IMTEX®

Andreas Sterzing

Innovation in Forming Technology – Solution Potentials of Future Challenges

Focus: Realization of Powertrain Components

Bangalore, January 22th 2020

Fraunhofer IWU

Table of Content

Fraunhofer IWU

Table of Content

Fraunhofer IWU

1 Introduction

Production-Relevant Megatrends (selected)

large **social**, **economic**, **political** and **technological changes**
(John Naisbitt)

Rising world population
- markets in growth regions
- growing demands

Individualization
- individual, user-specific products
- complex products / production processes

Sustainability
- efficiency in product realization / operation
- shortage of resources
- reduction of emissions

Demographic development
- aging of population
  (changing working conditions)
- down aging

Urbanization
- mobility
- living and production in mega cities

Globalization
- products / technologies for global markets
- global standards

Fraunhofer IWU

Table of Content

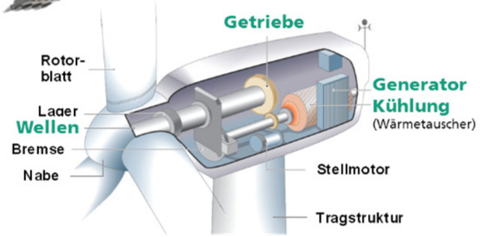
Fraunhofer IWU

2 Relevance for Production / Forming Technologies

Efficiency is becoming increasingly important.

- **Efficiency Increase in Product Operation**
  - reduction of energy use
  - reduction of emissions

  ➔ **Lightweighting**
  ➔ **Influencing of Part Characteristics**
  (incl. material design)



- **Efficiency Increase in Product Manufacturing**
  - reduction of resource use
    (material, energy, time, human, …)

  ➔ **Alternative Process Routes**
    → **shortening / optimization**
    (e. g. use of net-shape technologies)
  ➔ **Process Safety / Stability**
    → **virtual** process **development**
    → process **monitoring / influencing / control**
  ➔ **Flexibility** (process, tool, machine)

not only in **automotive industry**

- rail vehicle industry
- aircraft industry
- shipbuilding
- construction vehicles
- agricultural machines
- power generation
- …

Table of Content

3 Efficiency Increase in Product Operation
Innovative Components for Ship Powertrains

Today´s Situation

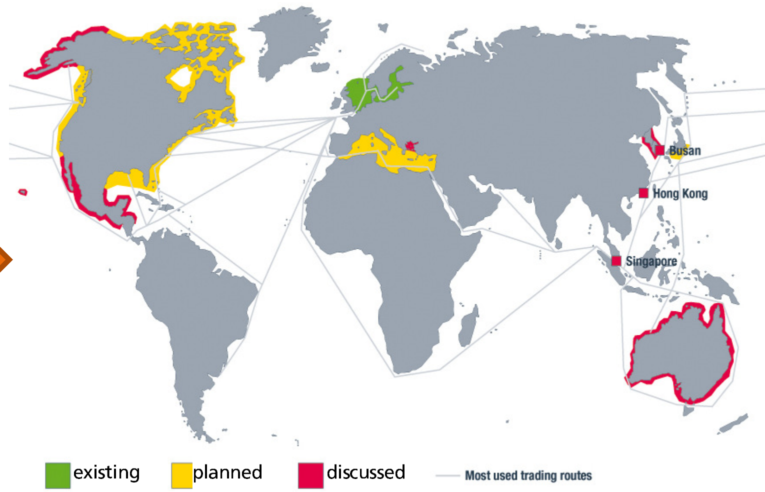
➢ world fleet (approx. 90 000 ocean-going ships)
- → 370 mio. tons fuel (mostly heavy oil)
- → emission
  - sulphur oxides (20 mio. tons) **SO_x** **13 %**
  - carbon dioxide **CO_2** **3 %**
  - nitrogen oxides **NO_x** **15 %**
  - sooty particles
  - fine dust

Challenges

➢ significant reduction of **emissions**

➢ establishment of **ECAs** (emission controlled areas)

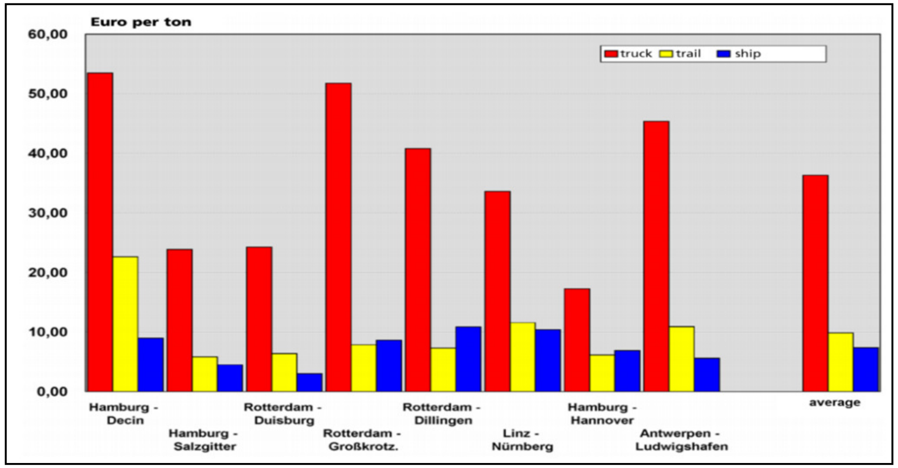
➢ implementation of emission **standards**
TIER I…III → soot, NO_x
TIER IV (from 2020) → additionally SO_x



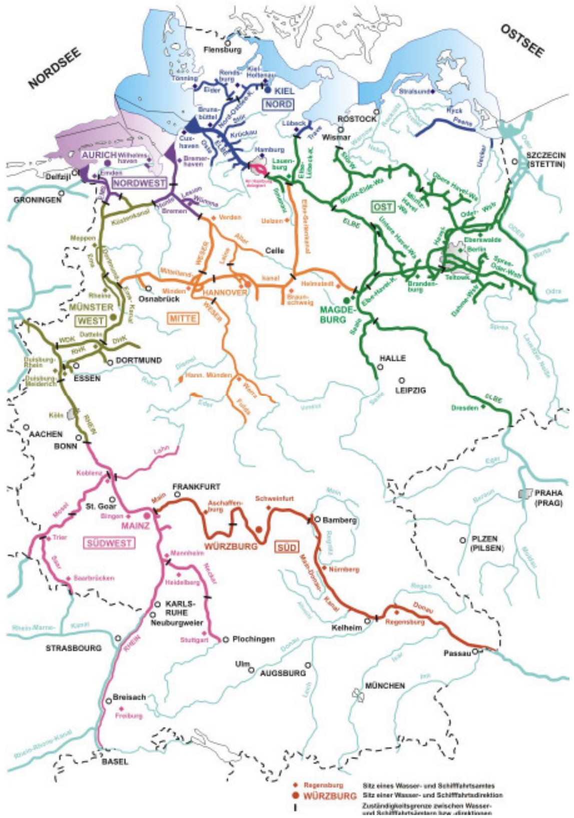
3 Efficiency Increase in Product Operation
Innovative Components for Ship Powertrains

Potentials of Inland Water Transportation

➔ **most efficient transport** method



comparison of transport costs



waterways (Germany)

➔ **reduction of emissions**

Fraunhofer IWU

3 Efficiency Increase in Product Operation
Innovative Components for Ship Powertrains

Approach / Promising Measures

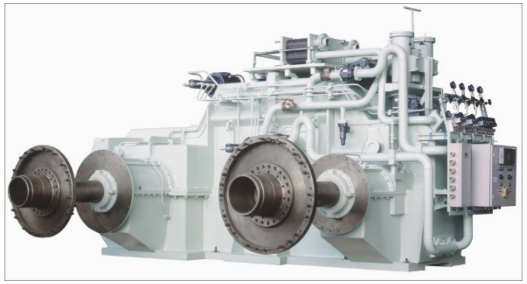
- **optimization** of **combustion behaviour**
  - ➔ **increase** of - combustion **temperature** (ϑ = 500°C → ϑ = 650°C)
    - average cylinder **pressure** (p = 25 bar → p = 40 bar)
    - → increase of **thermal** and **mechanical loading** of engine **components**
    - → use of **new material compounds** for **valves** and **pistons** (e. g. steel + Nimonic / Inconel)
      - strength increase
      - high-temperature stability

source **Hyundai Heavy Industries**

- **lightweighting**
  - ➔ **alternative** part **design** (e. g. hollow shafts)
    - → **feasibility**
    - → efficient **component realization**
    - → technology readiness level / **series capability**

