>
</tr>
<tr>
<td>Gear Box</td>
<td>4 speed constant mesh</td>
</tr>
</tbody>
</table>

EXISTING PM PARTS
- Kick start stopper
- Oil pump
- Oil pump drive gear
- Valve guide and VSI
- Wheel spacers
- Clutch holder hub

POTENTIAL PM PARTS identified
- Primary Driven Gear (PDG, GPD)
- Primary Drive Gear
- Kick starter ratchet and pinion
- Electric starter gear
- One-way clutch and race
- Transmission gears
- Shift forks
- Connecting rods
- Half shaft / crank shaft
- Cam lobes
- Valve spring seat
- Cam chain tensioner
- Counter weight
Application Driven – Recreation Vehicles

Crank Case Assembly

Transmission –
Gear Cluster & Final Drive
Application Driven - Automotive
Relative Cost Performance Rating

- Powder forging
- 2P2S
- Cu infiltration
- Warm Compaction
- Hipaloy
- 1P1S

Density (g/cc) vs. Relative cost
Hoganas Group Partnership with WZL Aachen University

New Opportunities opened up by Powder Metallurgy (PM) in Gear Manufacturing

- Techno-commercial Market Research Program
- Focused on key segments
- Understanding future OEM requirements in gear manufacturing technology

Outcomes
- Update on latest advances in Powder Metallurgy
- Contacts / Communication
- Clearer understanding of target applications
Hoganas Group Partnership with WZL Aachen University

Seminar by Höganäs on PM [20-30 min]
  • State of the art in PM
  • Advances in optimized gear shapes

Seminar by WZL [20-30 min]
  • Trends in gear manufacturing technologies

Discussion of manufacturing strategies and opportunities for improvements [30-45 min]
  • Case studies from WZL/Höganäs
  • Techno-commercial feasibility discussion of meeting partners' gears
Surface Densification – Radial Rolling

Hertzian Stress

Hardness

Density
Surface Densification

Core Density

7.0 g/cm³  
Cylindrical rollers  
Compressed 0.3 mm  
Material: Astaloy Mo + 0.3C

7.2 g/cm³  

7.3 g/cm³
Surface Densification of Sintered Components

**Process**
- Force Control
- Cycle time = 8-15 seconds
- Die Life approx 2 -300k parts (estimated from burnishing data)
Case Study 1

Transmission Gear for Manual Gearbox

Process
Compaction
Sintering
Hobbing of pre-form
Rolling (0.2-0.5mm)
Case hardening (0.3mm)
Surface Roughness Ra 0.12µm)

Materials
Astaloy 85 Mo
(Fe-0.85Mo Pre-alloyed)
Case Study 2

Planetary Gear – Scania Heavy Truck Transmission

Investigated gear
## Case Study 2
*Planetary Spur Gear – Scania Heavy Truck Transmission*

<table>
<thead>
<tr>
<th>Number of teeth Z</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal module $m_n$ (mm)</td>
<td>3.65</td>
</tr>
<tr>
<td>Press angle $a_n$</td>
<td>22.5°</td>
</tr>
<tr>
<td>Addendum modification coefficient</td>
<td>0.47</td>
</tr>
<tr>
<td>Over ball diameter (mm)</td>
<td>89.35</td>
</tr>
</tbody>
</table>

### Process
- Compaction
- Sintering
- Hobbing of preform
- Rolling
- Casehardening

### Result
- Gear quality DIN 8 (ISO 7, JIS 3)
- Tooth root bending fatigue strength exceeds level of wrought steel reference material.
- Improved surface roughness

### Materials
- Astaloy 85 Mo – 7.25g/cc
- Wrought steel ref. - SAE 8620

<table>
<thead>
<tr>
<th>Load (kN)</th>
<th>No. of cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface densified gear 33 kN</td>
<td><img src="image1.png" alt="Graph" /></td>
</tr>
<tr>
<td>Wrought steel gear 31 kN</td>
<td><img src="image2.png" alt="Graph" /></td>
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</table>
Case Study 3 Spur Gear Hipaloy CrL

Spur Gear – Hipaloy CrL

<table>
<thead>
<tr>
<th>Gear parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Module</td>
<td>3 mm</td>
</tr>
<tr>
<td>Pressure angle</td>
<td>20 degree</td>
</tr>
<tr>
<td>Number of teeth</td>
<td>26</td>
</tr>
<tr>
<td>Tooth width</td>
<td>10.0 mm</td>
</tr>
<tr>
<td>Outside diameter</td>
<td>84.0 mm</td>
</tr>
<tr>
<td>Pitch diameter</td>
<td>78.0 mm</td>
</tr>
<tr>
<td>Root diameter</td>
<td>70.5 mm</td>
</tr>
<tr>
<td>Addendum modification coef.</td>
<td>0.0</td>
</tr>
</tbody>
</table>
Surface Densification

