Plasma Nitriding
- especially in the Gear Industry

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Ralph Trigueros
Rübig GmbH & Co KG - Austria
CONTENT

- Overview Ruebig Company
- Short Introduction into Plasma Nitriding Technology
- Gear Production
  - Trends in Gear Production
  - Process Chain in Gear Production
  - Development of Process Chains in Gear Manufacturing
- Potential of Plasma Nitriding at Gear Manufacturing
  - Load and Stress Profiles on a Gear
  - Optimized local Properties due to Plasma Nitriding
  - Economic and Ecologic Aspects
- Examples: especially Ring Gear (Co. Oberaigner)
The Rubig group has been engaged in steel technology for more than 60 years. Knowledge and experience are the basis for our success. The synergetic cooperation of the three different divisions results in newest technologies.

- RUBIG – Die Forge
- RUBIG – Heat Treatment
- RUBIG – Engineering
RUBIG GROUP OF COMPANIES

**RUBIG – Die forge**
Your partner to develop forge parts also for smaller series, up to 4 Kg part weight
High quality management standards, we are working according to TS 16949
Mechanical machining, welding technology and heat treatment

**RUBIG – Heat Treatment**
Heat Treatment certified according to ISO 9001:2000 and VDA 6.1
Cooperation with academic institutes and steel producers are the basis for our status as technology leader
Expertise in material science drives the development for newest heat treat technologies

**RUBIG – Engineering**
Individual solutions for Plasma assisted nitriding and coating units
Vacuum furnaces and cleaning machines distinguish us from the competition
Fundamental research ensures application based solutions
PRODUCT PORTFOLIO

PLASNIT® / GASNIT®:
combined plasma and gas nitriding system

PLASTIT®
Plasma assisted CVD coating system
PRODUCT PORTFOLIO

MICROPULS®
plasma generators

HPG line

MAP line
PRODUCT PORTFOLIO

RUEBIG ®
vacuum hardening furnace

HELIVAC ®
helium - high pressure gas quenching system with integrated recycling unit
PRODUCT PORTFOLIO

HYDROVAC ®
metal parts cleaning unit
EXPORT COUNTRIES RÜBIG ENGINEERING

OVERSEAS
- Argentina
- Australia
- Brazil
- Hong Kong
- India
- Indonesia
- Iran
- Japan
- Canada
- Korea
- Mexico
- Singapore
- South Africa
- Taiwan
- Thailand
- Turkey
- USA
- United Arab. Emirates

EUROPE
- Belgium
- Denmark
- Germany
- Finland
- France
- Great Britain
- Italy
- Liechtenstein
- Netherland
- Austria
- Poland
- Romania
- Sweden
- Switzerland
- Slovakia
- Slovenia
- Czech Republic
- Hungary
Nitriding Methods and basics of Plasma Nitriding Technology
NITRIDING

Definition:
The surface layer of the work piece is enriched with nitrogen by thermo chemical treatment.

Process routes:
- salt bath nitriding
- gas nitriding
- plasma nitriding
OXIDE LAYER, WHITE LAYER AND DIFFUSION ZONE

oxide layer, 1-2 µm:
- Running-in layer
- Low friction coefficient
- Corrosion resistance

white layer, 5-20 µm:
- Ceramic layer
- Protection against abrasive and adhesive wear
- High hardness

diffusion zone, 10-1000 µm:
- High compressive stress
- High fatigue strength
- Hardness higher than substrate
COMMON NITRIDING AND NITROCARBURIZING METHODS

- Salt bath nitriding
- Gas nitriding
- Plasma nitriding
DESIGN AND MAIN COMPONENTS OF A RUBIG PLASMA NITRIDING SYSTEM

- inner fan
- pump stand
- ARC detection
- measuring electronic
- gas supply system
- CPU
- PC - data recording
- MICROPULS power supply
- insulation amplifier
- retort
- intermediate ring
- exhaust flap
- multiple cooling system
- fan/(cooling)
- heating
- Inlet flap (cooling)
DESIGN AND MAIN COMPONENTS OF A RUBIG PLASMA NITRIDING SYSTEM