Enabler (efficient component realization)

- innovative **manufacturing / forming processes**
- alternative **process routes** (e. g. forming-based)



source **Getriebetechnik Dessau GmbH**

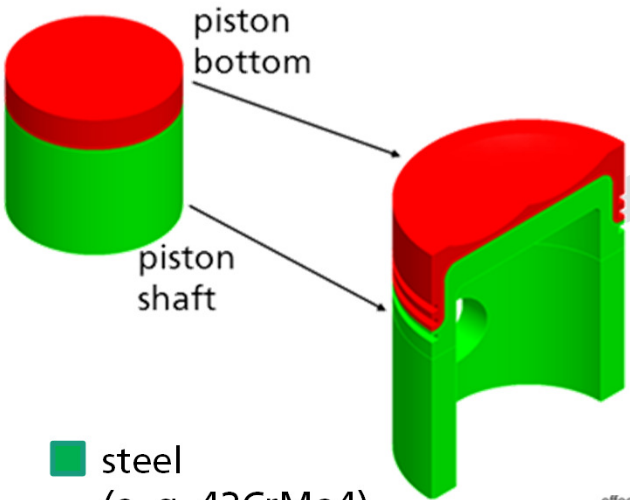
Fraunhofer IWU

3 Efficiency Increase in Product Operation
Innovative Components for Ship Powertrains

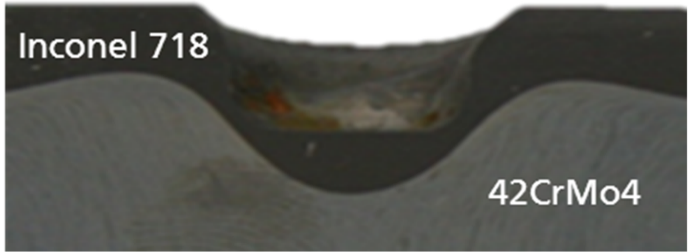
Use of Innovative Material Compounds for Piston Head

(in consideration of higher temperatures and pressures in the combustion chamber)

➔ strength increase
➔ high-temperature stability



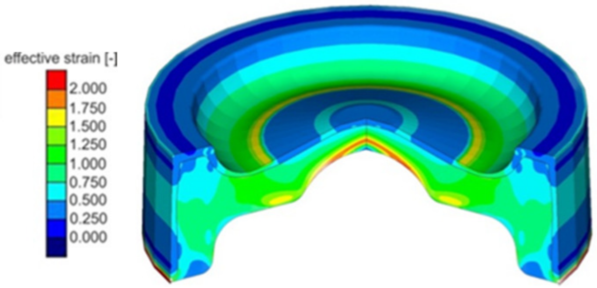
- steel (e. g. 42CrMo4)
- high-temperature alloy (e. g. Inconel 718)



systematic investigations for **realization** and **forming** of **compounds**

TU BA Freiberg,
Institut für Werkstofftechnik

Influence of
- temperature
- surface conditions
- ...



Simulation forming process

Realized piston head (D = 160 mm)

Bundesministerium für Wirtschaft und Technologie
PtJ Projektträger Jülich Forschungszentrum Jülich
Fraunhofer IWU

3 Efficiency Increase in Product Operation
Innovative Components for Ship Powertrains

Use of Innovative Material Compounds for Piston Heads

(in consideration of higher temperatures and pressures in the combustion chamber)

Summary / Conclusions

- Development, application and optimization of efficient **process route** for **hybrid piston heads** using **innovative material compound**
  - compound realization
  - forming of compound
  - part finishing

- Proof of **feasibility**

- Guarantee of required **part characteristics**
  e. g. resistance against high thermal and dynamic loading

- **Transferability** of **method** for other components
  e. g. valves

Bundesministerium für Wirtschaft und Technologie

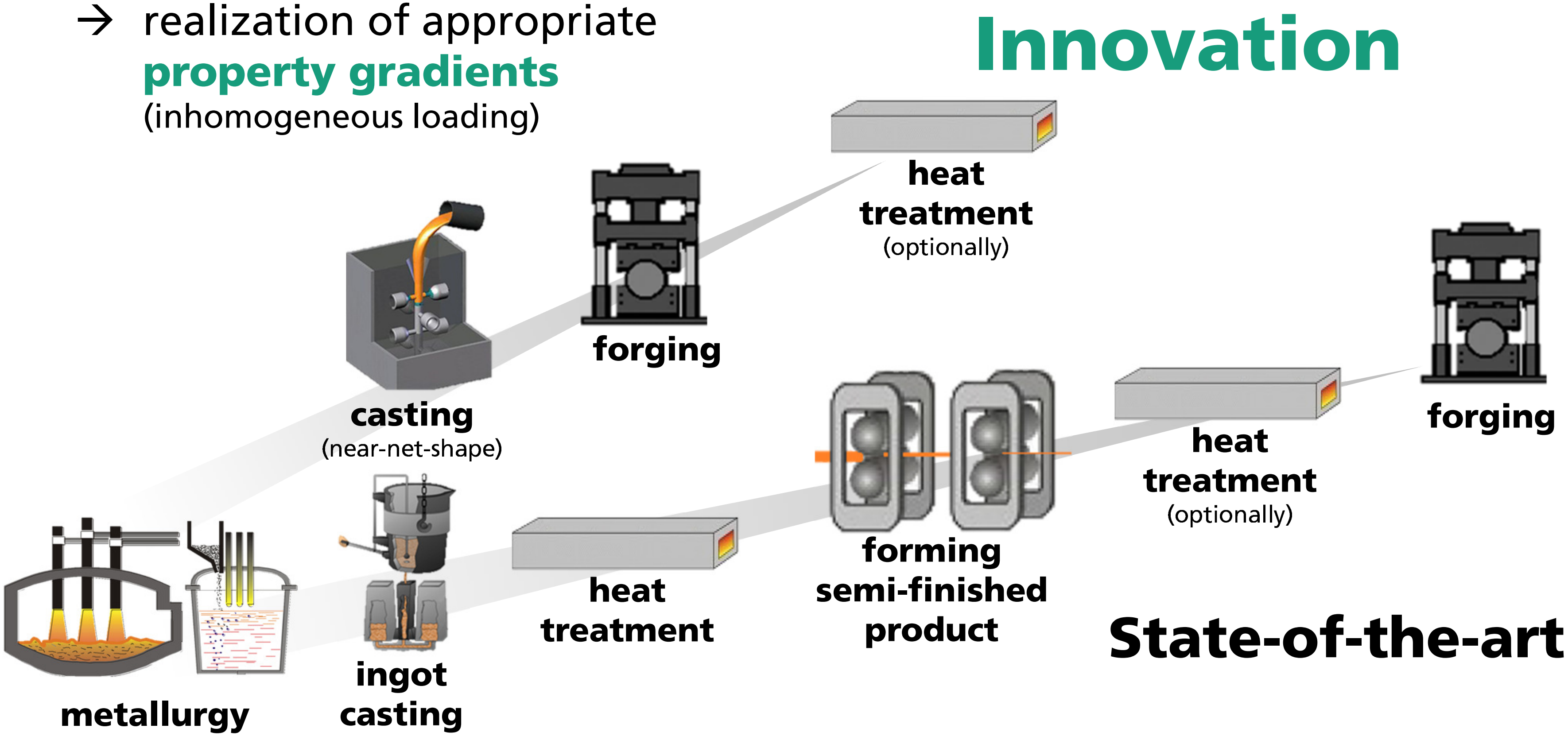
PtJ Projektträger Jülich Forschungszentrum Jülich

Fraunhofer IWU

3 Efficiency Increase in Product Operation
Innovative Components for Ship Powertrains

Lightweight Piston Based on Innovative Process Combination (lower part)

➔ **Casting + Forging**
- → resource **efficiency** ⇧ (time, material, energy)
- → geometrical part **complexity** ⇧
- → realization of appropriate **property gradients** (inhomogeneous loading)

