Challenges in modern Turbocharger Manufacturing

Aprill 2014

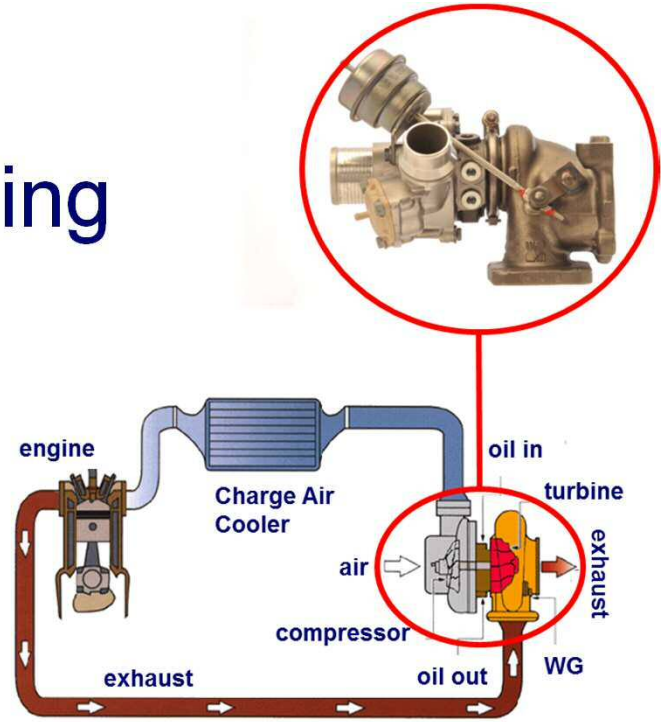
Our Beliefs

Respect
Collaboration
Excellence
Integrity
Community

BorgWarner

Agenda

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



2

BorgWarner

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

Engine 67% / SALES

Turbo Systems
- Wastegate
- Variable Turbine Geometry (VTG)
- Regulated 2-stage (R2S™)

Thermal Systems
- Thermal Management
- Components and Systems
- Visctronic® Systems
- Fans/Fan Drives

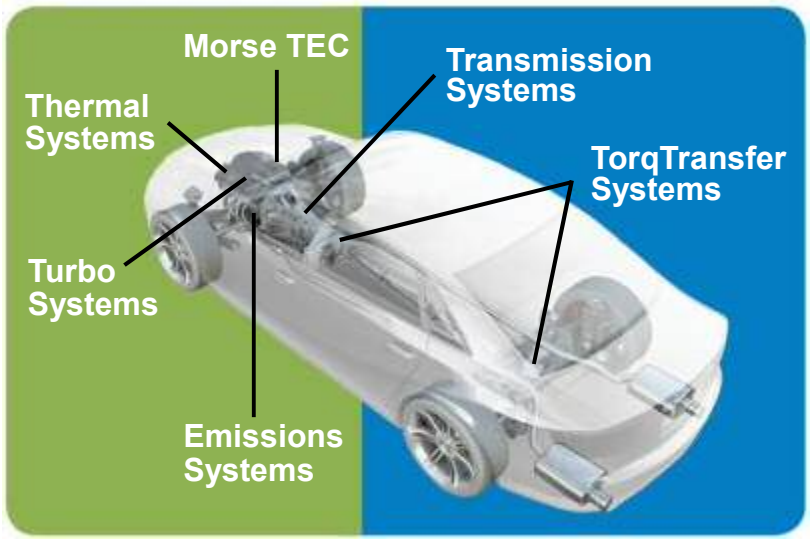
Morse TEC
- Engine Valve Timing Systems
  - Timing Chain
- Variable Cam Timing
  - Oil Pressure Actuated
  - Torsional Assist
  - Cam Torque Actuated
- HY-VO® Transmission Chain
  - Transmission/Transfer case chain

Emissions Systems
- Exhaust Gas Recirculation (EGR) Valves
- EGR Coolers & EGR tubes
- Integrated EGR Modules
- Secondary Air Systems
- Actuators
- Glow Plugs
- Instant Start System
- Pressure Sensor Glow Plugs
- Gasoline Ignition Technology
- Sensor Technology
- PTC Cabin Heaters
- Thermostats
- Coolant and Control Valves

