The International Academy for Production Engineering

70th Virtual CIRP General Assembly - Aug. 22-28, 2021

Grinding and fine finishing of future automotive powertrain components

by

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CIRP Annals - Manufacturing Technology
Volume 70, Issue 1, 2021

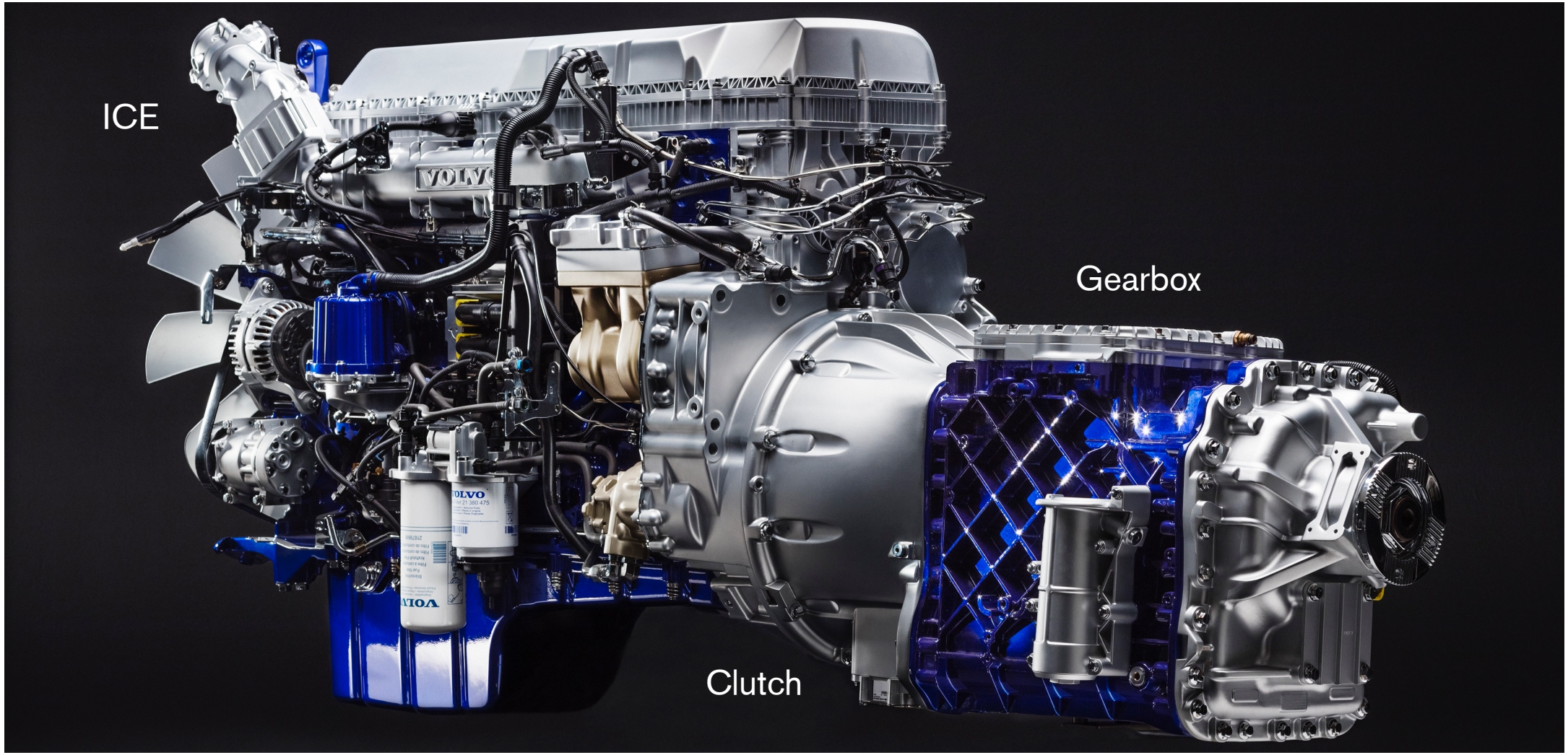
Approach

- Strategic high-level trends explored via interviews with 10 industry experts (incl. automotive OEMs, suppliers, machine-tool builders, SMEs, consultants)
- Industry-wide survey to explore grinding & fine finishing perspectives of 25 companies (entire value chain)
- Comprehensive review and critical analysis of the state of the art of “STC-G” aspects of grinding and abrasive fine finishing technologies
- Inclusion of selected case studies from the industry

Structure and content

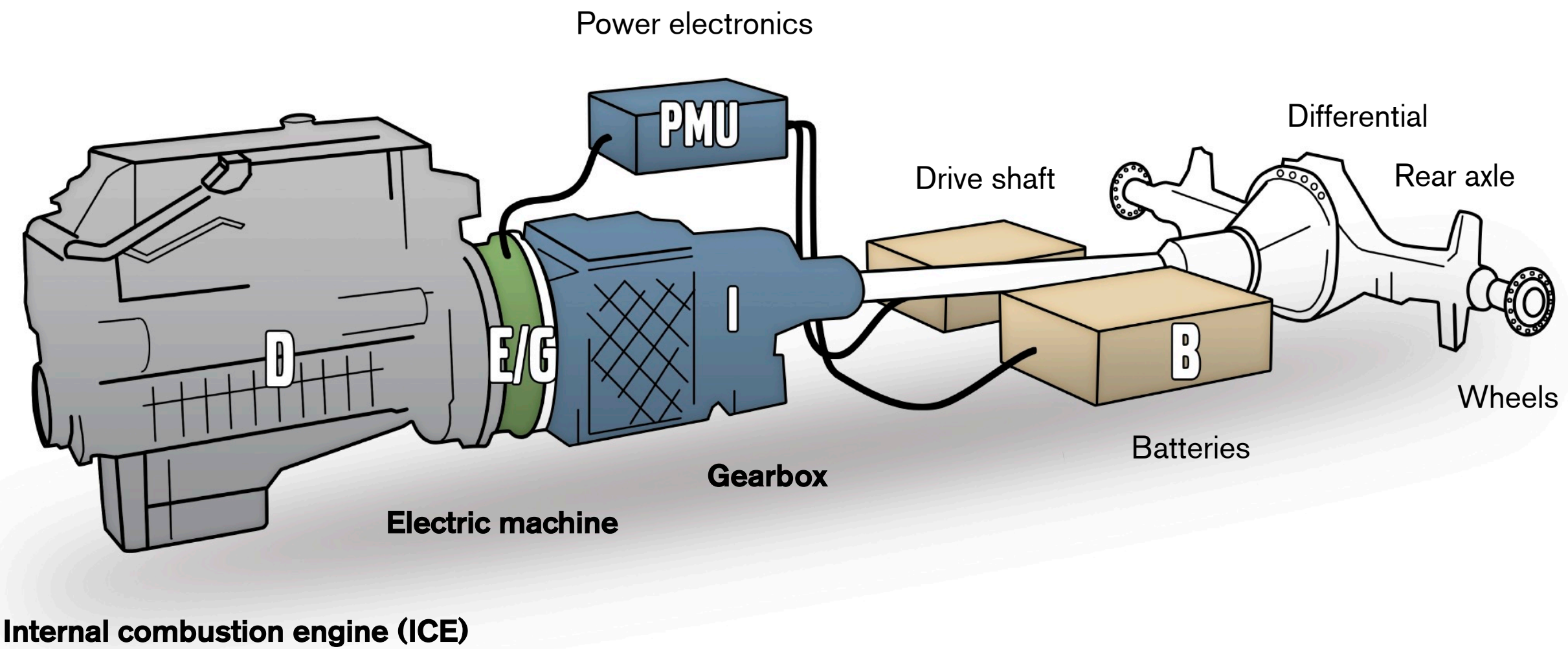
Section	Content
1. Introduction	• Drivers, objectives, structure
2. Future trends in the automotive industry	• Description of the different vehicle powertrains • Insights into how regulations affect production in the automotive industry • Interviews with industry professionals & a dedicated survey
3. Requirements for automotive powertrain components	• Requirements for bearings, gears, shafts and new components
4. Automotive powertrain production chains	• Addressing the changing production chains
5. Recent advances in grinding, dressing and texturing	• Update of 2009 CIRP keynote "*Industrial challenges in grinding*" & 2008 CIRP keynote "*Gear finishing by abrasive processes*"
6. Fine finishing of powertrain components	• Abrasive fine finishing of gears, bearings, shafts
7. Machines for grinding and fine finishing of automotive powertrain components	• Short sequel of 2017 CIRP keynote "*Recent advancements in grinding machines*" with addition of machines for abrasive fine finishing
8. Summary and outlook	• Summary of the major industrial and research challenges • Brief outlook for the future
References	• 272 references (incl. 24 patents)