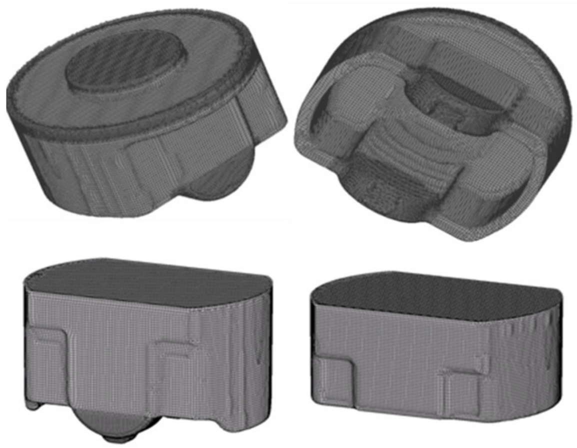


Bundesministerium für Wirtschaft und Technologie
Projektträger Jülich Forschungszentrum Jülich
Fraunhofer IWU

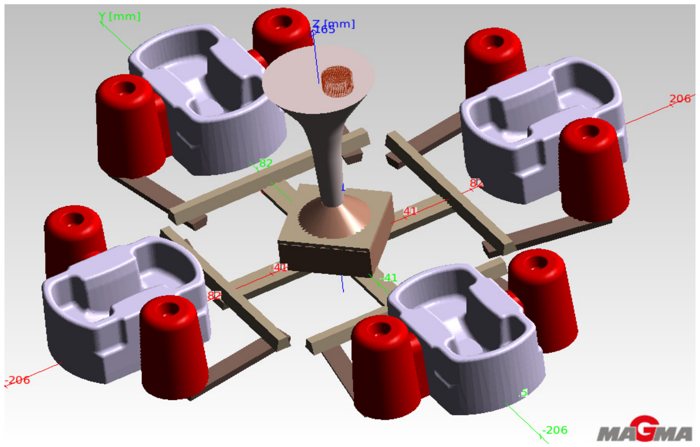
Lightweight Piston Based on Innovative Process Combination (lower part)

➔ Casting

- → **scaled demonstrator** components
- → derivation of **two different variants** (cast pre-forms) from selected piston design considering
  - piston loading (lower part)
  - casting requirements
  - subsequent forging process
- → design of **casting system**
  four cavities in one mould for systematic parameter investigation
- → **cast trials**
  $\vartheta_{casting}$ = 1630 °C +/- 15 K



Variant 1 **Variant 2**



Bundesministerium für Wirtschaft und Technologie
PtJ Projektträger Jülich Forschungszentrum Jülich
Fraunhofer IWU

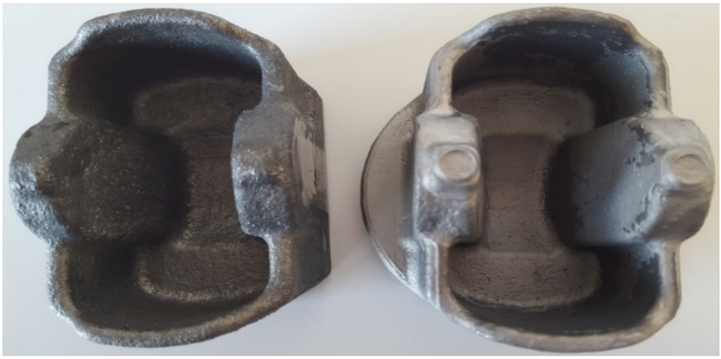
3 Efficiency Increase in Product Operation
Innovative Components for Ship Powertrains

Lightweight Piston Based on Innovative Process Combination (lower part)

➔ **Forging**

→ realization of **forging tool**
(design, construction, testing)

→ **forging trials**
$\vartheta_{forging}$ = 1100 °C



Feasibility ✓

complete mould filling using variant 1

Bundesministerium für Wirtschaft und Technologie
PtJ Projektträger Jülich Forschungszentrum Jülich
Fraunhofer IWU

3 Efficiency Increase in Product Operation
Innovative Components for Ship Powertrains

Lightweight Piston Based on Innovative Process Combination (lower part)

Summary / Conclusions

➔ **combination** of **advantages** of both technologies
  → **design freedom** of casting
  → **strength increase** based on forging

➔ completely new possibilities for **lightweighting**

➔ significant **resource saving** along the entire process route

Next Steps

➔ realization of lower part for a **real piston** (D = 160 mm)

➔ **optimization** of **casting** process
(accelerated solidification for microstructure refinement)

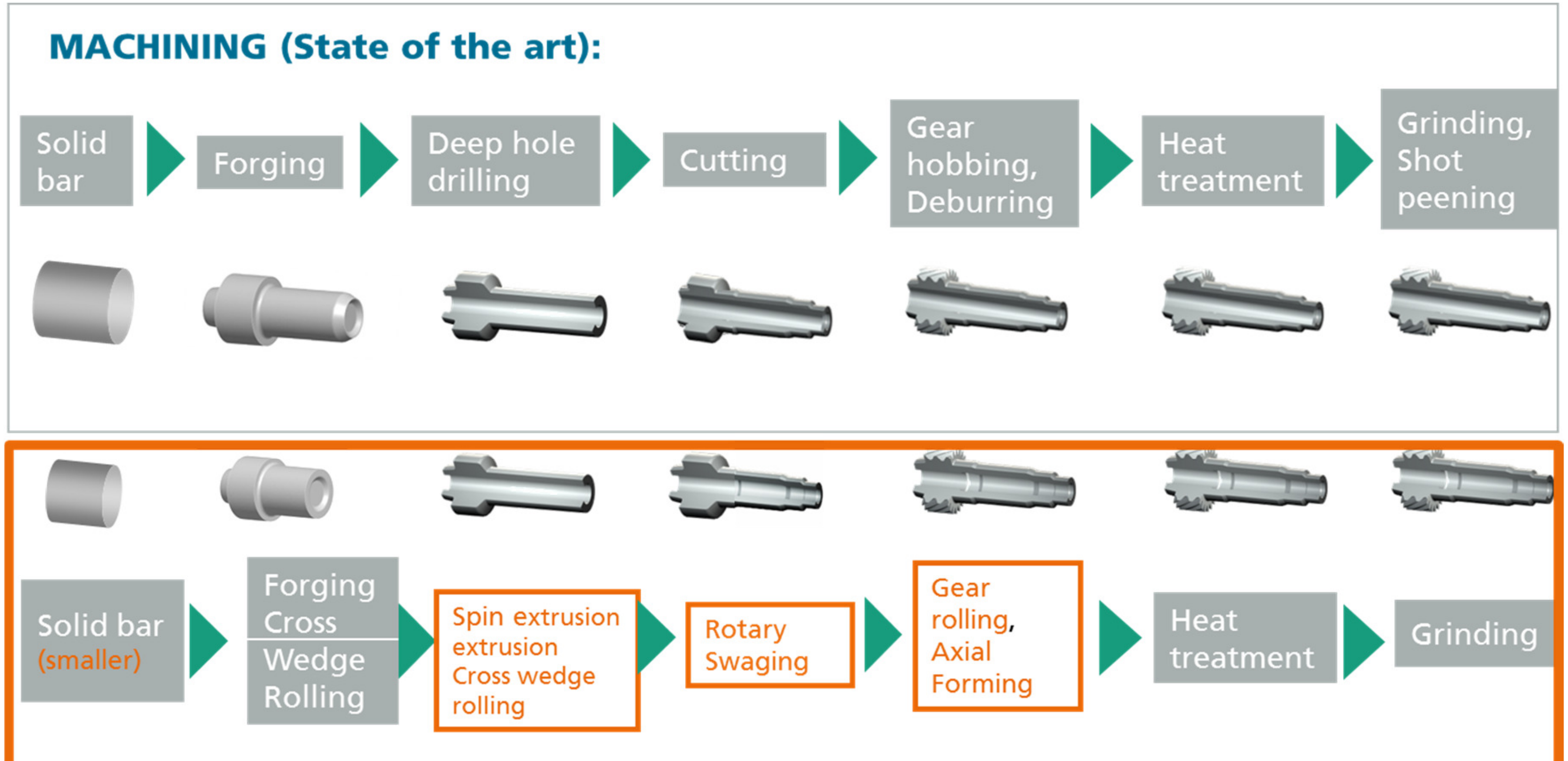
➔ realization of **complete piston** consisting of
- hybrid piston head
- lightweight lower part