Drivetrain 33% / SALES

Transmission Systems
- DualTronic® Systems for Dual Clutch Transmissions
- ECO-Launch™ Stop/Start Accumulator Solenoid Valves
- One-way Clutches and Modules
- Friction and Steel Plates

TorqTransfer Systems
- AWD Couplings
- Transfer Cases
- eGearDrive® Electric Drive Transmissions
- eAWD Torque Vectoring
- AWD Electronic Controls and Systems Integration



BorgWarner

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

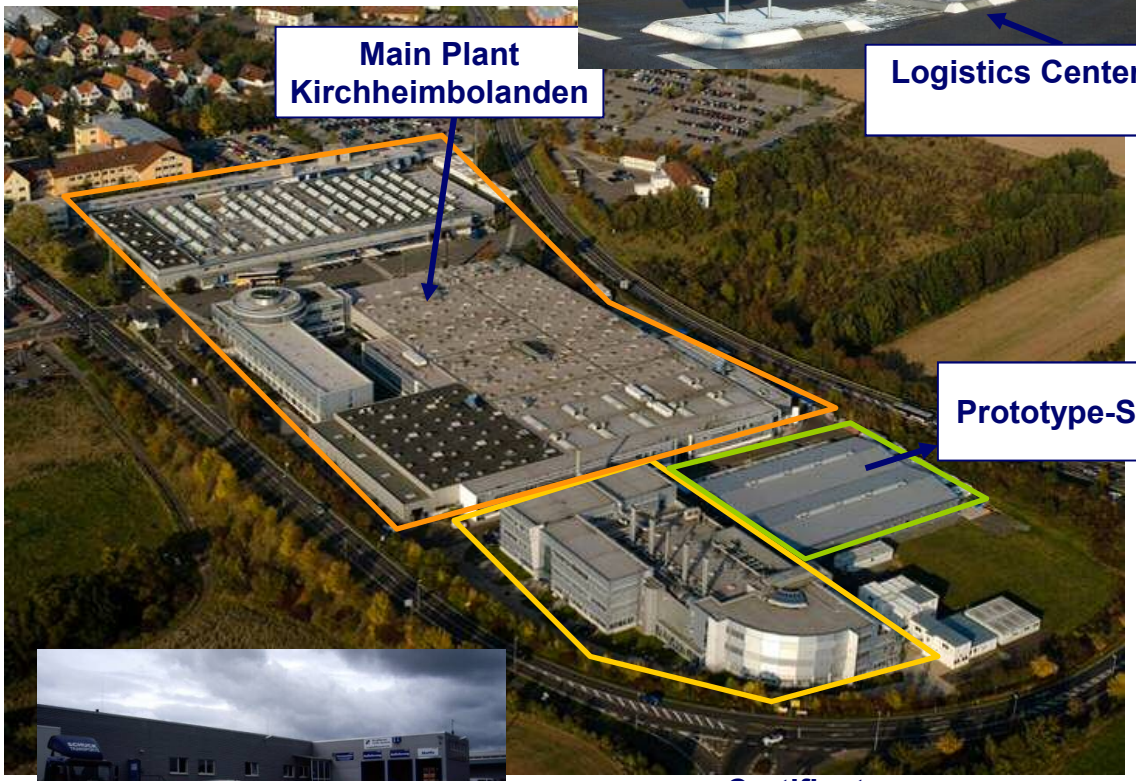
BorgWarner Turbo Systems Global Footprint