Conventional powertrain



Source: *Volvo Truck Corporation*

Hybrid powertrain

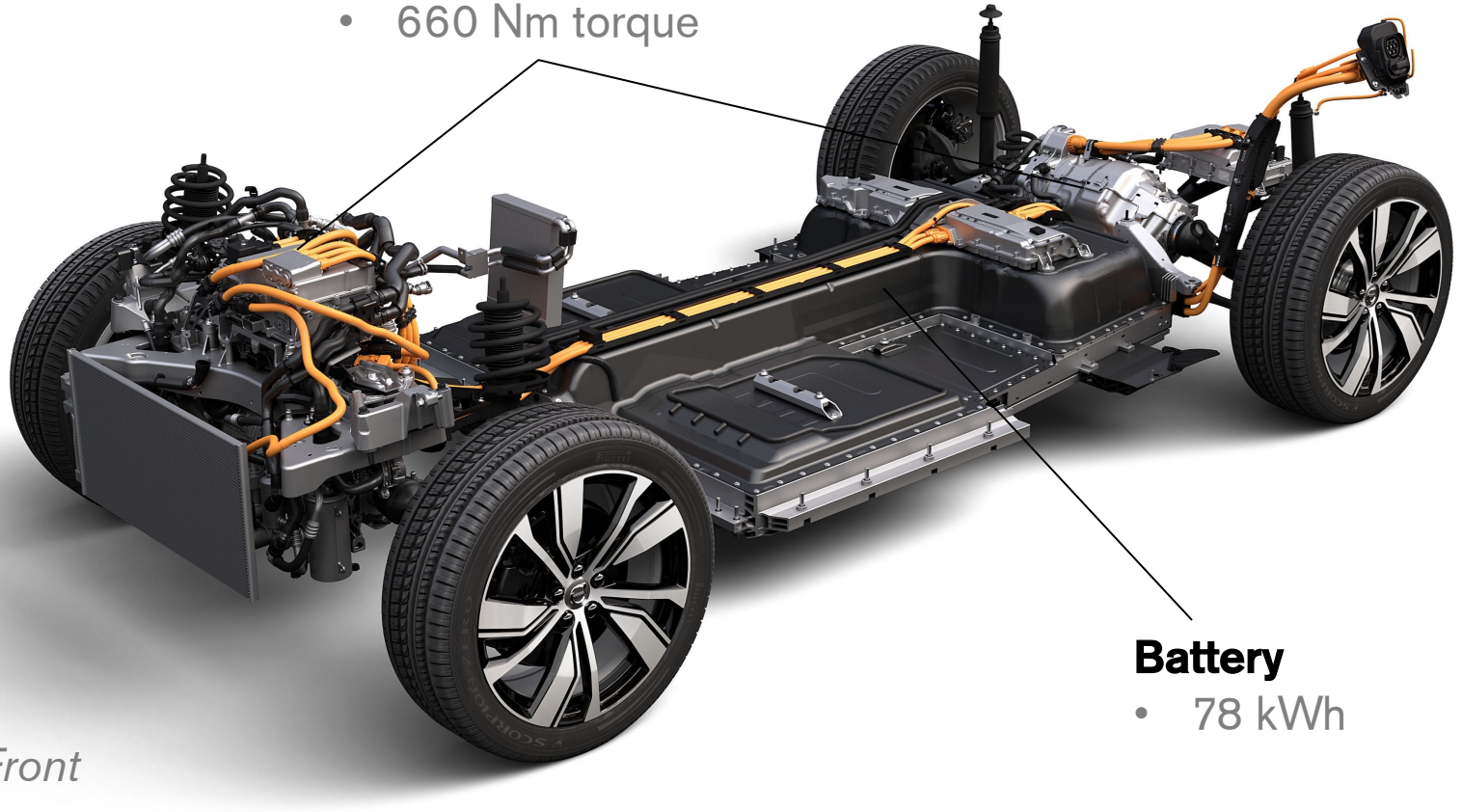


Source: *Volvo Truck Corporation*

Electric powertrain

Electric machines

- 2 x 150 kW power
- 660 Nm torque



Rear

Front

Battery

- 78 kWh

Source: *Volvo Car Group*

Source: *Volkswagen AG*

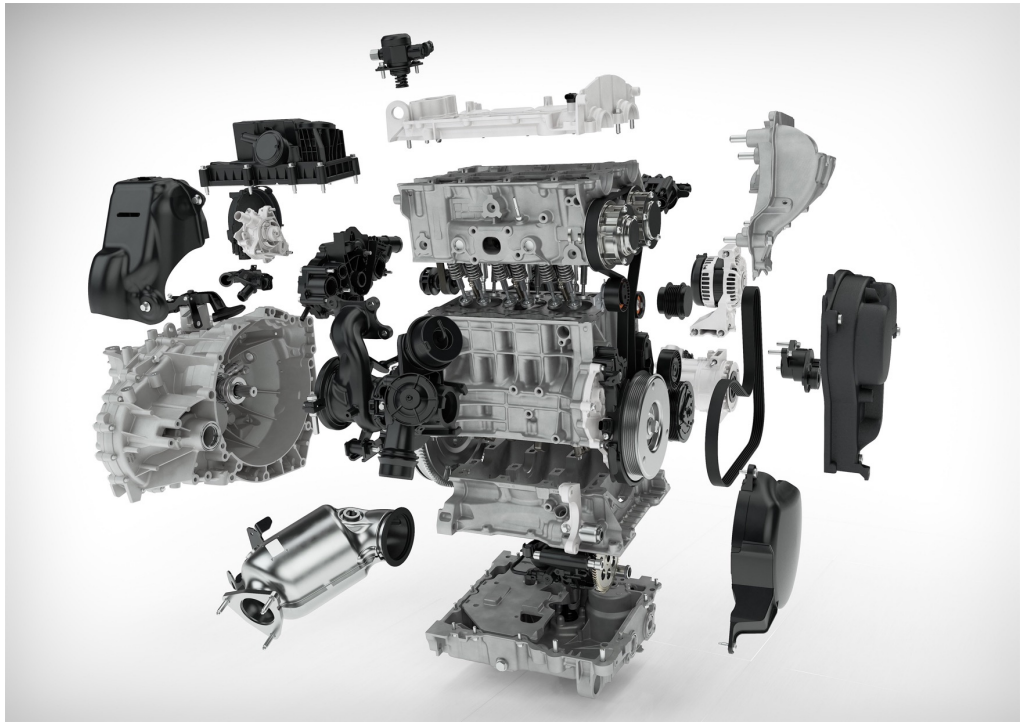
Electric vs. conventional vehicles

- Electric drive

- **Stator**
- **Rotor**
- Controls
- Bearings
- Gears

Source: *Volvo Car Group*

- Internal combustion engine



- **Mechanical simplicity** (*e.g. 80% less components – potential for low cost / low maintenance*)
- **On-demand performance** (*fast response, high torque on demand / instant off*)
- **Complex coordination** (*more efficient public transport and vehicle operation*)
- **Zero *local* emissions** (*reduced local emission in urban centers*)

Regulation-driven needs

- The electrification of the automotive powertrain is to a large extent driven by regulations – legislated via emission-reduction targets for CO_2, NO_2 and particulate matter.
- ***In July 2021, the European Union proposed an effective ban on the sale of new petrol and diesel cars from 2035, aiming to speed up the switch to electric vehicles (EVs).***
- Political decision-making regarding electrification do not always include LCA of the emissions produced in electricity generation or the impact of the materials cycle.
- Regulations also set noise-reducing measures for engines and transmissions and restrict using certain substances in electrical, electronic and powertrain components.
- Regulations affect the future design and production of powertrain components. This will transform the entire production value chain, from machines, metal forming, machining to grinding and fine finishing.

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July 14, 2021
4:59 PM CEST
Last Updated a month ago

Retail & Consumer

EU proposes effective ban for new fossil-fuel cars from 2035

5 minute read

By Nick Carey and Christoph Steitz

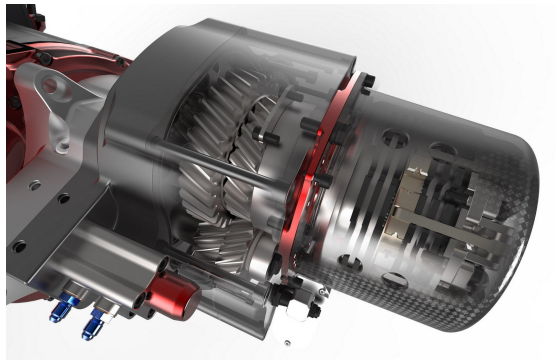
General requirements for automotive powertrain components

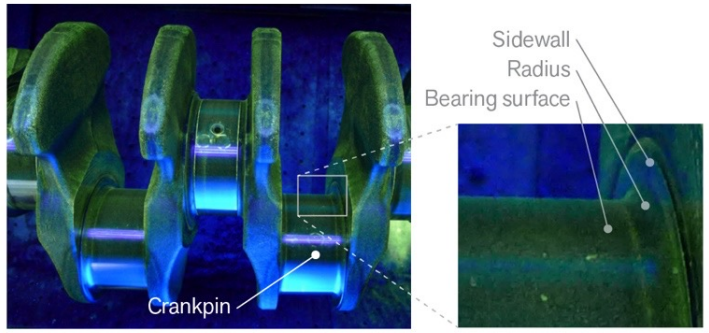
- The components in a vehicle which generate and transmit power are mainly associated with the ICE/e-drive and transmission.
- A focus is given to **shafts** and **gears** that that are largely produced by the automotive OEMs.
- **Bearings** are used in all powertrains.