- Process control system and visualization
  - Simple operation
  - Control system based on Siemens S7
  - Visualization under Windows
  - Process data logged in real time
  - Fully automatic and man-free operation
  - User surface in different languages available
DESIGN AND MAIN COMPONENTS OF A RUBIG PLASMA NITRIDING SYSTEM

recipe administration
DESIGN AND MAIN COMPONENTS OF A RUBIG PLASMA NITRIDING SYSTEM
OXIDE LAYER, WHITE LAYER AND DIFFUSION ZONE

- **salt bath nitriding**
  - high friction due to rough porous zone
  - post polishing necessary
  - very good corrosion resistance

- **gas nitriding**

- **plasma nitriding**
  - low friction due to smooth porous zone
  - no post polishing
  - good corrosion resistance

No GO
(for comparison purposes only)
### GAS vs. PLASMA; HEALTH AND ENVIRONMENT RELEVANT ASPECTS

<table>
<thead>
<tr>
<th><strong>Gas Nitriding</strong></th>
<th><strong>Plasma Nitriding</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Process Temperature</strong></td>
<td>530 – 600 °C</td>
</tr>
<tr>
<td><strong>Process Gases for Nitriding</strong></td>
<td>NH₃, N₂</td>
</tr>
<tr>
<td><strong>Carbon Precursor for Nitrocarburizing</strong></td>
<td>CO₂</td>
</tr>
<tr>
<td><strong>Gas Consumption in an Average Furnace Size</strong></td>
<td>4000 l/h</td>
</tr>
<tr>
<td><strong>High Influence of Cleaning on Nitriding Result</strong></td>
<td></td>
</tr>
<tr>
<td><strong>NH₃ as Nitrogen Precursor</strong></td>
<td></td>
</tr>
</tbody>
</table>

- **Decreased energy demand**
- **Used gases not relevant for the environment**
- **Reduced pollutant emissions**
- **No greenhouse gas emissions**
- **Reduced cleaning expenses**
- **Used gases not relevant for the health**
- **Final cleaning by „sputtering“**
ECOLOGICAL ADVANTAGE: EMISSIONS COMPARISON FOR GAS- AND PLASMA NITRIDERS

**Facts**

- 5.500 plasma nitriders produce less NO\textsubscript{x} than one gas nitriders
- 2.700 plasma nitriders produce less CO/CO\textsubscript{2} than one gas nitriders
- The gas consumption of a Plasma nitriders is at least 10 times lower than for a gas nitriders

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<table>
<thead>
<tr>
<th>Effluent emission data for plasma and gaseous nitrocarburising</th>
<th>Plasma</th>
<th>Gaseous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amount of gas used</td>
<td>0.6</td>
<td>6.0</td>
</tr>
<tr>
<td>Total carbon emission via CO/CO\textsubscript{2}</td>
<td>504</td>
<td>137253</td>
</tr>
<tr>
<td>Total amount of NO\textsubscript{x} gas</td>
<td>1.2</td>
<td>664</td>
</tr>
<tr>
<td>Output of residual carbon bearing gas</td>
<td>302</td>
<td>823518</td>
</tr>
<tr>
<td>Output of residual NO\textsubscript{x} gas</td>
<td>0.72</td>
<td>3984</td>
</tr>
</tbody>
</table>

Source: T. Bell
TECHNICAL ADVANTAGE – PLASMA NITRIDING

Process Reproducibility - Homogeneity

evaluation period 12/2008-12/2009 – witness loads 5 samples / charging level
## AUTOMOBILE – GEAR MANUFACTURING

Global gear production – regional production in mio.

<table>
<thead>
<tr>
<th>Region</th>
<th>2007</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Japan / Korea</td>
<td>24</td>
<td>27</td>
</tr>
<tr>
<td>Western Europe</td>
<td>18</td>
<td>21</td>
</tr>
<tr>
<td>North America</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>China</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>South Asia</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Eastern Europe + South America</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td><strong>total</strong></td>
<td>63</td>
<td>81</td>
</tr>
</tbody>
</table>

+ 28%

Non automotive gears are not included in the numbers (approx. 11 million gear boxes additionally)
PROCESSES IN GEAR MANUFACTURING

Lecture of Klocke F., Weck M. at WZL Forum 1998 in Aachen: Warum Feinbearbeitung?