Bundesministerium für Wirtschaft und Technologie
PtJ Projektträger Jülich Forschungszentrum Jülich
Fraunhofer IWU

3 Efficiency Increase in Product Operation
Innovative Components for Ship Powertrains

Forming-Based Process Route for Hollow Gear Shafts

Initially Situation (focus: automotive powertrain)



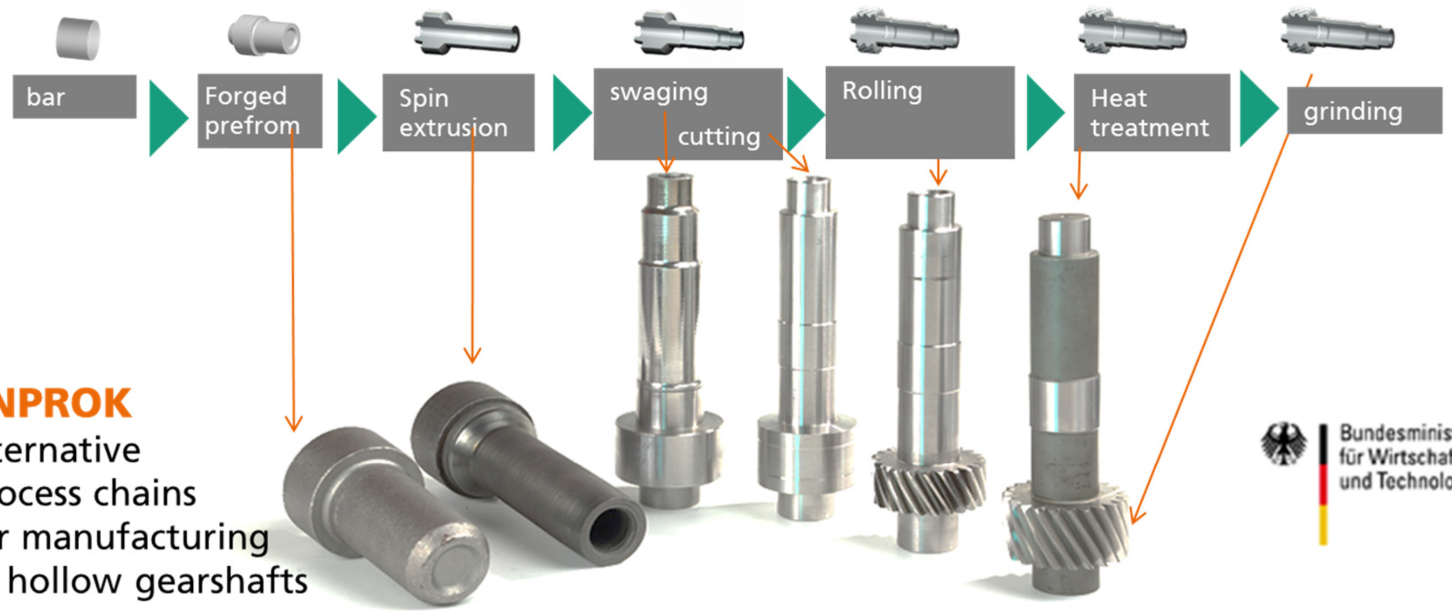
Focus: **forming processes**
Holistic Approach: **from pre-forming…finishing**

Fraunhofer IWU

3 Efficiency Increase in Product Operation
Innovative Components for Ship Powertrains

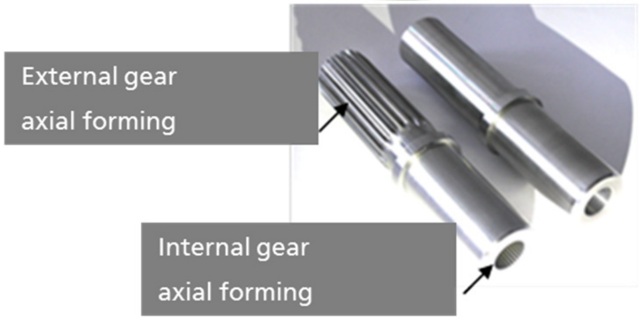
<u>Forming-Based Process Route for Hollow Gear Shafts</u>

Initially Situation (focus: automotive powertrain)



ENPROK
alternative process chains for manufacturing of hollow gearshafts

Bundesministerium für Wirtschaft und Technologie



Fraunhofer IWU

3 Efficiency Increase in Product Operation

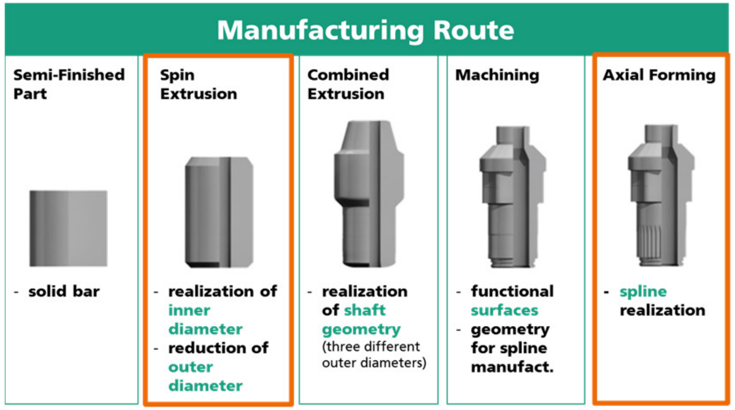
Innovative Components for Ship Powertrains

<u>Forming-Based Process Route for Hollow Gear Shafts</u>

Initially Situation (focus: automotive powertrain)

Example: Output Shaft – Achieved Effects

- **part weight** ⇩ (- 22 %)
- power density ⇧ (+ 28 %)
- **material use** ⇩ (- 36 %)
- new fixing concept
  → reduction of **notch effect**
  → improvement of bevel gear centering
- staged design
  → improved **assembling conditions** for bevel gear
- **elimination** of **hardening process**
  → hardness ⇧ in spline section (+15 %)



Fraunhofer IWU

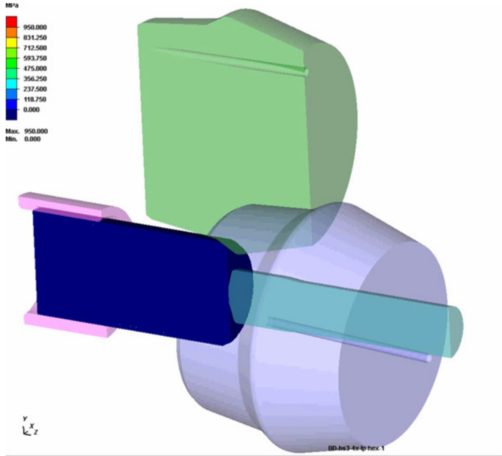
3 Efficiency Increase in Product Operation
Innovative Components for Ship Powertrains

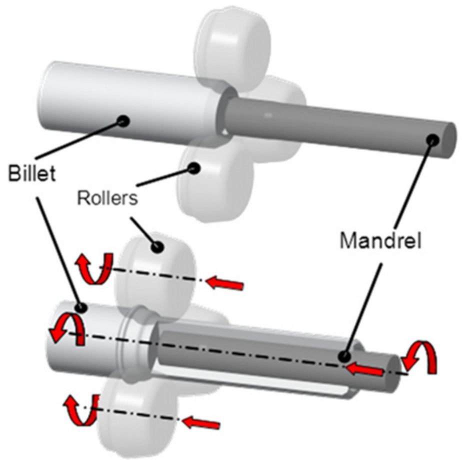
Forming-Based Process Route for Hollow Gear Shafts

Spin Extrusion – Realization of Hollow Preform

Principle

- realization of **hollow parts** based on a combination of **backward cup extrusion** and **flow forming**
- realization of **inner profiles** or shaft shoulders
- incremental forming process
- depending on material
  → cold or temperature-supported forming process