Critical fields	Dominant factors
Geometrical	Dimensions (OD, ID, Width)
accuracy	Profile (Straighness, convex, concave)
	Roundness, flatness, squareness
Surface	2D surface roughness parameters
topography	3D surface roughness parameters
	Surface texture
Surface	Residual stresses
integrity	Heat affected zone
	Near surface microstructure

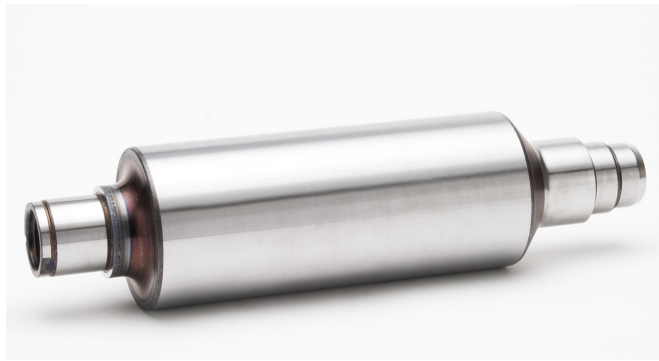
Functional performance

High-power density
Wear resistance
Fatigue life
Wettability
Rust resistance
Torque
Noise/vibration
Heat generation
Cleanliness





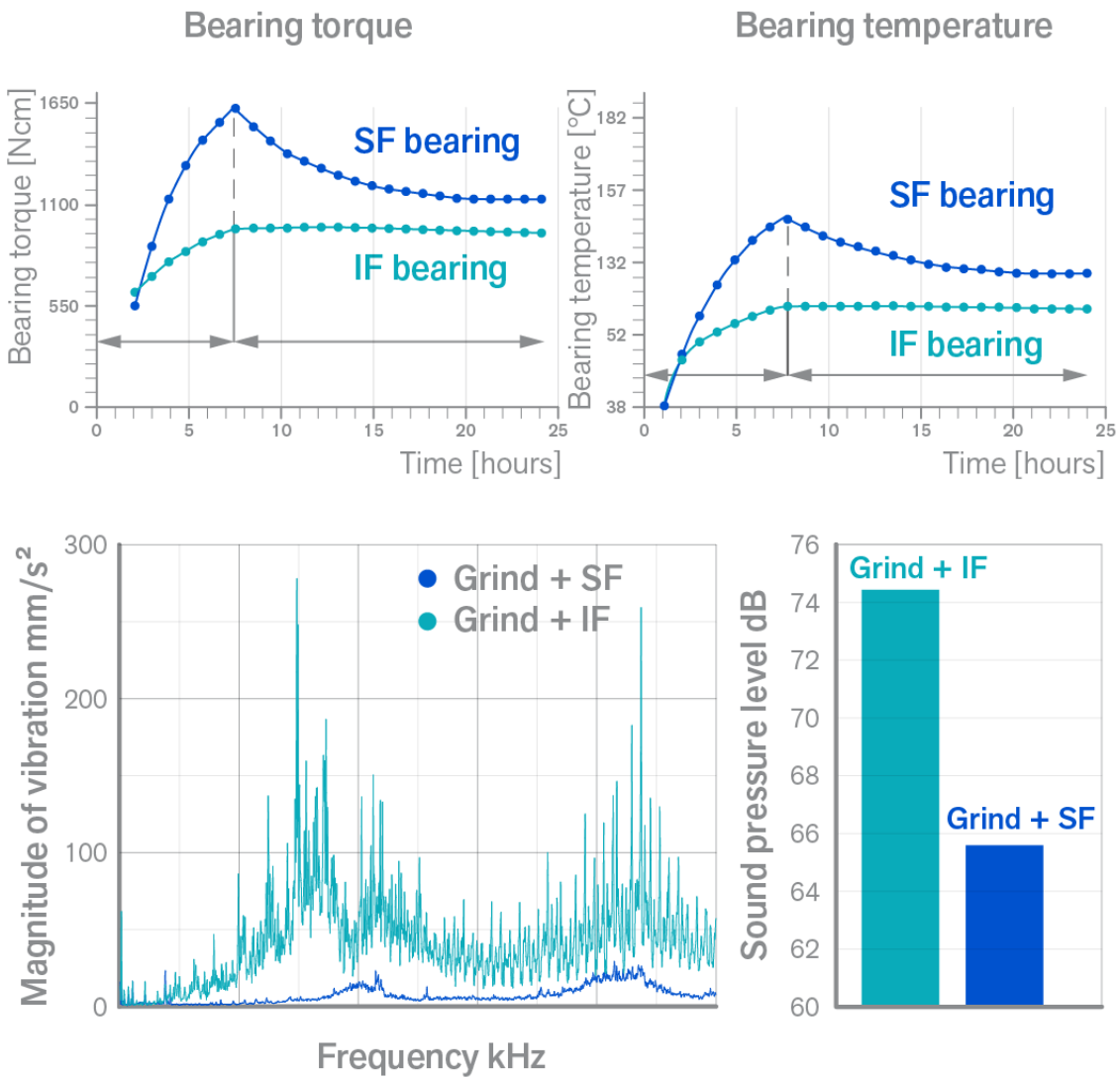
Source: *Rimac Automobili*



Source: *Hirschvogel Automotive Group*

Specific requirements for bearings, gears and shafts

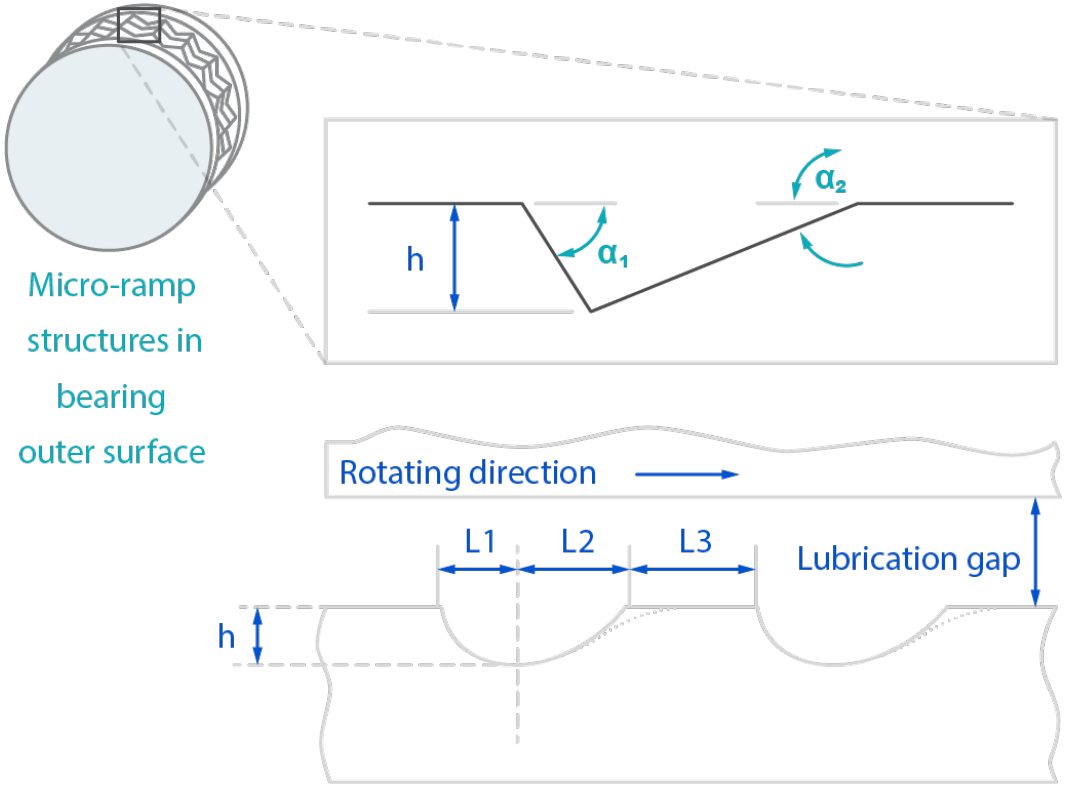
- **Bearings** in the automotive powertrain are required to achieve a long fatigue life, low torque, high wear resistance, and low noise under conditions of high-stress at contact.
- The requirements for **gears** in heavy-duty vehicles primarily involve load-carrying capacity, whereas requirements for passenger cars mainly involve optimization of noise, vibration and harshness (NVH).
- **Camshafts** and **crankshafts** are critical for the latest generation of ICEs and HEVs. The recent requirements include: (i) texturing of the bearing surfaces to achieve reduced friction, and (ii) grinding/superfinishing a curved (e.g. concave) bearing surface.