1. Raw material
2. Turning
3. Gear cutting (soft machining)
4. Soft finishing
5. Carburizing
6. Hard machining
7. Sorting / Rejecting
8. Fabricated gear
DEVELOPMENT OF GEAR BOX PRODUCTION
Factory Kassel – VW Gear Manufacturing-Engineering

Percentage of Hard Machined Gears at VW

- 2000: 5%
- 2008: 49%
- 2011: 58%

J. Fenstermann, Getpro 2009: Ganzheitliche Prozessoptimierung in der Getriebefertigung bei VW
REASONS FOR HARD MACHINING

Noise reduction

Maximizing of bearing capacity

Reaching the quality necessary for the application

Reduction of gearing failures

Gear modifications

Impovement of surface quality and fabrication of advantageous surface structures

Angle errors
Pitch errors
Rotation errors
Reeling errors

Angle corrections
Convexities
Retractions
Topological corrections
Design optimization
(tooth root)

Lecture of Klocke F., Weck M. at WZL Forum 1998 in Aachen: Warum Feinbearbeitung?
Up to **40% of production costs** are nowadays necessary to **compensate the distortion due to the heat treatment and to improve the surface quality.**

**Passenger cars – gear box assembling**  
(aprox. 16,000 gear systems for passenger cars)

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J. Fenstermann, Getpro 2009: Ganzheitliche Prozessoptimierung in der Getriebefertigung bei VW
Potential of Plasma Nitriding at Gear Manufacturing
LOAD AND STRESS PROFILE ON A GEAR

Tooth root

Tooth flank

Micro Pitting

Pit Marks
DIFFERENT RECOMMENDATIONS FOR DIFFUSION DEPTH AT ROOT AND FLANK

Case depth and nitriding depth for gears according Linke (Stirnverzahnungen, 1996):

<table>
<thead>
<tr>
<th>Modulus in mm:</th>
<th>1,0 to 2,4</th>
<th>2,5 to 3,5</th>
<th>3,5 to 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>CD</td>
<td>0,3 + 0,2</td>
<td>0,5 + 0,3</td>
<td>0,8 + 0,4</td>
</tr>
<tr>
<td>ND</td>
<td>0,2 + 0,1</td>
<td>0,3 + 0,1</td>
<td>0,4 + 0,1</td>
</tr>
</tbody>
</table>
OPTIMIZED LOCAL PROPERTIES

Plasmanitriding offers an intelligent material / heat treatment design → required material properties exactly where they are needed

**properties on the gear tooth**

**white layer**
- thin white layer on flank
  - reduces wear
  - increases sliding behaviour
  - increases pitting resistance

no / small white layer on tooth root
- increases tooth root bending strength

**nitriding depth**
- average nitriding depth on flank
  - increases pitting resistance
- small nitriding depth at tooth root
  - increases tooth bending strength
MICROGRAPH OF A RING GEAR, MODULUS 0.35
CORE MESSAGE

Appropriate Material + Adequate Micropuls Plasmanitriding offers

The same or even better mechanical properties than carburized gear parts

Considerably more homogeneous fatigue values compared to carburized gears

The material properties exactly where they are needed and adjustable according to demands
RUBIG PLASMA NITRIDING INITIATIVE

Rotating bending tests
until middle 2007

RCF tests
until end of 2007

tooth root bending strength
until end of 2009

tooth flank pitting strength
until middle 2010

modulus 1.25

modulus 2.75
TOOTH ROOT FATIGUE STRENGTH
Comparison case hardening and gas- / plasma nitriding

Data from DIN 3990 – Literature Data – Rübig Tests

- R935
- 31CrMoV9

Tests with shaved and plasma nitrided gears, m=1,25 and 2,75; done at FZG- Institute TU-Munich 2007 to 2010
INFLUENCE OF WHITE LAYER ON TOOTH ROOT FATIGUE STRENGTH
Test results of plasma nitrided gears 31CrMoV9 modulus 5 mm