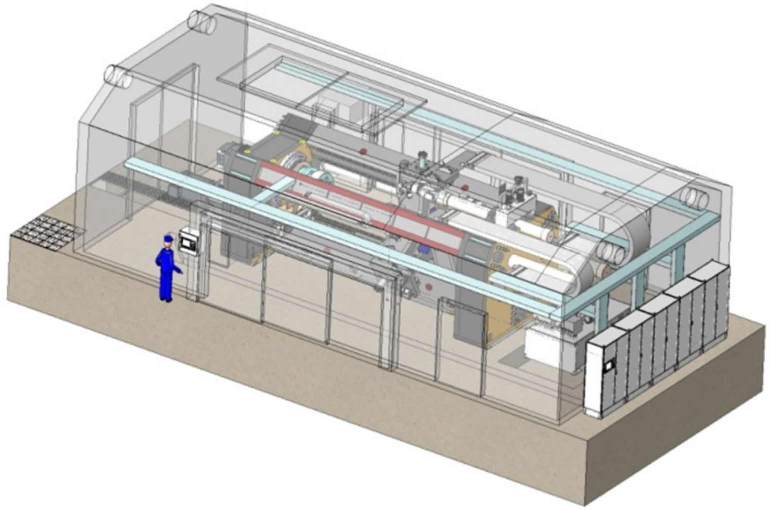
- axial punch clamping
- alignment of rolls to punch
- **synchronous rotation** of **rolls** and **punch**
- **synchronous axial feed** of **rolls**

➔ **material flow**
in opposite direction

Fraunhofer IWU

Forming-Based Process Route for Hollow Gear Shafts

Spin Extrusion – Technology Adaption



large shafts

(l_{max} ≈ 2000 mm; D_{max} ≈ 600 mm)

- **ship** industry
- **aircraft** industry
- **energy** generation
- commercial **vehicles**

Objectives

- technology development
- development / realization of special purpose (test) machine

Current Status

start-up of test machine

Construction of test machine

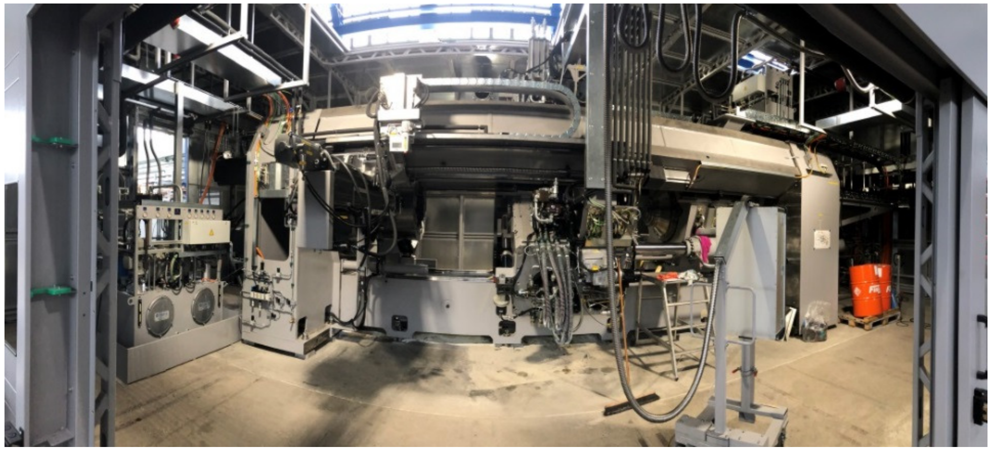


Table of Content

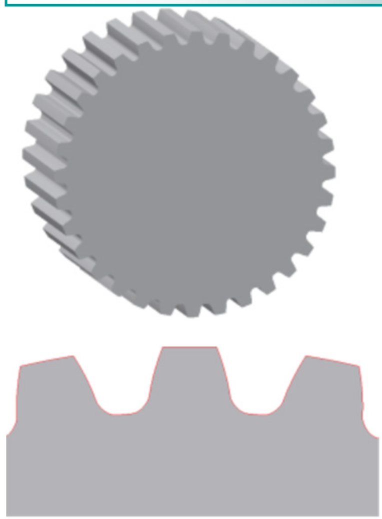
4 Efficiency Increase in Product Manufacturing
Temperature-Supported Gear Rolling

Process Development

State-of-the-Art

First, successful research results of Fraunhofer IWU

Stub Tooth Gears

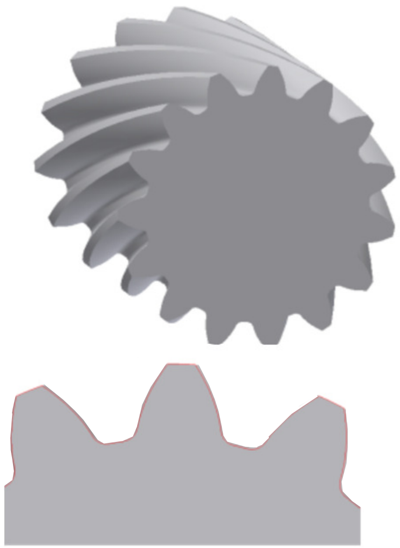


Tooth height factor
y = 1

➔ short, compact teeth with high strength

➔ transmission of high forces / torques

Conventional Gears

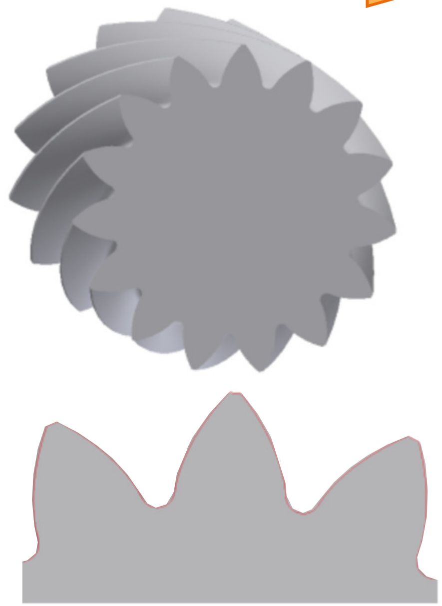


Tooth height factor
y ≤ 2

➔ typical pressure angle 20°

➔ use in gear manufacturing (automobile)

High Gears



Tooth height factor
h ≥ 2

➔ large profile overlap

➔ increased running smoothness

Fraunhofer IWU

4 Efficiency Increase in Product Manufacturing
Temperature-Supported Gear Rolling

Process Sequence (conventional)

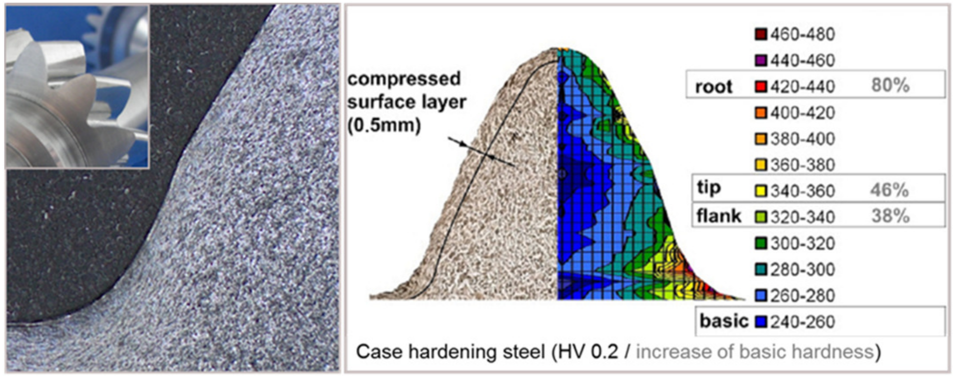
Fraunhofer IWU

4 Efficiency Increase in Product Manufacturing
Temperature-Supported Gear Rolling

Advantages

➔ Process

- **shortening** of **process time** (up to 50%)
- **material saving**
  (no chips ➔ up to 30 %)
- **low forming forces**
  (incremental forming)



Improvement of part characteristics
(based on forming process)

➔ Component

- strain **hardened surface layer**
- **contour related fibre** orientation
  (no separated)
- higher **contour stability** after hardening
- high tooth **root strengths** / flank **load capacity**
- **surface roughness**
  (R_a = 0.2 … 0.5 µm / R_z = 1.4 … 3 µm)