BorgWarner

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

Logistics Center



Main Plant Kirchheimbolanden

Prototype-Shop

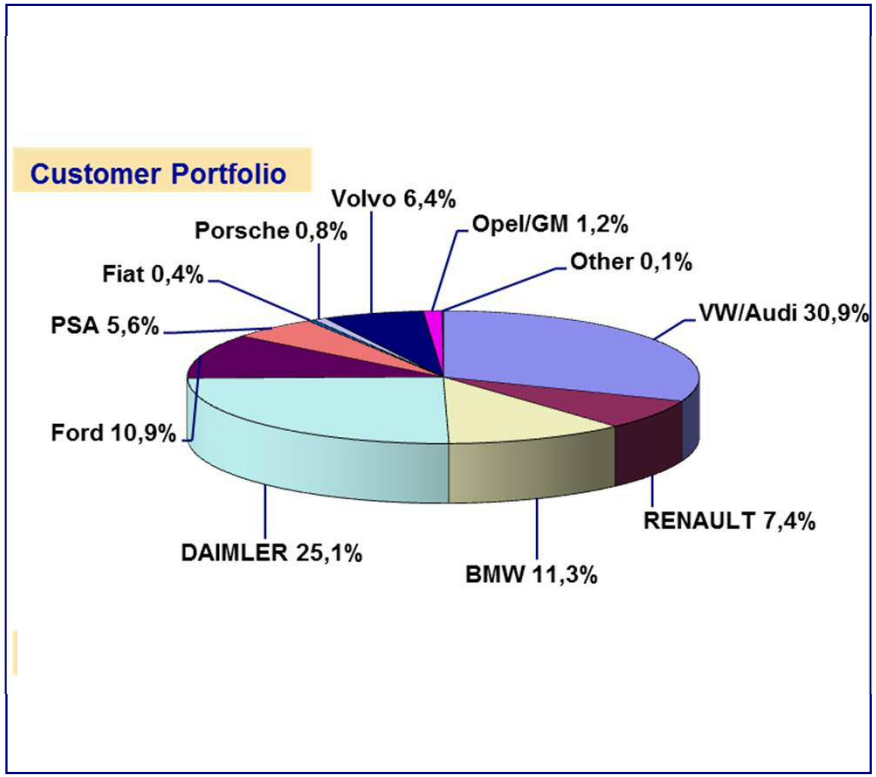
Plant 2 and Reman Production in Kirchheimbolanden

•Certificates:
- ISO 14001
- OHSAS 18001
- ISO/TS 16949
- ISO 50000

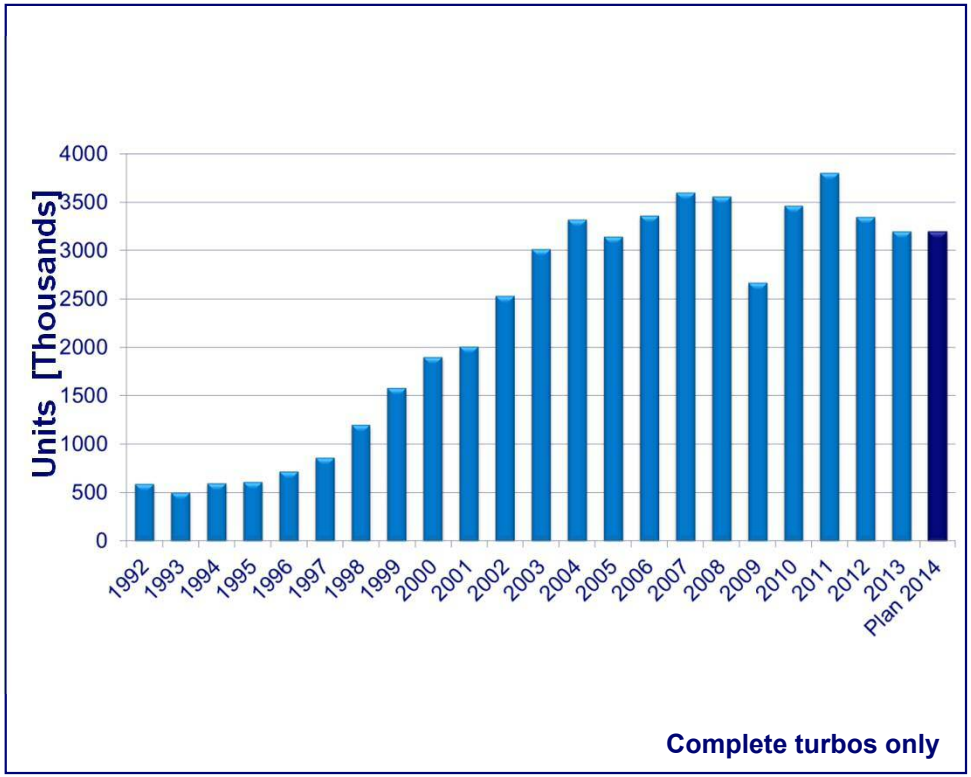
BorgWarner

Kibo Customers and Volumes

Customer Portfolio 2013



Turbo Volumes 1992 - 2013



BorgWarner

How does a Turbocharger work?