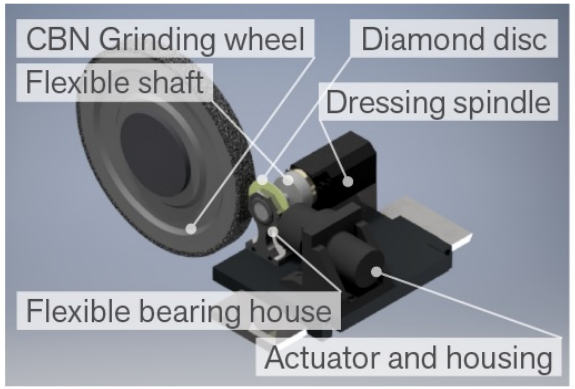


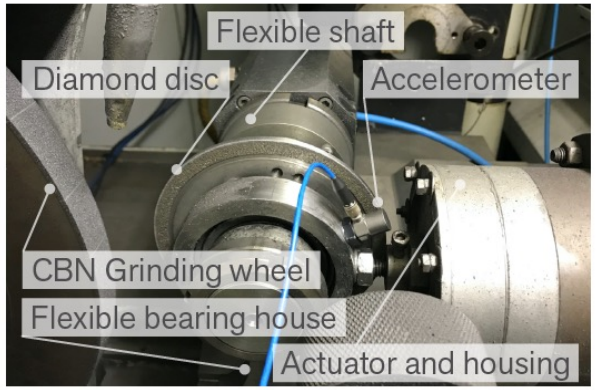
2016 Hashimoto et al. Published by Elsevier on behalf of CIRP

Textured surfaces

- **Textured surfaces** improve the functional performance of automotive powertrain components by optimizing the tribological conditions via maximized hydrodynamic effects.
- For texturing of bearing surfaces, grinding is a viable alternative to laser.
- The success of **grind-texturing** depends on the capability with respect to the dimensional and geometrical requirements of the components.



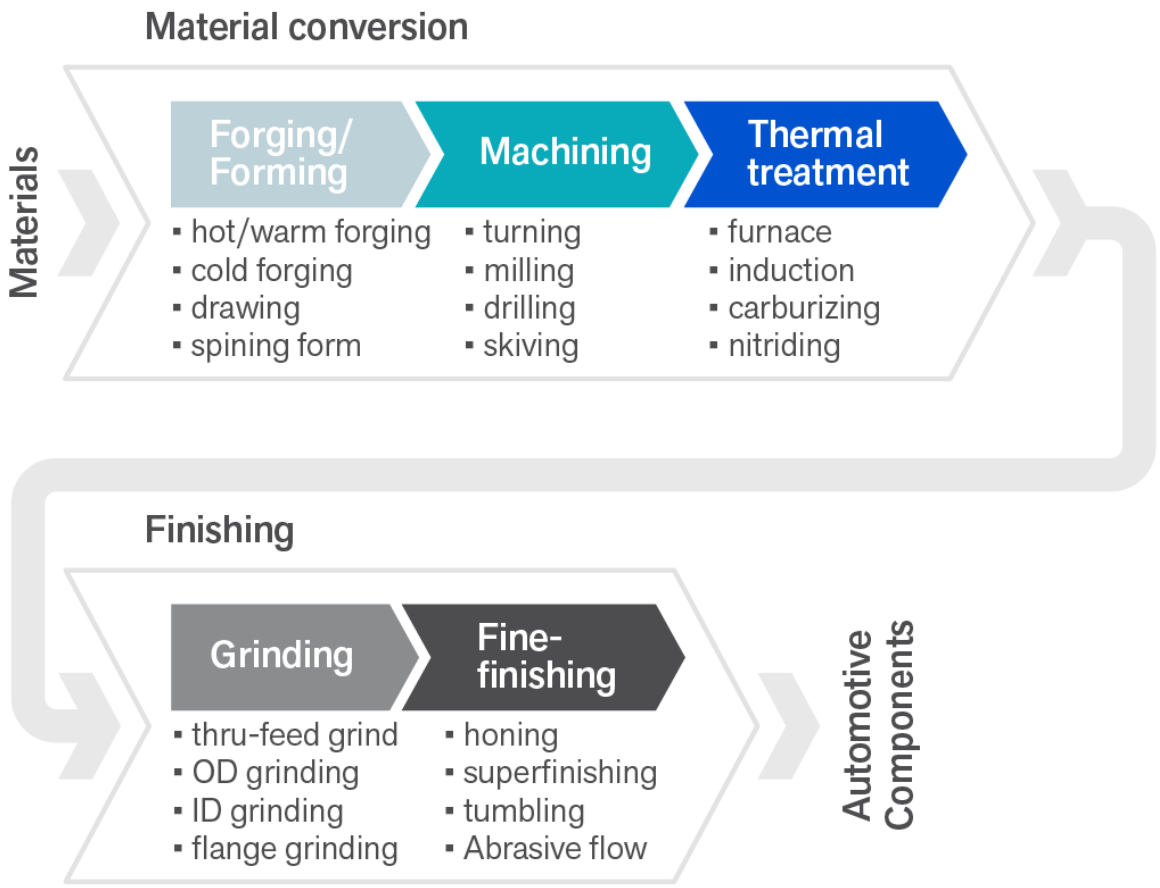




2018 da Silva et al. Published by Elsevier on behalf of CIRP

Automotive powertrain production chains

- Traditional production chain



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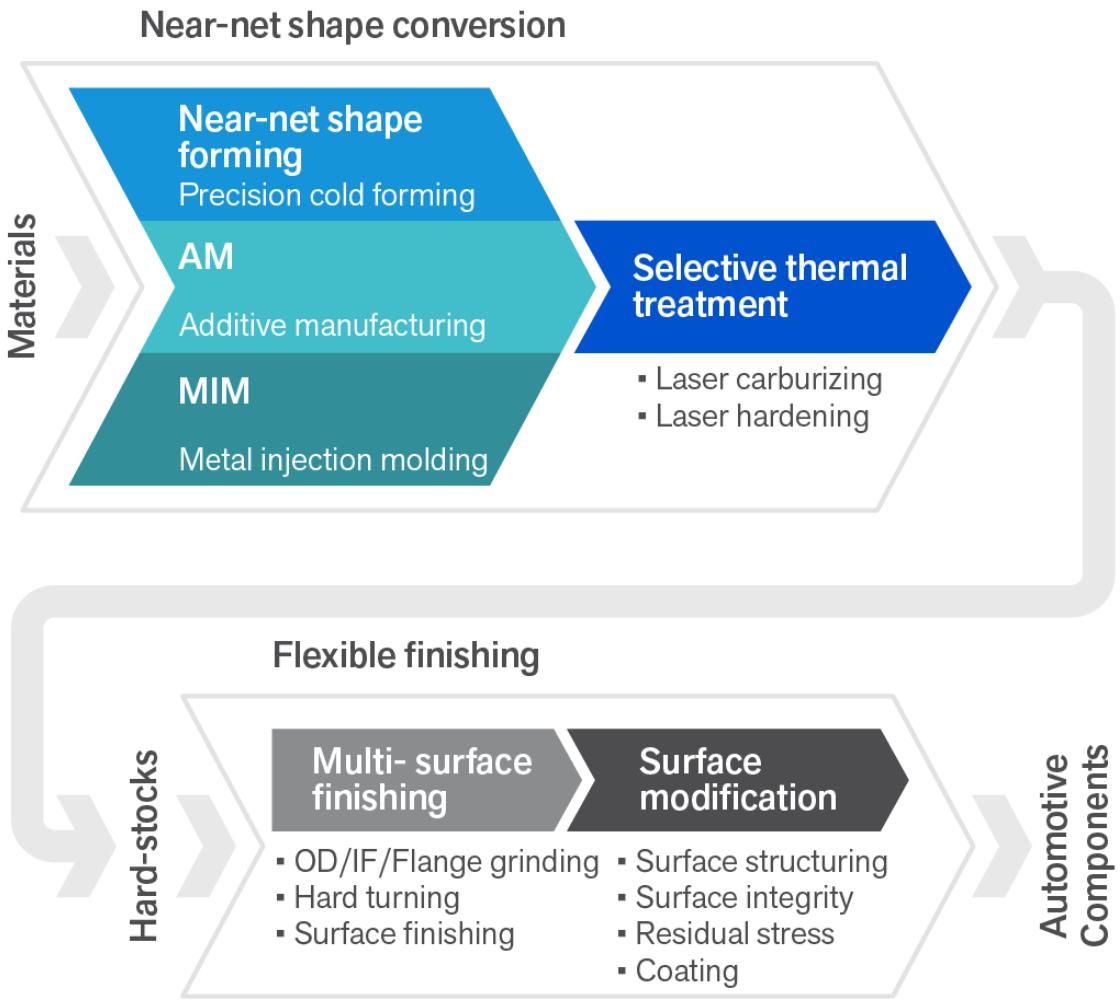
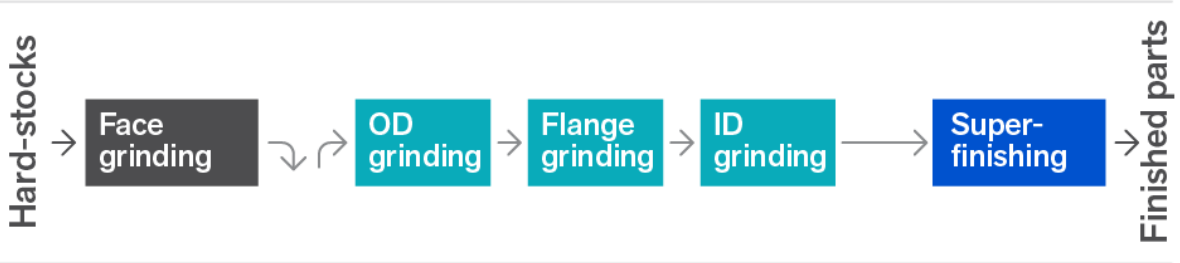
- Flexible production chain for small batches