Fraunhofer IWU

4 Efficiency Increase in Product Manufacturing

Temperature-Supported Gear Rolling

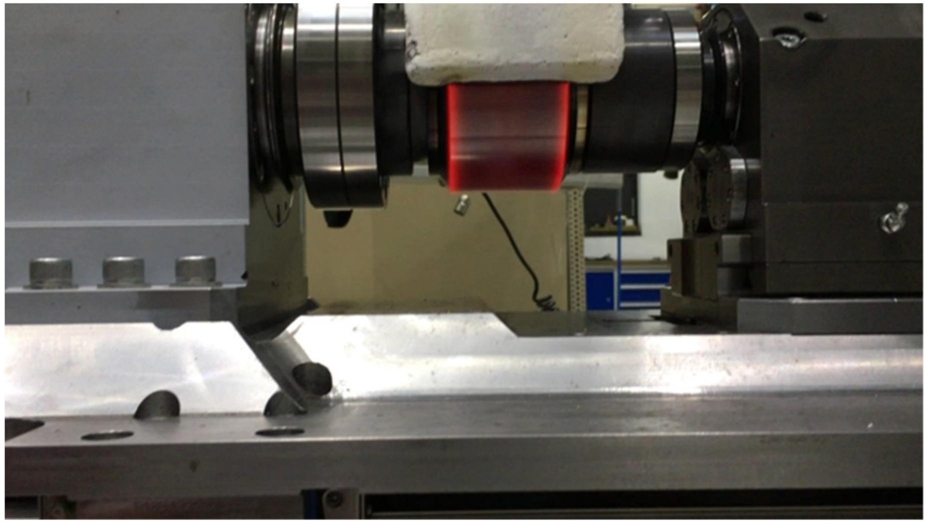
Challenges

I Tool Optimization
- ➔ loadings (bending)
- ➔ **life time**

II Extension of Process Limits
- ➔ part spectrum
  - "new", **high-strength materials**
    - → **compact gears**
  - increasing **modules** (m = 8 mm…12 mm)
  - gear size

use of **temperature** as **process parameter**

$\vartheta_{rolling} \approx 1000°C$



III Improvement of Part **Quality**
- ➔ improvement of quality parameters (dimensions, geometry)
- ➔ acoustic behaviour

IV Process Integration

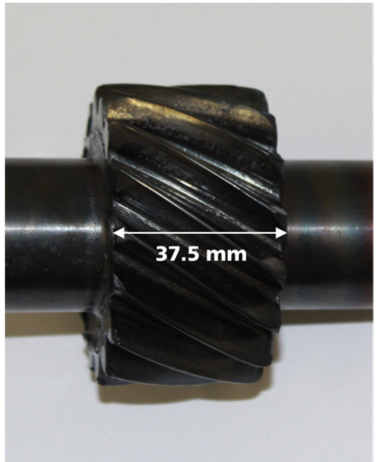
Fraunhofer IWU

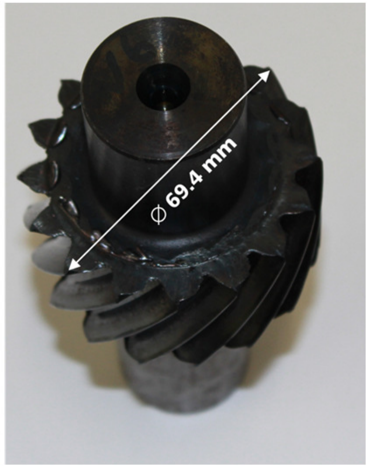
4 Efficiency Increase in Product Manufacturing

Temperature-Supported Gear Rolling

Research Focus

- **process** development / optimization
- proof of **feasibility**
- improvement of part **quality**
- achievement of **series capability**





Ring Gear
18CrNiMo7-6
Da = 122,86 mm
m = 4 mm
z = 27

Geared Shaft
20MoCr4
Da = 108,25 mm
m = 4,5 mm
z = 22

Fraunhofer IWU

4 Efficiency Increase in Product Manufacturing
Temperature-Supported Gear Rolling

GEAR FORM

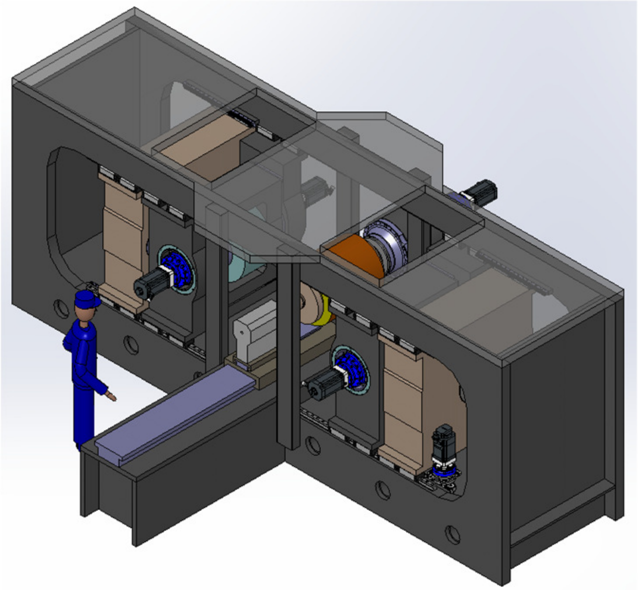
Technology Adaption

large gears ($D_{max} \approx 1000$ mm)

- **energy** generation
- **ship** industry
- commercial **vehicles**

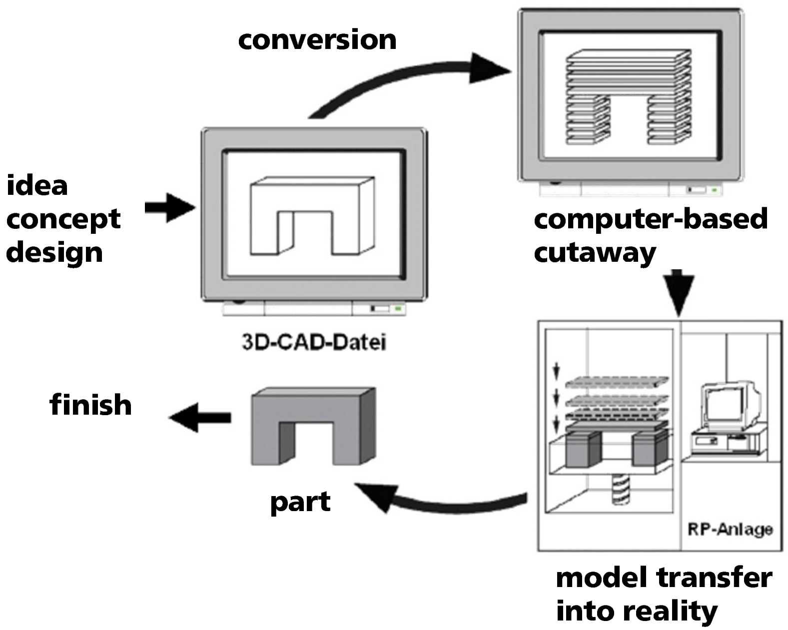
Foci

- **technology** development
- development and realization of **test machine**



Fraunhofer IWU

Introduction



principle of additive manufacturing process
source Gebhardt, A.: Generative Fertigungsverfahren

- **additive** [from Latin] – to add, to join; in this case: building up, e. g. layer by layer, **additive**
- **Rapid Prototyping (RP):** additive generation of parts with limited functionality (prototypes, test parts)
- **Additive Manufacturing (AM):** additive manufacturing of end products / series parts

Rapid Tooling:
use of additive methods and processes for tool and die making

4 Efficiency Increase in Product Manufacturing

Potentials of Additive Manufacturing for Forming Processes

Advantages

time to product

- no tools needed
- no job preparation / technology planning
- single step process

freedom of shape

- any complex geometries
- undercuts
- internal geometric shapes
- delicate structures
- geometries not producible by conventional manufacturing methods

material diversity

- aluminium
- titanium
- hot and cold work steel
- nickel-based alloys (Inconel)

lightweight design / bionics

- hollow and lattice-like structures
- 100 % topology optimized parts
- bionic structures
- structures with graded porosity

Fraunhofer IWU

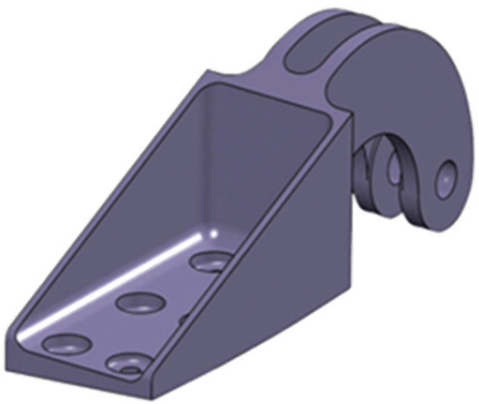
4 Efficiency Increase in Product Manufacturing