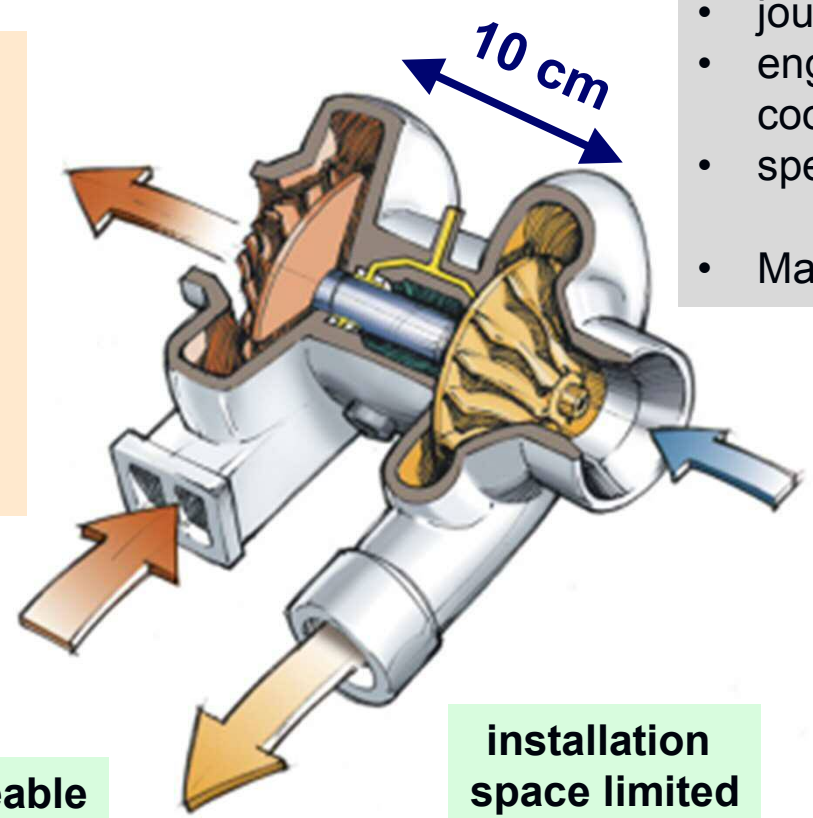
Turbocharger Requirements

thermodynamically coupled to the internal combustion engine

Turbine

T_{inlet} = 830 °C (diesel)
T_{inlet} = 1050 °C (gas.)
$u_{tip, max}$ = 530 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

rigid mounting to engine block

No noticeable noise

installation space limited

Compressor

- T_{inlet} = 20°C
- π = 2,5 (gasoline)
- π = 3,0 (diesel)
- $u_{tip, max}$ = 585 m/s
- material: Al alloy