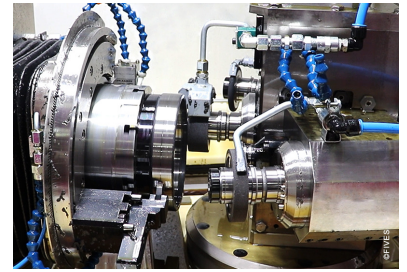
Traditional vs. flexible grinding of bearings

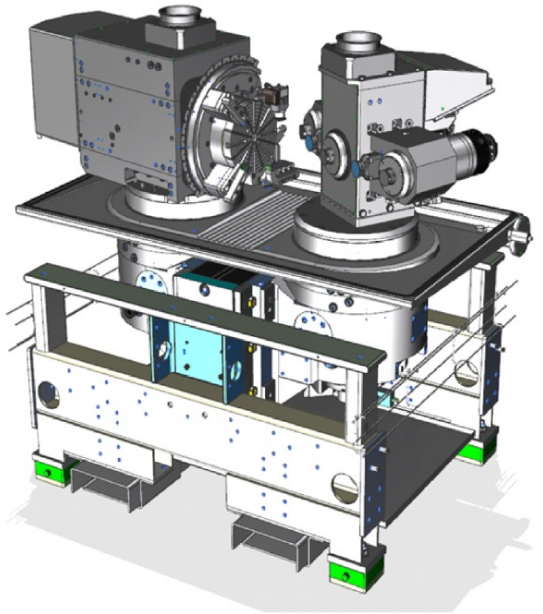
- Traditional line for the (automotive) inner rings
- Due to their inflexibility and high tooling costs, the line is designed for high-volume production
- High productivity; long changeover times



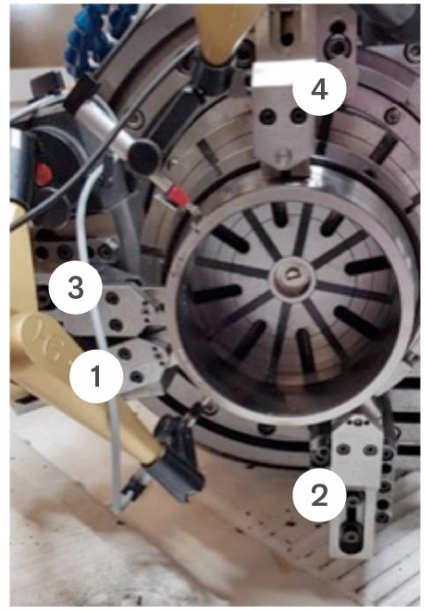
Method	Through-feed	In-feed	In-feed
Machine	Double disk grinder	Shoe centerless grinders	Plunge superfinshing
Batch size	1k-100k [pcs]	1,000 – 100,000	1,000 –100,000
Production rate	10-100 [pcs/min]	2-5	2-5
Changeover time	1-4 hours	3-6 hours	1-2 hours

- Highly flexible machine
- Reduced changeover time





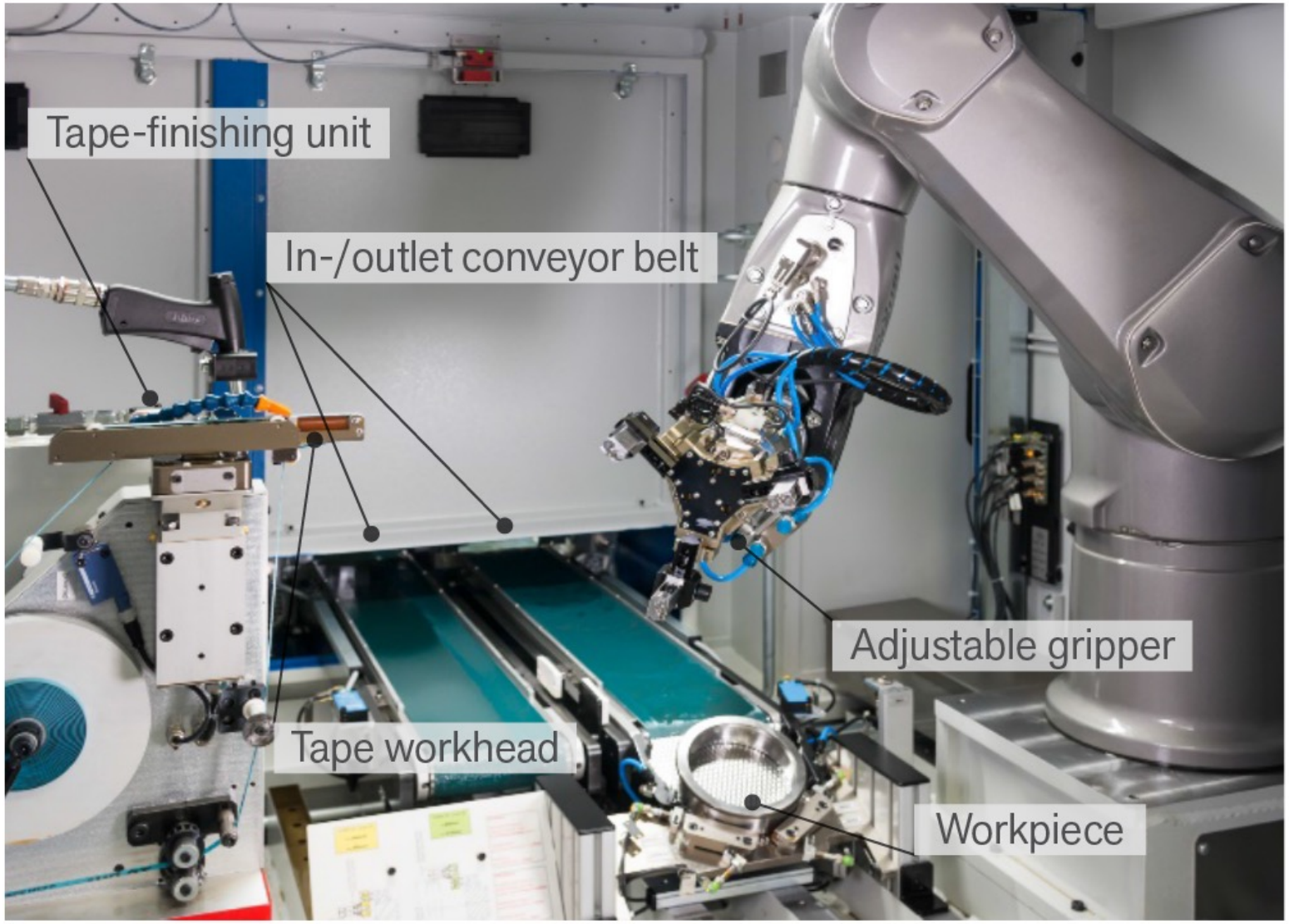
(a) Machine configuration



(b) Novel shoe setup

Source: *Fives-Cranfield Precision*

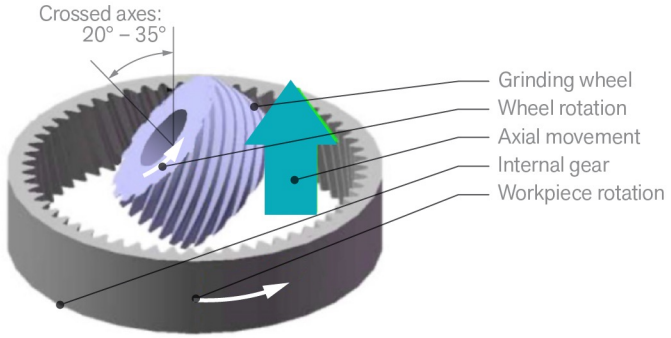
Flexible fine finishing of precision components



