Challenges in modern Turbocharger Manufacturing
Agenda

- BW Global – BW Turbo Systems
- BWTS Plant Kirchheimbolanden
- Turbocharger Challenges
- Compressor Wheel Machining
- Imbalance Measurement
- End of Line Test
- Future Outlook
- Summary
BorgWarner at a Glance

- **2013 Sales:** $7.4 Billion ($8.2B unconsolidated)
- **Employees:** 19,700
- **Operations:**
  - 56 Locations
  - 19 Countries
- **Products:**
  - Engine, Transmission and Driveline systems
- **Market Drivers:**
  - Fuel Economy, Emissions, Performance

Financial, Employee and Operation information as of December 31, 2013
A Portfolio of Leading Powertrain Solutions

<table>
<thead>
<tr>
<th>Engine 67% / SALES</th>
<th>Drivetrain 33% / SALES</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Turbo Systems</strong></td>
<td><strong>Emissions Systems</strong></td>
</tr>
<tr>
<td>Wastegate</td>
<td>Exhaust Gas Recirculation (EGR) Valves</td>
</tr>
<tr>
<td>Variable Turbine Geometry (VTG)</td>
<td>EGR Coolers &amp; EGR tubes</td>
</tr>
<tr>
<td>Regulated 2-stage (R2S™)</td>
<td>Integrated EGR Modules</td>
</tr>
<tr>
<td><strong>Thermal Systems</strong></td>
<td><strong>Transmission Systems</strong></td>
</tr>
<tr>
<td>Thermal Management</td>
<td>DualTronic® Systems for Dual Clutch Transmissions</td>
</tr>
<tr>
<td>Components and Systems</td>
<td>ECO-Launch™ Stop/Start Accumulator Solenoid Valves</td>
</tr>
<tr>
<td>Visctronic® Systems</td>
<td>One-way Clutches and Modules</td>
</tr>
<tr>
<td>Fans/Fan Drives</td>
<td>Friction and Steel Plates</td>
</tr>
<tr>
<td><strong>Morse TEC</strong></td>
<td></td>
</tr>
<tr>
<td>Engine Valve Timing Systems</td>
<td></td>
</tr>
<tr>
<td>Timing Chain</td>
<td></td>
</tr>
<tr>
<td>Variable Cam Timing</td>
<td></td>
</tr>
<tr>
<td>Oil Pressure Actuated</td>
<td></td>
</tr>
<tr>
<td>Torsional Assist</td>
<td></td>
</tr>
<tr>
<td>Cam Torque Actuated</td>
<td></td>
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<tr>
<td>HY-VO® Transmission Chain</td>
<td></td>
</tr>
<tr>
<td>Transmission/Transfer case chain</td>
<td></td>
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<td></td>
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<tr>
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<td></td>
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<tr>
<td>Transmission Systems</td>
<td></td>
</tr>
<tr>
<td>TorqTransfer Systems</td>
<td></td>
</tr>
<tr>
<td>AWD Couplings</td>
<td></td>
</tr>
<tr>
<td>Transfer Cases</td>
<td></td>
</tr>
<tr>
<td>eGearDrive® Electric Drive Transmissions</td>
<td></td>
</tr>
<tr>
<td>eAWD Torque Vectoring</td>
<td></td>
</tr>
<tr>
<td>AWD Electronic Controls and Systems Integration</td>
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</tbody>
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BorgWarner Turbo Systems at a Glance

- **Employees:** ~ 6,000
- **Facilities:**
  - 14 Locations
  - 12 Countries
- **2013 Production:** approx. 9 m Turbochargers
- **Products:**
  - Turbochargers for Passenger cars, Light, Medium and Heavy Trucks and Off Highway applications as well as Aftermarket Solutions
BWTS Kirchheimbolanden

- Founded: 1960
- Capacity: 3.5 Mio. Turbos
- Volume 2013: 3.2 Mio. Turbos

Plant:
- Prototype-Shop
- Parts Manufacturing
- Turbocharger Assembly
- Logistic-Center
- Apprentice Workshop

- Space: 46.000m²
  - 30.000m² Production
  - 16.000m² Logistics

- Head Count: 1.930
  - 1.460 Plant
  - 470 Sales, Project Management, Application

Certificates:
- ISO 14001
- OHSAS 18001
- ISO/TS 16949
- ISO 50000
Kibo Customers and Volumes

Customer Portfolio
2013

Turbo Volumes
1992 - 2013

Complete turbos only

Customer Portfolio

- DAIMLER 25.1%
- BMW 11.3%
- REUTAU 7.4%
- Ford 10.9%
- PSA 5.6%
- Volkswagen/Audi 30.9%
- Porsche 0.8%
- Fiat 0.4%
- Opel/GM 1.2%
- Other 0.1%
- Volvo 6.4%