<table>
<thead>
<tr>
<th>Plasma nitriding - variants</th>
<th>VAR 1</th>
<th>VAR 2</th>
<th>VAR 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>core hardness</td>
<td>N/mm²</td>
<td>950</td>
<td>950</td>
</tr>
<tr>
<td>white layer WS</td>
<td>µm</td>
<td>with</td>
<td>with</td>
</tr>
<tr>
<td>nitriding temperature</td>
<td>ºC</td>
<td>530</td>
<td>520</td>
</tr>
<tr>
<td>nitriding time</td>
<td>hours</td>
<td>60</td>
<td>36</td>
</tr>
<tr>
<td>case hardness</td>
<td>HV 0,5</td>
<td>750</td>
<td>750</td>
</tr>
<tr>
<td>nitriding depth Nd in tooth root</td>
<td>mm</td>
<td>0,4</td>
<td>0,3</td>
</tr>
<tr>
<td>tooth root fatigue strength σ_{Film} (DIN 3990)</td>
<td>N/mm²</td>
<td>390</td>
<td>340</td>
</tr>
<tr>
<td>percentage</td>
<td>%</td>
<td>72</td>
<td>63</td>
</tr>
</tbody>
</table>

PITTING RESISTANCE $\sigma_{\text{Hlim}}$ - SITUATION

Standard- and test values of literature / data Rübig

Standard DIN 3990 values $\sigma_{\text{Hlim}}$
(fatigue strength, 1% failure probability)

- Carburizing: $1300 - 1650 \text{ N/mm}^2$
- Nitriding: $1120 - 1450 \text{ N/mm}^2$

Values diss. Schlötermann, $m=5$

PN: $\sigma_{\text{Hlim}} = 1590 - 1760 \text{ N/mm}^2$

Failure not by pitting, only by wear on the driving gear between pitch circle and tooth root (load $= 8,5 \times 10^7$)

Fatigue data according to DIN 3990-5:
- Tempered steel: $1220 \text{ N/mm}^2$
- Nitriding steel gas nitrided: $1450 \text{ N/mm}^2$
- Case-hardened steel: $1650 \text{ N/mm}^2$

Dissertation Schlötermann 1988:
- Nitriding steel plasma nitrided: $1760 \text{ N/mm}^2$
- Case-hardened steel: $1760 \text{ N/mm}^2$

Actual data Rübig:
- Development Rübig: $1760 \text{ N/mm}^2$
- Case-hardened steel: $1400 \text{ N/mm}^2$
APPLICATION – COATING OF GEARS

W-C:H coated gears give an efficient protection against grey spotting and also pitting. ⇒ weight reduction

→ Increase of pitting resistance through coating: 27 %
COMMERCIAL ADVANTAGE – LESS HARD MACHINING

Today

Raw material / processing (forging)

Turning

Gear cutting (soft machining)

Soft finishing

Carburizing

Hard machining

Sorting/rejecting

Tomorrow

Plasmanitriding

Fabricated gear
Examples
EXAMPLES OF GEARS AND OTHER PARTS PERFECTLY DEDICATED FOR PLASMA NITRIDING
EXAMPLES OF GEARS AND OTHER PARTS PERFECTLY DEDICATED FOR PLASMA NITRIDING
EXAMPLES OF GEARS AND OTHER PARTS PERFECTLY DEDICATED FOR PLASMA NITRIDING

- PN 100/180 DUO
- Installation in production area
- Process time 20 hours.
- $\Delta T = \pm 3^\circ C$
COMPANY WILHELM OBERAIGNER GMBH

■ Founded 1977 – approx. 80 Employees
■ One of the leading specialists in development and production of automotive system components
■ Service offer includes also complete drive axles, differential locks and gear drives
■ Company Wilhelm Oberaigner GmbH is also responsible for the development and supply of components for the AWD-versions of Mercedes Vito/Viano (NCV2) and Mercedes Sprinter (T1N & NCV3)
■ The drive components for these cars are produced at Oberaigner and sent directly to the assembly lines of the appropriate factories
■ Oberaigner invests essential amounts in R&D as well as in the production of new technologies like Hybrid or Electro drives
■ Furthermore Oberaigner Aerospace (aircraft engines and business jets) is in development
COMPANY WILHELM OBERAIGNER GMBH
ALL-WHEEL FRONT AXLE: RING GEAR INTEGRATED INTO THE AXLE HOUSING