Potentials of Additive Manufacturing for Forming Processes

Advantages

- Realization of **any complex part structures** that are conventionally not realizable
  e. g. by casting, cutting, **forming**, …
  (or only with high manufacturing effort)
- Realization of **bionically inspired products**
  ➔ **maximum lightweight effects**
- **Highest flexibility**

bracket prototype (stainless steel)
Source: EOS, EADSs



nacelle
hinge bracket
(titanium)
Source: EOS, EADSs

Fraunhofer IWU

Competition with Forging Technology

Statement during FIA Fall Meeting 2013

San Antonio, October 21-23, 2013
Workshops on the topic "Future Challenges"

Additive Manufacturing

"…one of the **most important competitive manufacturing technologies** for the **American Forging Industry** in the future…"

Fraunhofer IWU

4 Efficiency Increase in Product Manufacturing
Potentials of Additive Manufacturing for Forming Processes

Rapid Tooling

Example **Rapid Tooling**

➔ Efficiency increase in prototype realization
approach: realization of forming tools by additive manufacturing

Potentials

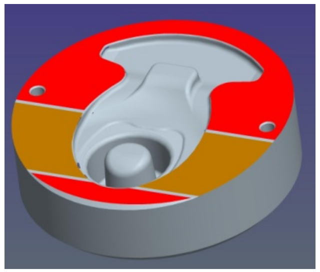
- realization of any **complex geometries**
  e. g. undercuts, delicate geometry areas
- **material diversity** (for forming tools)
- **NC programming** conditionally required

Challenges (Today)

- **surface** quality
- **material** (powder) **costs**
- **manufacturing** time and **costs**

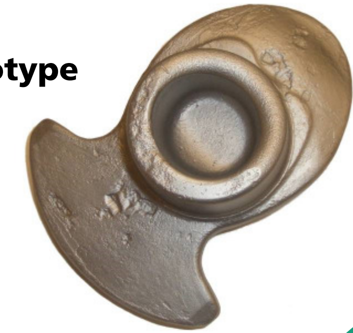
Demonstrator "**Crankshaft segment**"

die insert (design)



die insert
(realized)

prototype



Feasibility

- tool manufacturing
- forging process

Part quality

Fraunhofer IWU

4 Efficiency Increase in Product Manufacturing
Potentials of Additive Manufacturing for Forming Processes

Alternative Process Routes – Process Combination

- **additive manufacturing**
  → realization of **pre-form**
  - load-adapted, complex part design
- **forming** (e. g. forging)
  → realization of final **geometry**
  → guarantee and improvement of **part characteristics**
  e. g. - density ⇧ (globally, locally)
  - strength ⇧ (globally, locally)
  ⇨ tailored, graded properties
  ⇨ further lightweight effects
- **part finishing**
  → **surfaces**

aircraft door component

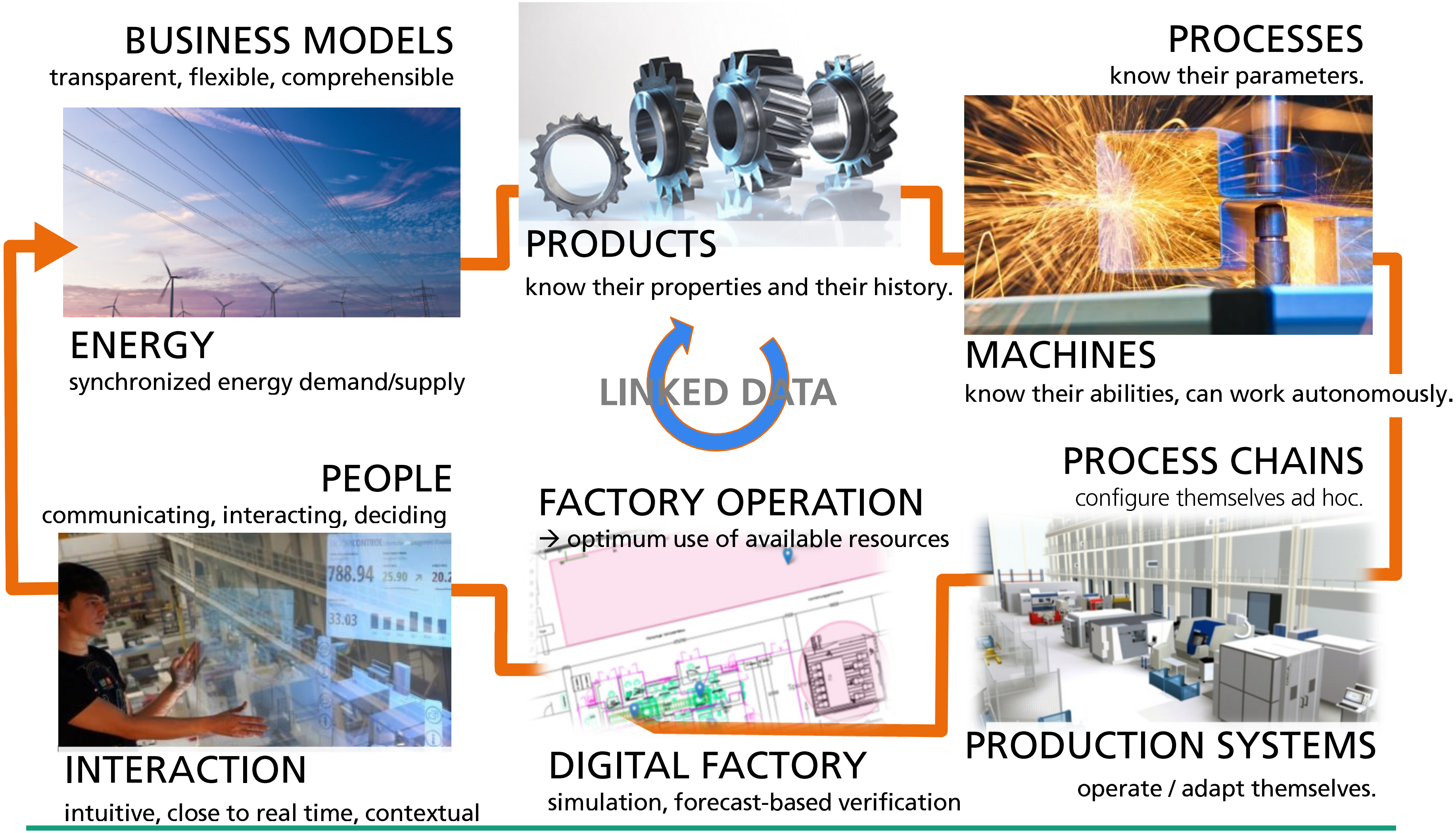
determination of **CAD data** (part scanning) → **topology** analysis/ optimization ↓ **re-design** → **additive manufacturing** → **forming** → part **finishing**

Fraunhofer IWU

Table of Content

Fraunhofer IWU

X Industry 4.0 – Relevance for Forging Industry
Data-Driven Intelligent Production



Fraunhofer IWU

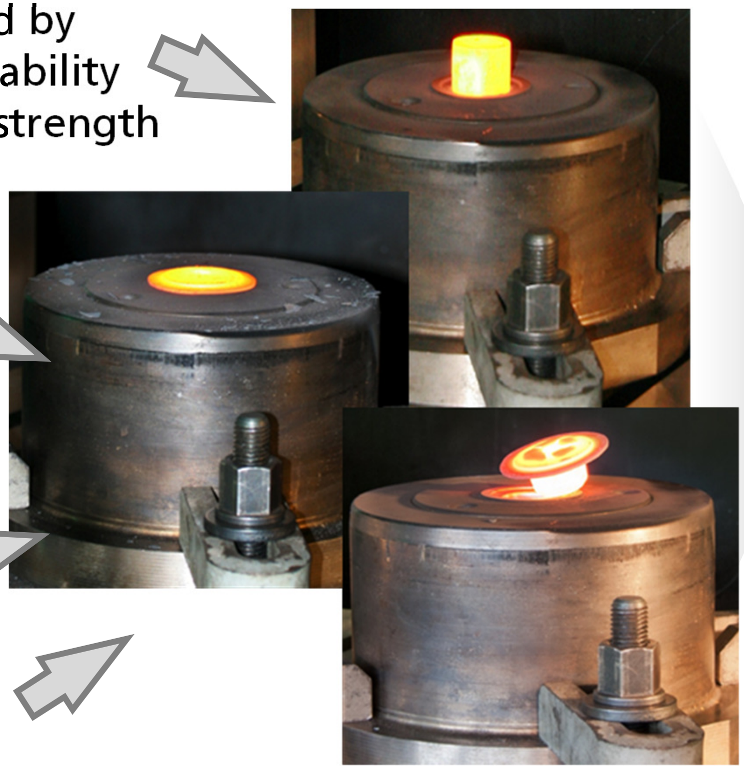
5 Industry 4.0 – Relevance for Forging Industry
Process Monitoring, Influencing and Control