BorgWarner

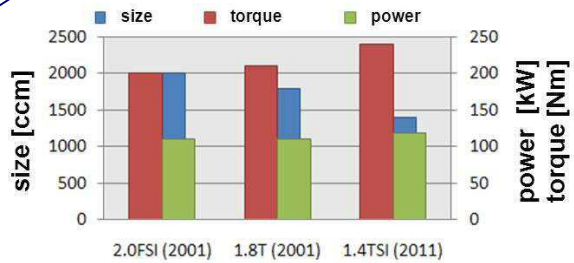
Turbocharger Challenges

Complexity

Legal Requirements

-

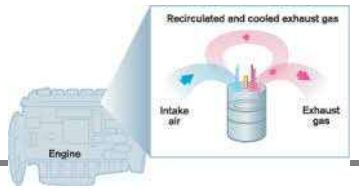
Downsizing



Performance

Shorter Time to Market

New Technologies



BorgWarner

Kibo In-House Production

Machining of Components

Bearing Housing

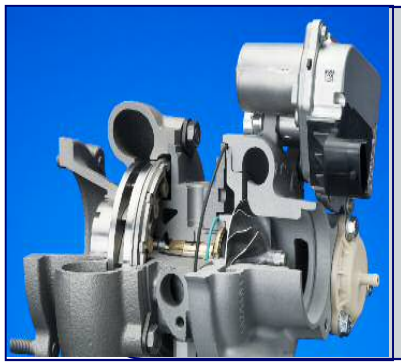
Turbine Housing

Comp. Wheel

Shaft & Wheel

Assembly & Testing

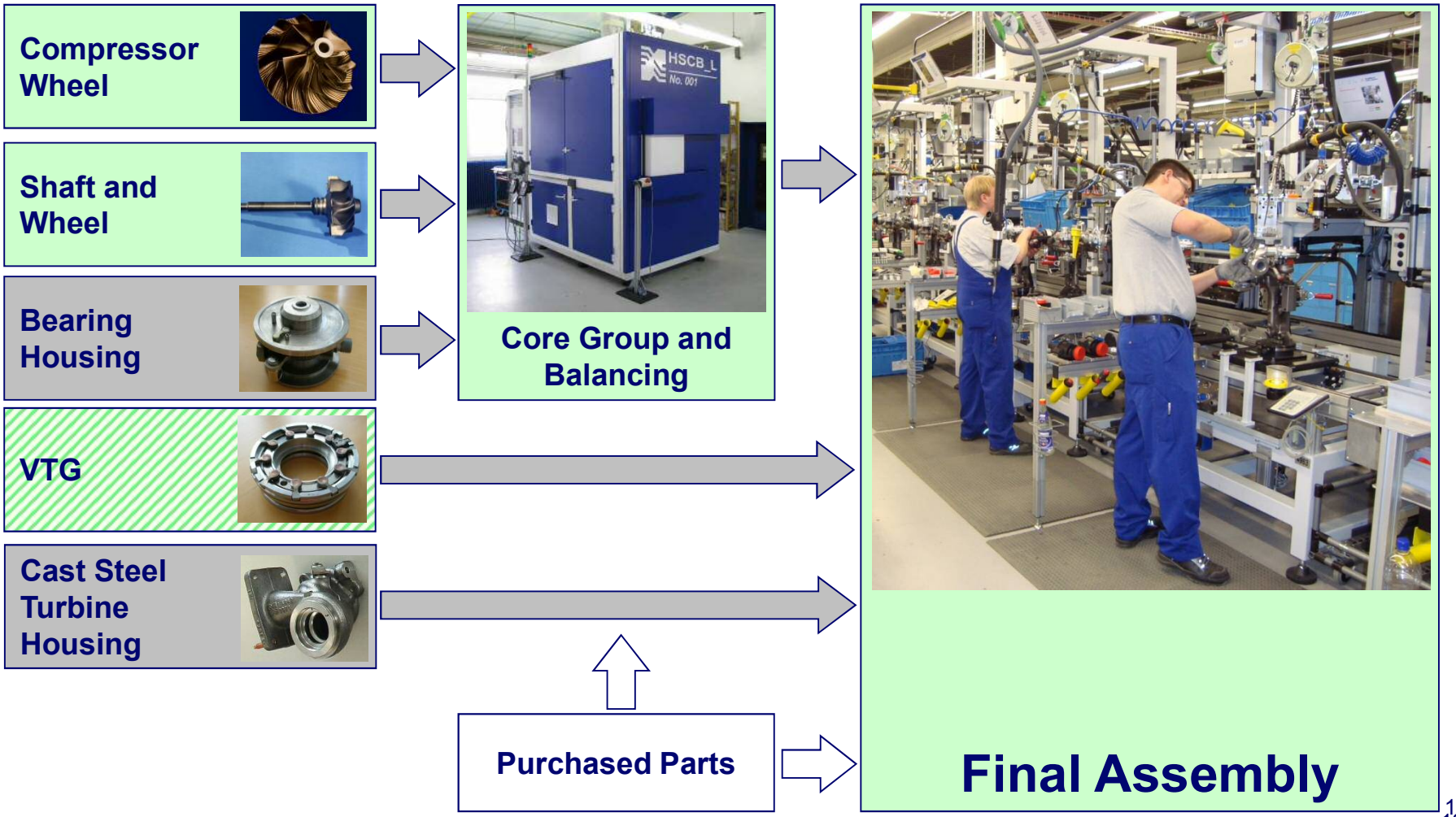
VTG



Assy & Testing

BorgWarner

Kibo In-House Production



13

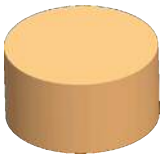
BorgWarner

Compressor Wheel Manufacturing

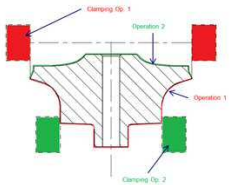
Challenges:

- Thermodynamics
- Life Time
- Acoustics
- Material and Coating

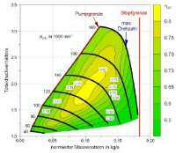
Milled

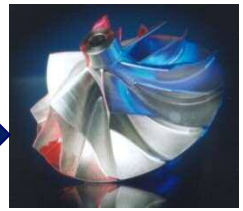


Bar Material



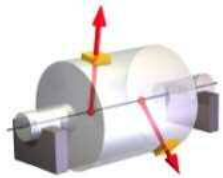
Preturning





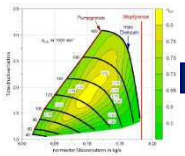
CAD Data

Milled wheel



Dynamic Balancing

Cast

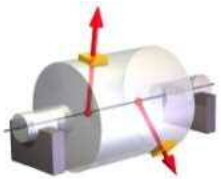


CAD Data

Silicon Model

Plaster Form

Cast Wheel

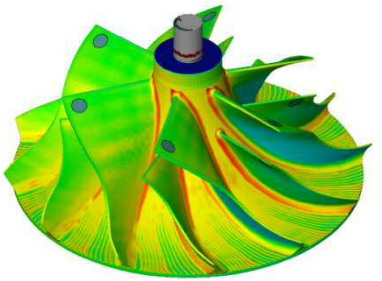


Dynamic Balancing

BorgWarner

CW Manufacturing Development

- **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



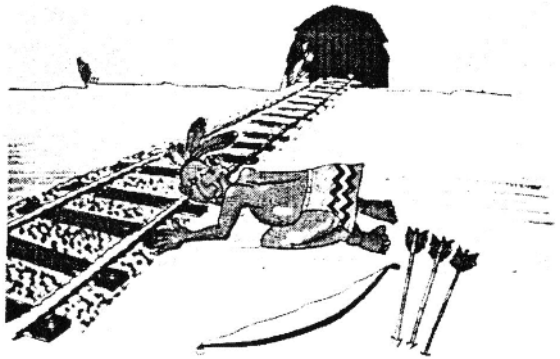
- **Basis for Success are active interdisciplinary Partnerships**

chiron CNC-FERTIGUNGSZENTREN
SIEMENS
Borg Warner Turbo Systems
SWS Tech
RHEINISCH-WESTFÄLISCHE TECHNISCHE HOCHSCHULE AACHEN RWTH
WOLF WOLF Gruppe

BorgWarner

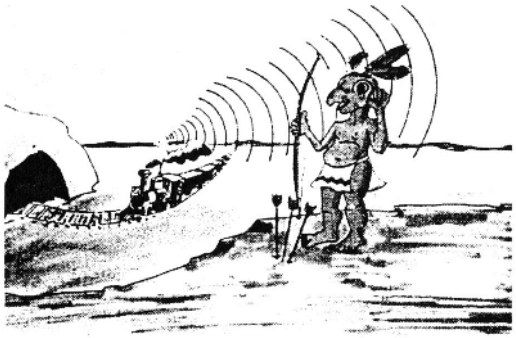
Turbocharger Noise

- Imbalance Whistle
- Constant Noise



Structure Borne Noise

- Pulsation Whistle
- Instability Noise
- Pumping Noise
- Turbulence Noise
- …



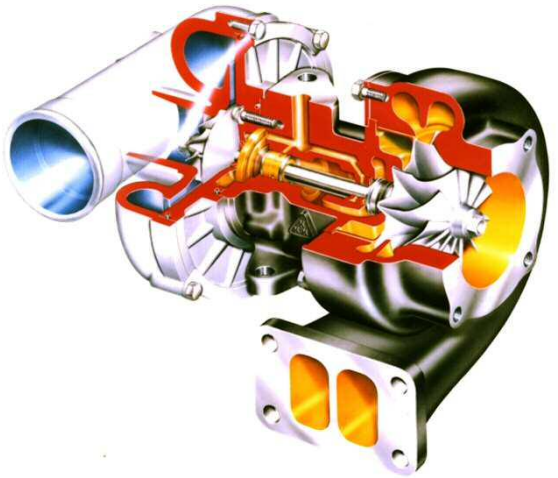
Airborne Noise

BorgWarner

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

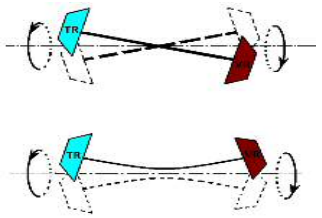
Bsp. Reifen

Rotor Einzelteile

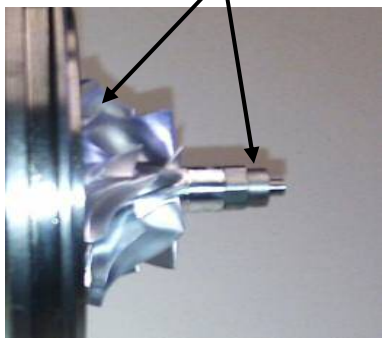
Balancing at high speeds (HSCB) -> Core assembly