To improve RCF Life of PM

Extrapolated Hertzian pressure of ZF-RCF-test resistance (MPa)

- Astaloy Mo +0.3C, 7.4g/cm³, R, CH
- Astaloy Mo +0.3C, 7.2g/cm³, R, CH
- Astaloy Mo +0.5C, 7.2g/cm³, R, CH
- Hipaloy CrL+0.2C, 7.5g/cm², R, CH
- Hipaloy CrL+0.2C+0.7Ni, 7.5g/cm², R, CH
- DIN EN 20 NiCrMo2 (SAE8620), CH
- Hipaloy CrL+0.2C+0.7Ni, 7.5g/cm², SP, B, CH

Materials:
- NAH74
- A1
- A2
- A3
- B1
- H6
- H7
- H8
- H9
Surface Densification Summary

• Commercially used for Gear Tolerance Qualification (with limited selective surface densification)

• True Surface Densification still being developed

• Main barriers are
  • HT occurs after Rolling (i.e. destroying imparted tolerance)
  • Need for Design Software for calculating pre-form profile

• Ref EPMA Conference Manheim SIP MIBA, GKN and PMG
The Potential of Ausforming

Surface densification via radial surface rolling

- Provides RCF required for PM materials
- But, still Dimensional Quality issues

Compaction

Sintering

Rolling

Case hardening

Hard finishing
Alternative Gear Profile Geometries

- Gear box redesign
- Mfg of PM Gears with alt. gear profile
- Re-build Gear Box and fit
- Test Drive

Targeted Benefits:

- Improved Pitting life
- Improved Tooth Root Fatigue
- Eliminate need for Surf Dense
High Pressure Compaction - HIPALOY™

**Diagram:**
- Plot showing the green density (g/cc) vs. compaction pressure (MPa) for different materials.
- Materials compared:
  - Hipaloy (1.5Cr 0.2Mo) + 0.25%C-UF
  - Hipaloy (1.5Cr 0.2Mo) + 0.85%C-UF
  - AstaloyCrL + 0.85C-UF + 0.7%Kenolube

**Table:**

<table>
<thead>
<tr>
<th></th>
<th>Sintered</th>
<th>Q&amp;T</th>
</tr>
</thead>
<tbody>
<tr>
<td>TS (MPa)</td>
<td>1000</td>
<td>1650</td>
</tr>
<tr>
<td>YS (MPa)</td>
<td>750</td>
<td>1300</td>
</tr>
<tr>
<td>Elong (%)</td>
<td>4</td>
<td>1.5</td>
</tr>
<tr>
<td>IE (J)</td>
<td>50</td>
<td>50</td>
</tr>
</tbody>
</table>
What is the HIPALOY™?

- Pre-alloyed material with 1.5% Cr and 0.2% Mo
- Modified particle size and distribution
- Integrated lubricant system ~0.3% organic additive
- Supplied as pre-mixed with additives graphite, Ni etc.

- High compacting pressures 900-1100 MPa
- High temperature sintering >1250°C
High compacting pressures

⇒ Needed for lubrication and in order to achieve high density

Consequence:
• Robust design of tools required
• Limited to simpler geometries
• CNC Controlled Hydraulic Pressing
High temperature sintering

⇒ Needed in order to get good bonding between the particles

1280°C
- good particle bonding

1120°C
- insufficient diffusion and particle bonding
Fatigue performance (as case hardened)
Tooth Root Bending Fatigue

- **Compacted @ 1100 MPa**
- **Sintered @ 1280°C/30 min**
- **Case Hardened**

- **GD=7.55 g/cc**
- **SD=7.63 g/cc**

- DIN 15CrNi6 (1.5Cr 1.5Ni 0.5Mo 0.15C) - wrought steel
- Hipaloy (1.5Cr 0.2Mo 0.7Ni 0.25C)
- Hipaloy (1.5Cr 0.2Mo 0.7Ni 0.25C) shot peening *

* shot peening after sintering / before case hardening
Total press area: 1178mm²

Weight: 103.5gram

Total press force: 1120kN (for 950 MPa)
Sample #10 - 800 MPa  
Sintered 1280°C 30 mins 90/10  
Sintered density 7.41 g/cc  

Green average density 7.34
Sample 950 MPa  Sintered 1280°C 30 min 90/10  Hipaloy 0.55C
Sintered density 7.50 g/cc

Green average density 7.40

7.42  7.35  7.40
Relative Cost Performance Rating

- Powder forging
- 2P2S
- Cu infiltration
- Warm Compaction
- Hipaloy
- 1P1S

Density (g/cc) vs. Relative cost
High Pressure Compaction Next Generation

Single Press Single Sinter to 7.40g/cc min @ 55tsi max
Thank You!