Units [Thousands]
How does a Turbocharger work?
**Turbocharger Requirements**

**Compressor**
- \( T_{\text{inlet}} = 20 ^\circ C \)
- \( \pi = 2,5 \) (gasoline)
- \( \pi = 3,0 \) (diesel)
- \( u_{\text{tip, max}} = 585 \text{ m/s} \)
- Material: Al alloy

**Turbine**
- \( T_{\text{inlet}} = 830 ^\circ C \) (diesel)
- \( T_{\text{inlet}} = 1050 ^\circ C \) (gas.)
- \( u_{\text{tip, max}} = 530 \text{ m/s} \)
- Material:
  - GGV (<820°C)
  - Ni-base alloys (>820°C)

**Core Housing**
- Journal bearings
- Engine oil for lubricating, cooling & damping
- Speed up to 330 000 rpm
- Material: grey iron

**Installation**
- No noticeable noise
- Space limited
- Thermodynamically coupled to the internal combustion engine

**Rigid mounting**
- To engine block

**Notes**
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Turbocharger Challenges

Complexity

Legal Requirements

Downsizing

Performance

Shorter Time to Market

New Technologies

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Kibo In-House Production

Machining of Components

Bearing Housing

Turbine Housing

Comp. Wheel

Shaft & Wheel

Assembly & Testing

VTG

Assy & Testing
Kibo In-House Production

- Compressor Wheel
- Shaft and Wheel
- Bearing Housing
- VTG
- Cast Steel Turbine Housing
- Core Group and Balancing
- Purchased Parts
- Final Assembly
Compressor Wheel Manufacturing

Challenges:
- Thermodynamics
- Life Time
- Acoustics
- Material and Coating

Milled
- Bar Material
- Preturning
- CAD Data
- Milled wheel
- Dynamic Balancing

Cast
- CAD Data
- Silicon Model
- Plaster Form
- Cast Wheel
- Dynamic Balancing
Machining

- From Single Spindle to Double Spindle 5-Axis Milling Machines
- Highly educated Workforce
- Materials: Coated Aluminium and Titanium Compressor Wheel Production
- Reduction of original Imbalance thru optimized Machine Setup
- Fast Time to Market thru CAM Software

Basis for Success are active interdisciplinary Partnerships
Turbocharger Noise

- Imbalance Whistle
- Constant Noise

- Pulsation Whistle
- Instability Noise
- Pumping Noise
- Turbulence Noise
- ...

Structure Borne Noise

Airborne Noise
**Turbocharger Noise**

- **Cause**
  - Imbalance of the complete rotor after assembly too high
    - Imbalance of compressor wheel or shaft and wheel assembly too high
    - Geometrical deviations of single parts
    - Assembly errors
  - ... 

  Single causes can compensate or intensify the effect of imbalance noise

- **Frequency range**
  - Proportional / synchronal with TC speed - 1 oscillation per round
  - approx. 1200 – 4500 Hz (72 000 1/min…270 000 1/min)

- **Transmission (structure-borne noise)**
  - Rotor => Bearing => TC Housing => exhaust pipe => car body
Part and Core Group Balancing

**Balancing at low speeds**
- Single parts

Assumptions:
- Rigid rotor
- Identical vibration level of a given imbalance for all speeds

**Balancing at high speeds (HSCB)**
- Core assembly

Reasons:
- Nonlinear behavior of bearing bushes
- Non rigid behavior of rotor assembly
- Assembly of rotor influences noise behavior over speed
- Production Process influence within Microns

Bsp. Reifen  
Rotor Einzelteile
Läufer
Verdichter -rad

Material Removal in two Planes

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FEM Analysis for optimized Process

- Decoupling of Turbocharger from Machine Structure
- Symmetrical Fixturing for better simulation results
- Flexible Coupling replaces rigid fixturing

Goal: Consistent vibrational reply of measurement machine in relation to rotational speed
Turbocharger Cold Test

- Functional Turbocharger Test – Simulation of Turbocharger in Motor Environment
- Reduction of ppm’s

**Input Values**
- Oil Pressure
- Oil Temperature
- Air Mass Turbine
- Activate Actuator

**Output Values**
- Oil Flow
- Air Mass Compressor
- rpm
- Pressures
- Air Borne Noise / Structure Borne Noise

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Future Outlook

- Electrification
  - eBooster™ – Electrically operated Turbocharger
- Fuel Cell Air Supply – Cooled Air Supply Aggregate for Fuel Cell

- Reduction of CO₂ and Fuel Consumption
  - Alternative Material – Titanaluminide or Ceramics
  - Minimizing of Friction Losses – Implementation of Ball Bearing instead of Friction Bearing
Summary

- Constantly increasing
  - Technical Challenges – increasing Temperature and Speed, Downsizing, challenging Materials
  - Cost Pressure – increasing Competition in Turbo Charger Market
  - Decreasing Time to Market
  - Zero Claim Strategy

Guarantee ongoing Challenges in the Automotive industry

Interdisciplinary Comprehensive Network is mandatory for Success
Thank You

feel good about driving

better fuel economy
reduced emissions
great performance