Source: *Supfina Grieshaber GmbH & Co KG*

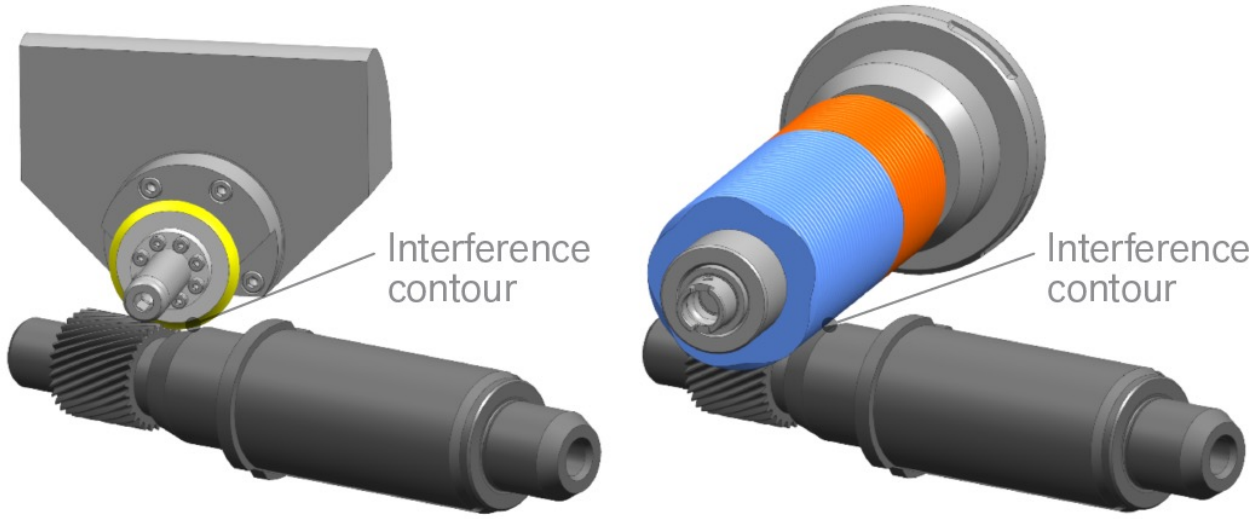
Advances in grinding of gears

- Larger gear ratios are required to reduce the high input speeds of electric machines
- Grinding of a drive shaft of a hybrid transmission:
  - Discontinuous cBN profile grinding
  - Generating grinding with combined worm for grinding/grind-finishing

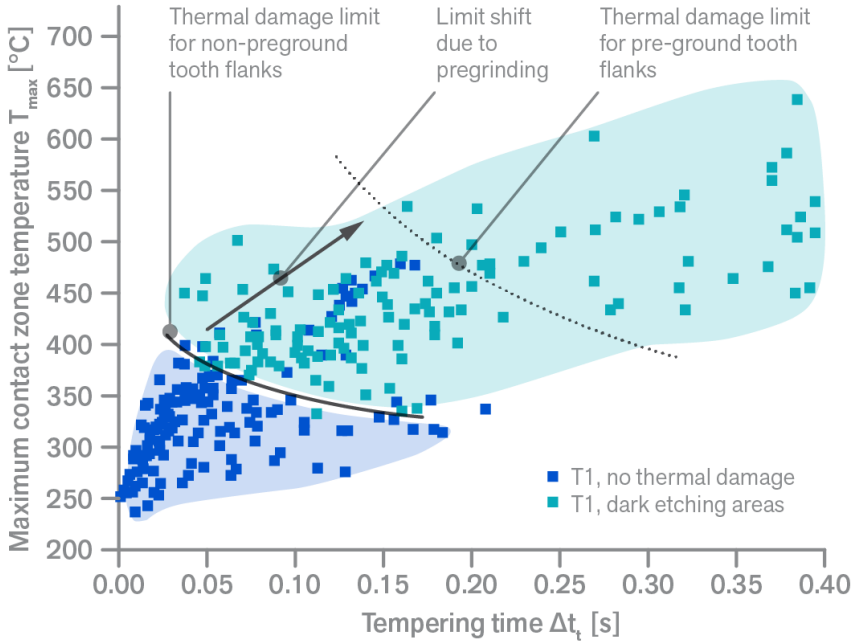


Source: *Mitsubishi Heavy Industries, Ltd.*

- The need for grinding and fine finishing of **internal gears** is rising
- Continuous generating grinding of internal gears with barrel-shaped wheels at large crossed-axes angles



Source: *KAPP NILES GmbH & Co. KG*



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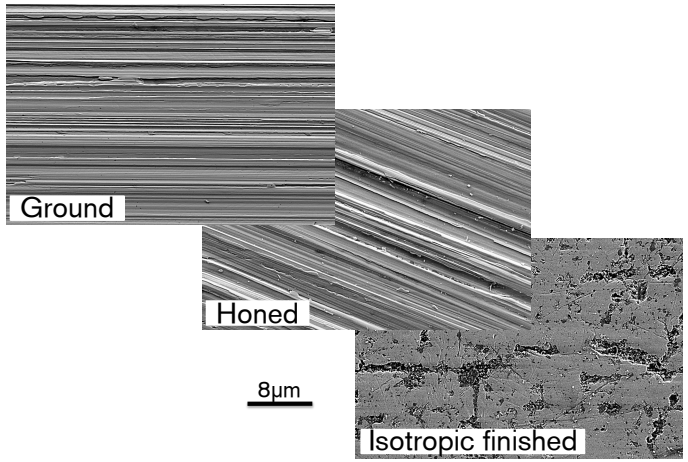
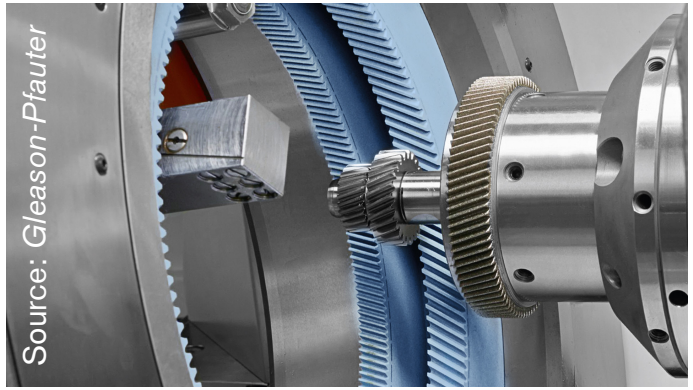
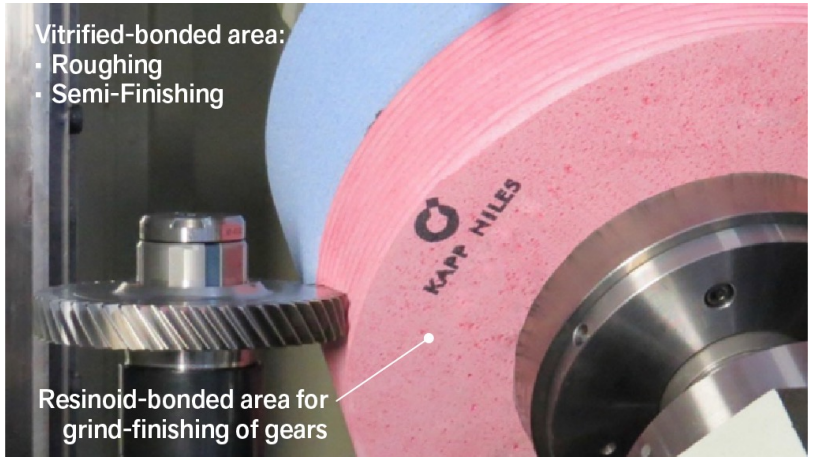
Advances in fine finishing of gears

- Surface topography of ground, honed and isotropic (mass) finished gears



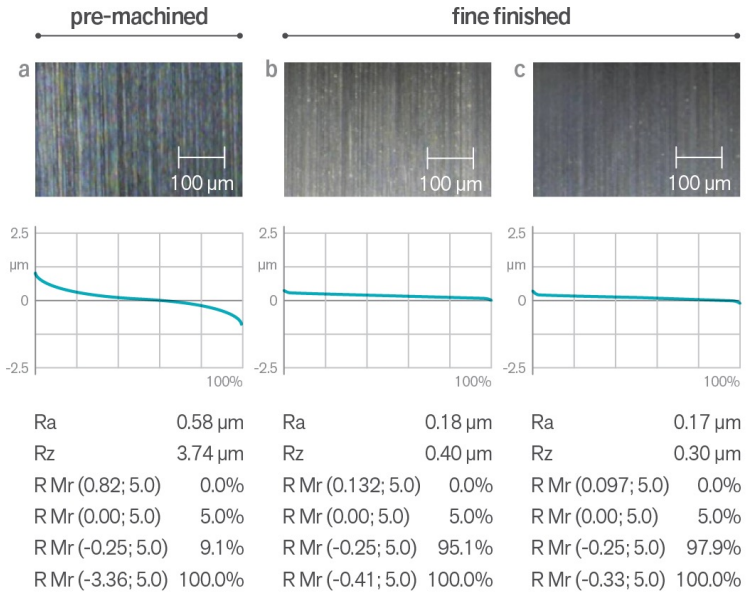
- Electric drives include planetary transmissions using stepped pinions