→ Increase of clearance height due to bevel gear ($i \approx 1,5$)
→ Planetary gear set in front axle (integrated in axle casing)
→ speed reduction due to planetary gear set ($i \approx 2,5$)
GOAL

- since approx. 7 years ring gear is in use as linear/straight ring gear
- Heat treatment
  - Carburizing + bolt hardening → reduction of distortion to increase quality concerning homogenous case depth and to reduce hard machining (grinding,…)
  - However very much effort for hard machining
- Goal
  - Noise reduction
  - Elimination / Reduction of hard machining
  - No loss in performance!
# RING GEAR → SPECIFICATION

<table>
<thead>
<tr>
<th>Bolt case hardening</th>
<th>Plasma nitriding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material: 20MnCrS5 (1.7149)</td>
<td>Material: 31CrMoV9 (1.8519)</td>
</tr>
<tr>
<td>Surface hardness [HRc]: 58 + 4</td>
<td>Surface hardness [HV10]: 750 + 150</td>
</tr>
<tr>
<td>Case depth [mm]: 0,65 + 0,2</td>
<td>Nitriding depth [mm]: 0,2 + 0,2</td>
</tr>
<tr>
<td>Core hardness [MPa]: &gt; 1000</td>
<td>Core hardness [MPa]: 1000 - 1200</td>
</tr>
</tbody>
</table>

Gear grade: 6-7 (Automotive)
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Position</th>
<th>Measured value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface hardness</td>
<td>Tooth crest</td>
<td>862 HV10</td>
</tr>
<tr>
<td>Target: 750-900 HV10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>White layer</td>
<td>Tooth flank</td>
<td>6,7µm</td>
</tr>
<tr>
<td>Target: 4-10µm</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tooth root</td>
<td>3,0µm</td>
</tr>
<tr>
<td>Nitriding depth</td>
<td>Tooth flank</td>
<td>0,27mm</td>
</tr>
<tr>
<td>Target: 0,2-0,4mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tooth root</td>
<td>0,24mm</td>
</tr>
</tbody>
</table>
RING GEAR RESULTS AFTER PLASMA NITRIDING

Nitriding depth

Nitriding depth

Distance from surface [mm]

Hardness [HV0,5]

Tooth flank 1
Tooth flank 2
Tooth root
Limit hardness
Comparison of average difference values before and after PN and BCH. Maximal difference values are by PN and DEH approximately with factor 2 higher.

Measures at respectively ten gears - left and right flank (PN and BCH). For each gear four teeth were measured and mean value was created. With these mean values the average difference values were calculated and displayed in the charts.
RING GEAR – COST COMPARISON
Plasma Nitriding (PN) with Bolt-Case Hardening (BCH)

<table>
<thead>
<tr>
<th>portion of costs in %</th>
<th>20MnCrS5 – BCH</th>
<th>31CrMoV9 - PN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Var. A</td>
<td>-</td>
<td>16</td>
</tr>
<tr>
<td>Var. B</td>
<td>-</td>
<td>17</td>
</tr>
<tr>
<td>savings</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>structure honing</td>
<td>-</td>
<td>8</td>
</tr>
<tr>
<td>hard machining</td>
<td>32</td>
<td>-</td>
</tr>
<tr>
<td>hardening</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>soft finishing</td>
<td>54</td>
<td>61</td>
</tr>
<tr>
<td>stress annealing</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>pre-machining</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>material</td>
<td>7</td>
<td>9</td>
</tr>
</tbody>
</table>

Bolt-Case Hardening
Plasma Nitriding Route A Route B

RÜBIG
SUMMERY & OUTLOOK

Summery

- **Distortion**
  - Distortion after plasma nitriding only a fraction compared to bolt case hardening
  - No change of gear grade after plasma nitriding
  - Probably no subsequent machining necessary

- **Costs**
  - Reduction of costs: 16 – 17%

- **Throughput time**
  - Reduction: 8 – 14%

Outlook

- First performance check positive
- Currently endurance test in a 6x6 Mercedes Sprinter
Thank you for your attention!