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

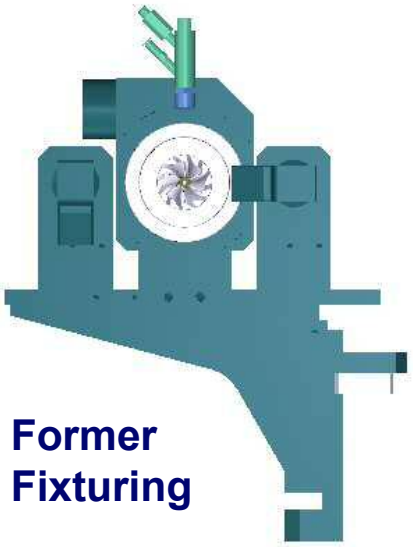


Material Removal in two Planes



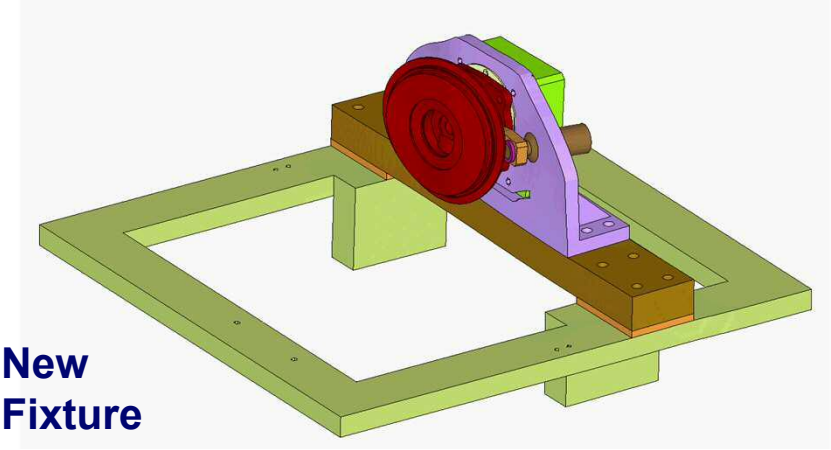
BorgWarner

FEM Analysis for optimized Process

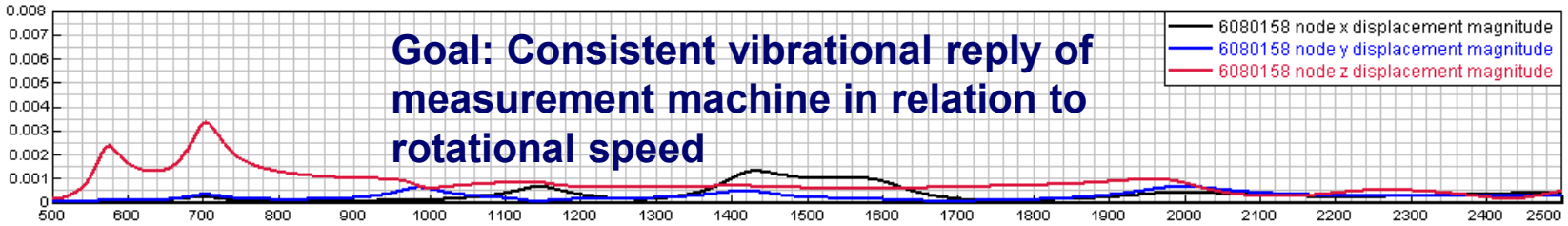


Former Fixturing

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



New Fixture

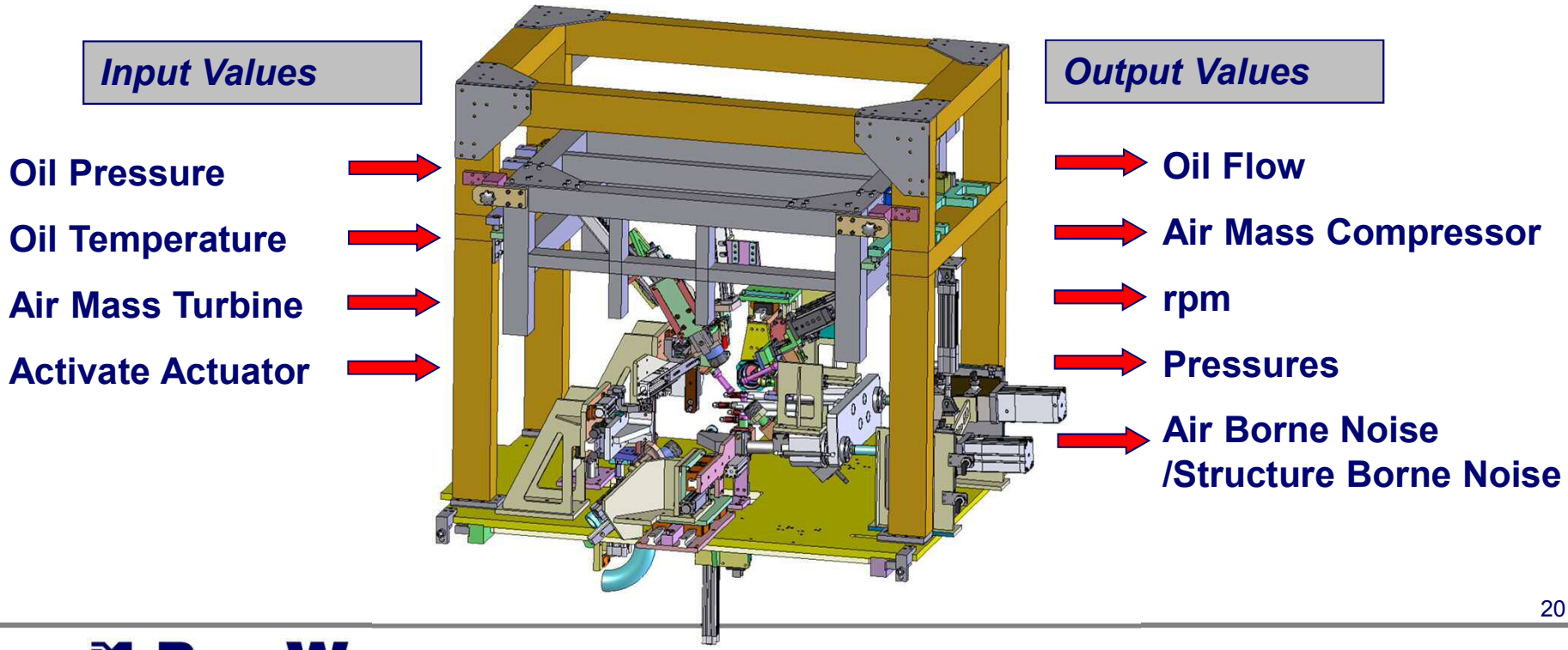


Goal: Consistent vibrational reply of measurement machine in relation to rotational speed

BorgWarner

Turbocharger Cold Test

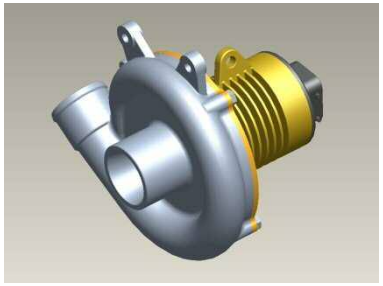
- Functional Turbocharger Test – Simulation of Turbocharger in Motor Environment
- Reduction of ppm's



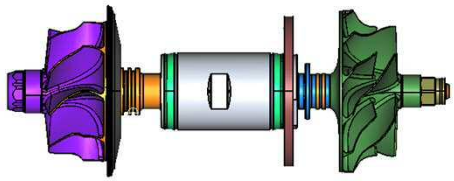
BorgWarner

Future Outlook

- Electrification
  - eBooster™ – Electrically operated Turbocharger



  - Fuel Cell Air Supply – Cooled Air Supply Aggregate for Fuel Cell
- Reduction of CO_2 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

BorgWarner