Source: *KAPP NILES GmbH & Co. KG*

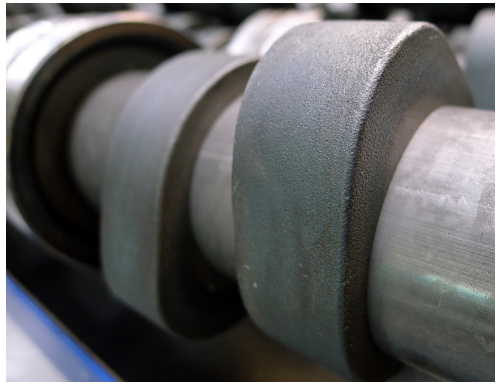
Source: *Reishauer AG*



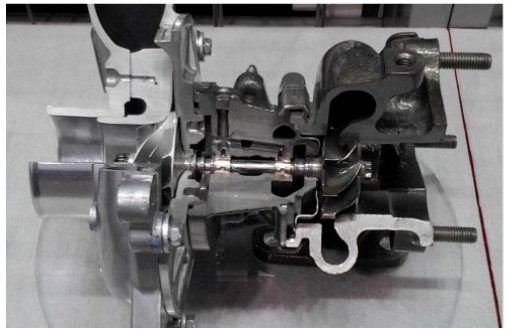
2013 Heinzel et al. Published by Elsevier on behalf of CIRP

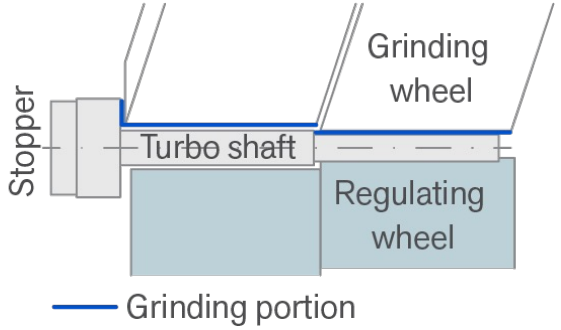
Advances in grinding and fine finishing of shafts

- Grinding of engine shafts to a large extent involves customized grinding operations for camshafts and crankshafts



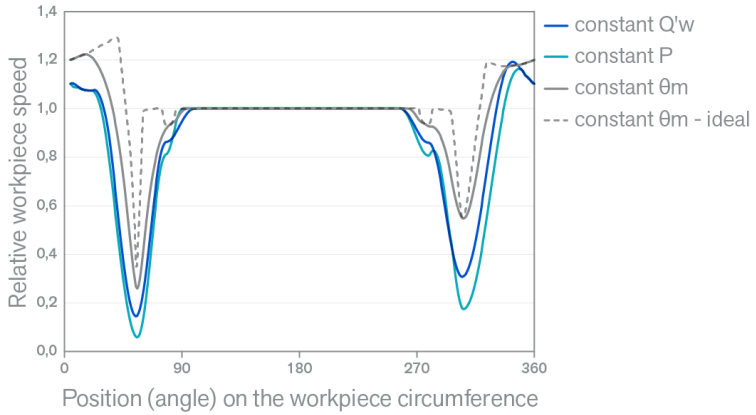
- Centerless grinding is traditionally used for grinding of shafts, ranging from gear shafts to turbo shafts



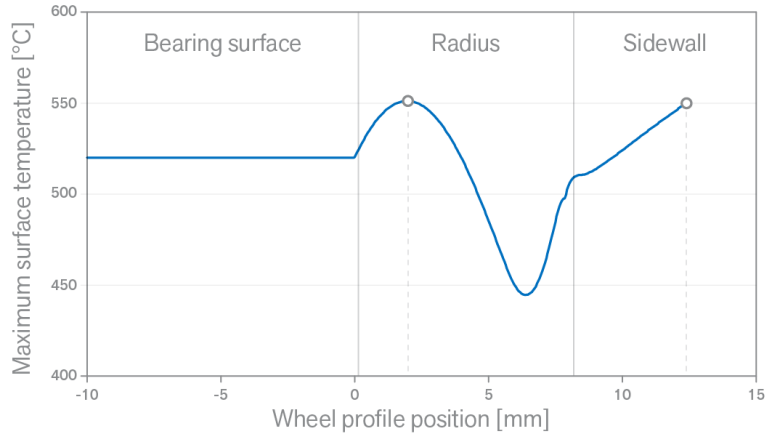


Source: *Tohshin Seiki/Tohshin Technical*

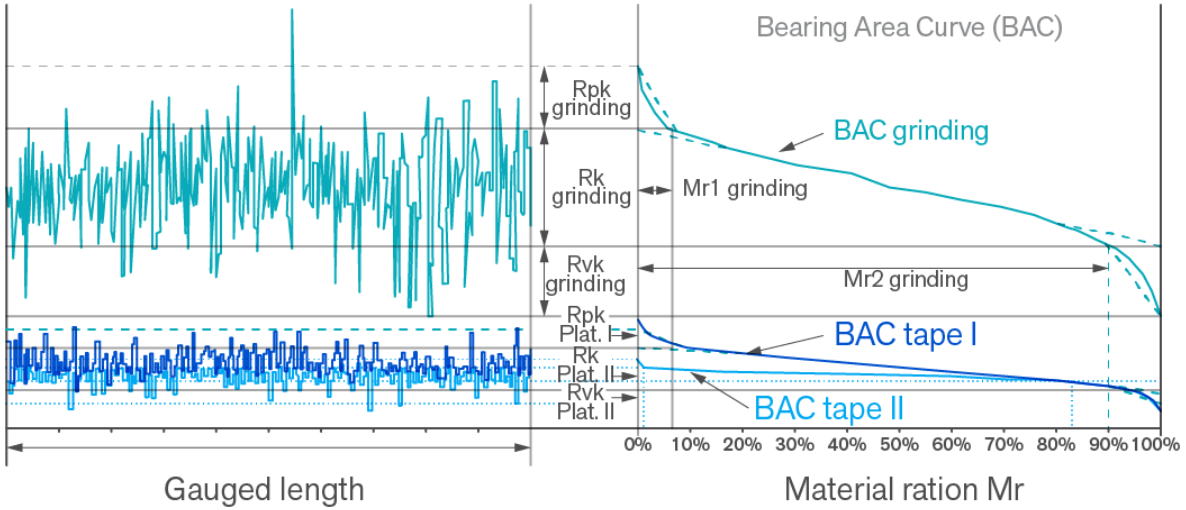
- Camshaft grinding



- Crankshaft grinding



- Three-step superfinishing of crankshafts

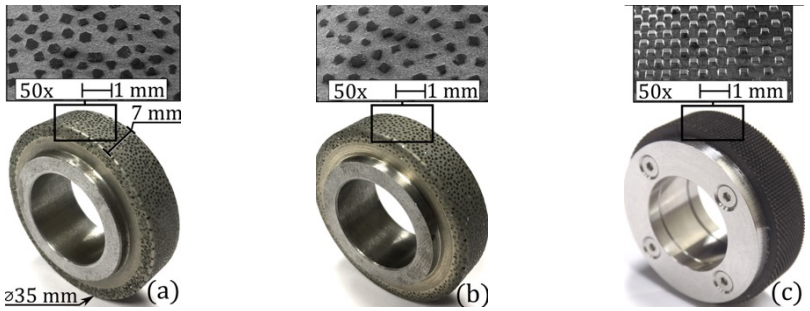


Source: *Supfina Grieshaber GmbH & Co KG*

Advances in dressing tools and grinding wheels

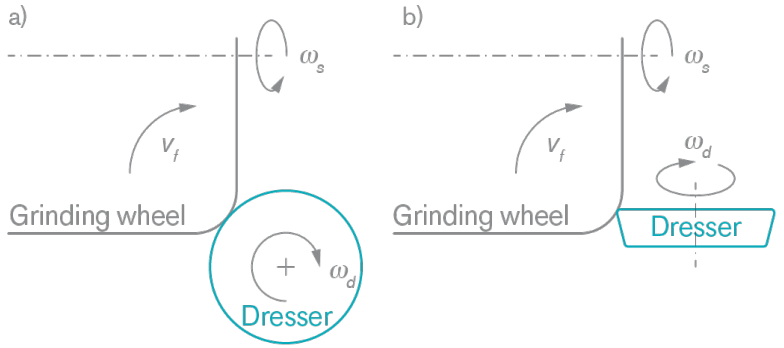
- Dressing using stationary and rotary tools

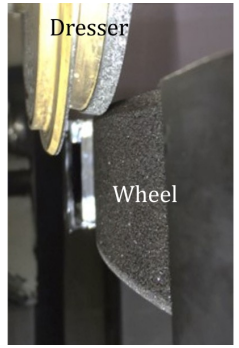
Source: *Meister Abrasives AG*

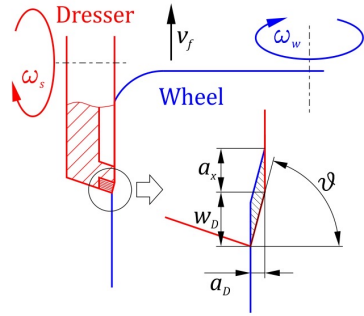


- Dressing operations that impart specific macro- and micro-features in the grinding-wheel topography

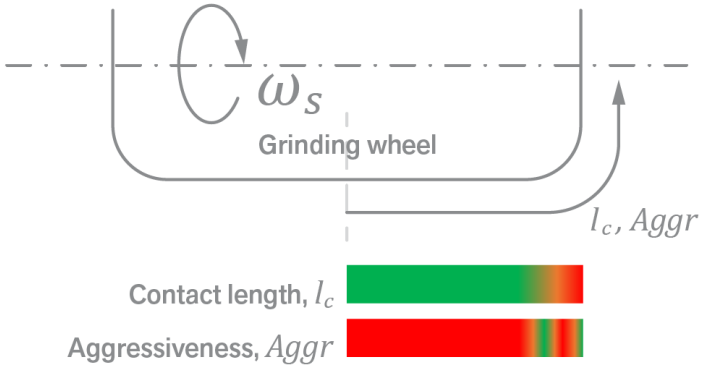
- Distinct dressing-system layouts in crankshaft grinders

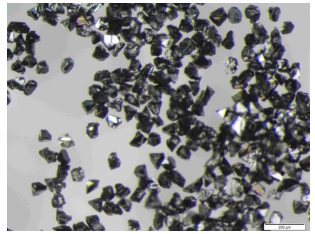


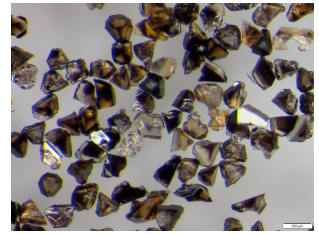




- Multi-grit wheels featuring customized cBN grit shapes, properties and grit concentrations for crankshaft grinding



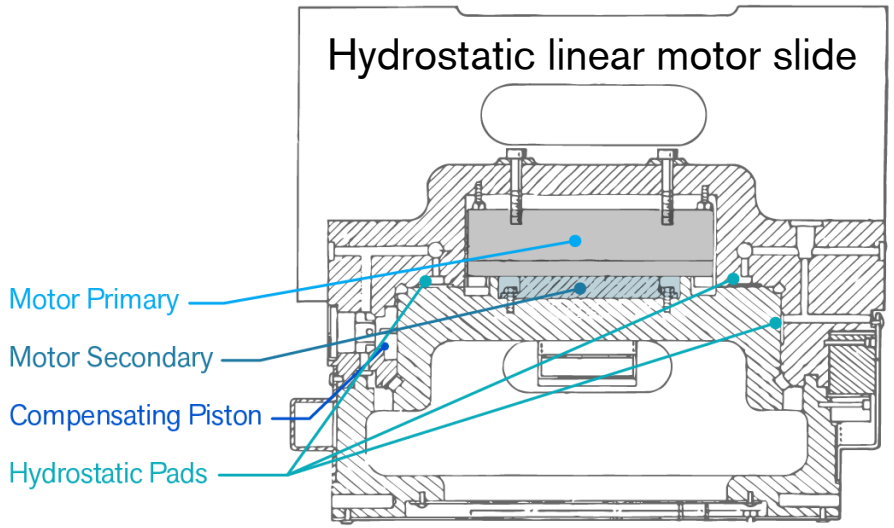




Source: *Element Six UK Ltd.*

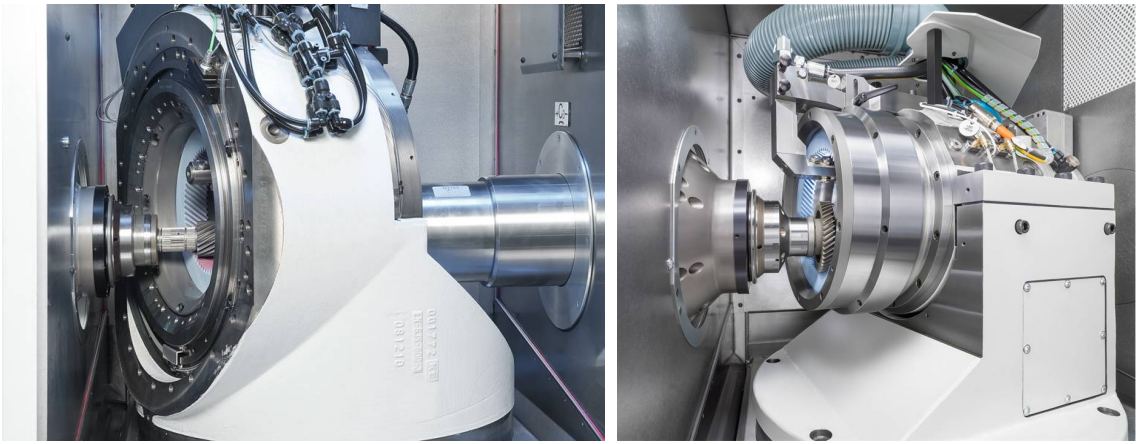
Machines for grinding and fine finishing of powertrain components

- The uncertainty about the future market uptake of the different automotive powertrains constitutes a significant reason for reduced orders and production volumes of machine tools since 2017.
- Future components necessitate a shift towards higher, automation-enabled flexibility and easy customization, in addition to the trend toward smaller and faster machine tools.
- Advances in grinding machines for automotive powertrain production still mainly refer to camshaft and crankshaft grinding machines.
- Recent developments in gear-honing machines:
  - Increased cutting speed to maximize Q'_w
  - Capability of honing a stepped pinion in a single setup



Source: *FIVES Landis Corp.*

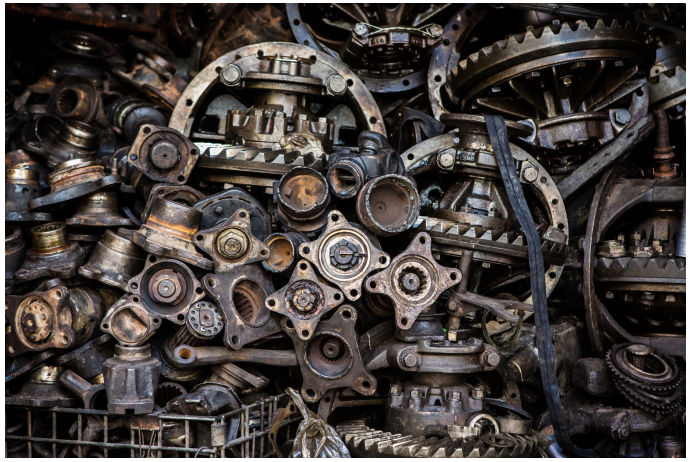
- Ring-type vs. cup-type honing head



Source: *Gleason-Pfauter*

Summary and outlook

- This keynote is CIRP's first systematic attempt at addressing the challenges of transforming automotive industry; in this case through the STC-G lens of finishing technology
- The new requirements are pushing the transformation of longstanding principles in the automotive industry and are advancing numerous manufacturing processes – including grinding and fine-finishing
- Automotive powertrain components will not simply disappear. Rather, as the powertrain portfolio diversifies (from ICE to HEV, BEV, FCEV), the powertrain components are becoming more demanding to produce
- Gears have the toughest requirements for surface finish and geometrical accuracies (e.g. new lead modifications and asymmetric gears) – more research is needed
- The current finishing sequences might be replaced with more-flexible, multi-surface-finishing and fine-finishing capabilities
- The received contributions by industrial partners have been overwhelming and serve as an opportunity to further bridge the gap between academic research and industrial development



Acknowledgments

1. **Dirk Biermann** (ISF, TU Dortmund University, Germany)
2. **Marion Merklein** (IFW, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany)
3. **Albert Shih** (University of Michigan, USA)
4. **Benjamin Kirsch** (FBK, University of Kaiserslautern, Germany)
5. **Andreas Klink** (WZL, RWTH Aachen University, Germany)
6. **Eckart Uhlmann** (IWF, TU Berlin)
7. **Danfang Chen** (Volvo Group, Sweden)
8. **Jeffrey Badger** (Grinding Doc, USA)
9. **Konrad Wegener** (IWF, ETH Zürich, Switzerland)
10. **Tobias Hüsemann** (IWT, Leibniz Institute for Materials Engineering, Germany)
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