Challenges

„New“ Materials
e. g. characterized by limited formability and/or high strength

Part Complexity ⇧

Part Quality ⇧
e. g. dimensional tolerances



Part Functionality ⇧
e. g. demands on microstructure

Increase of Efficiency
- **costs** ⇩
- **resource** use ⇩

e. g. minimization of
→ scrap
→ rework
→ try-out

monitoring / **sensing** strategy for **forging** processes

Fraunhofer IWU

5 Industry 4.0 – Relevance for Forging Industry
Process Monitoring, Influencing and Control

<u>Challenges</u>

➔ **information** about
- **current** forming **process**
- process **result** / forged **part**
  (e. g. dimensions, failures, etc.)
- tool **wear** / wear **development**

considering
➔ press
➔ tool
➔ part

- relevant **parameters**
  → description of process status
  → related to part quality
- suitable **sensors** for **data acquisition**
  → robustness/reliability
  → costs
  → maintenance
  → capability for industrial application
- **data processing**
  → derivation of information
  → basis for process control / closed-loop control

Fraunhofer IWU

X Industry 4.0 – Relevance for Forging Industry
Process Monitoring, Influencing and Control

Foci

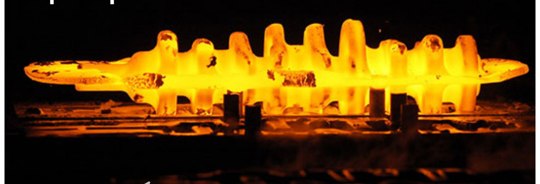
MACHINE
- **process parameters** (provided)
- **machine** / component **conditions**
  → predictive maintenance

SEMI-FINISHED PRODUCT
- **geometry** / dimensions
- **properties / microstructure** conditions
- **temperature** (heating process)

TOOLING
- **tool loading**
- **tool** / component **conditions**
- **wear** situation / development
  → predictive maintenance

NEED FOR ACTIVITIES
- identification of **relevant parameters** (related to process status / part quality)
- suitable **sensors** for **data acquisition** (robustness, reliability, costs, …)
- **data processing**

FORGED PART
- geometry / dimensions / quality features
- properties / microstructure



PROCESS
- **process parameters** (acting)
  → expected process result
- **process-related information**
  → basis for closed-loop control

5 Industry 4.0 – Relevance for Forging Industry
Process Monitoring

Measurement of Hot Forgings

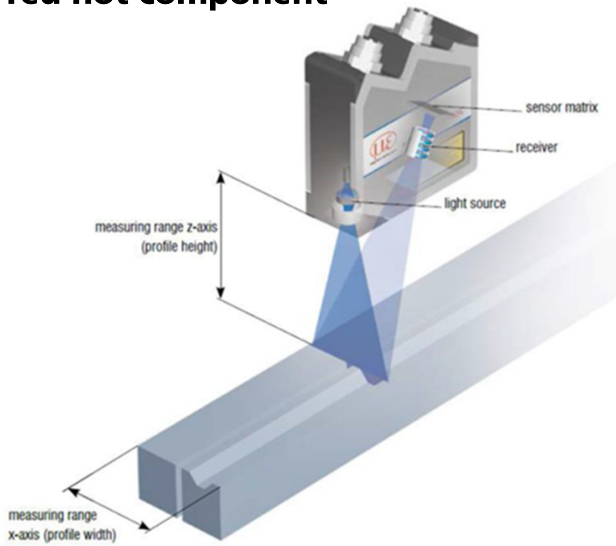
State-of-the-Art

- ➔ up to now
  three-dimensional measurements of **complex** formed **parts** / geometries
  - → **maximal ϑ ≈ 200 °C**
    (castings, forgings, moldings)
- ➔ "hot" parts and components
  - → laser measurement, particularly laser triangulation
    (bars, tubes, slabs, thick plates)
- ➔ **not existent**
  - → **three-dimensional measurement** of complex, **red-hot forgings** at forging-relevant temperatures
    (e. g. steel ϑ = 950…1250 °C)

Approach

- ➔ use of **blue laser light**
  - → red laser light on red-hot surfaces not detectable

Preliminary tests with blue laser on red-hot component

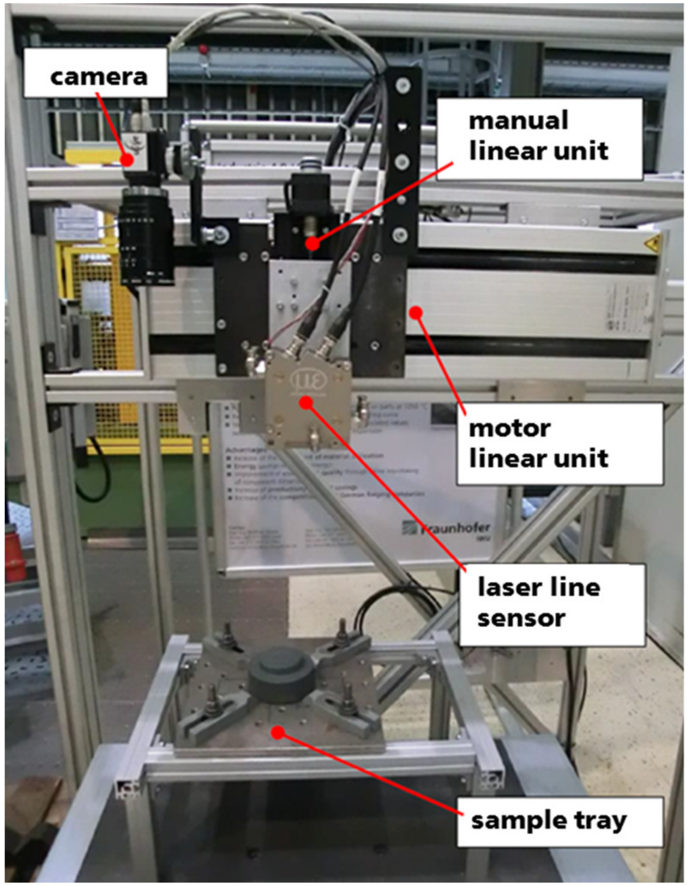


Principle of laser scan system

5 Industry 4.0 – Relevance for Forging Industry
Process Monitoring

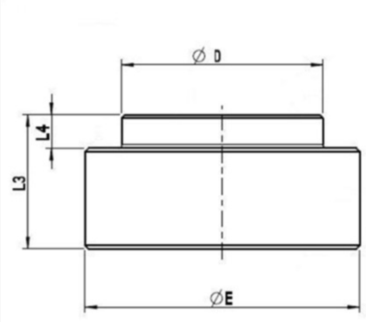
Measurement of Hot Forgings

Development of Methodology using Blue Laser
➔ detection of form and dimensional deviations



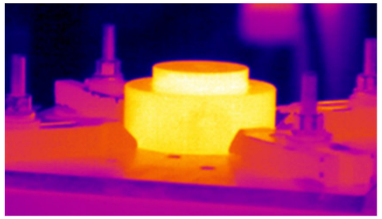
- conception and implementation of a **measuring station** for $\vartheta_{part\ max}$ > 1000 °C
- **sensor** coupled with **movement mechanism**
  → reduction of the thermal load caused by heat radiation

  nevertheless:
  additional **heat protection** measures for **scanner** and **camera**
- sample part made of Stellite
  → no scale formation up to ϑ > 1200 °C



	nominal value	tolerance
E	80mm	+1,2 / -0,6
D	51mm	+1,2 / -0,6
L3	40mm	+1,2 / -0,6
L4	10mm	+1,1 / -0,5

*) dimensional tolerances for steel forgings according to DIN EN 10243-1

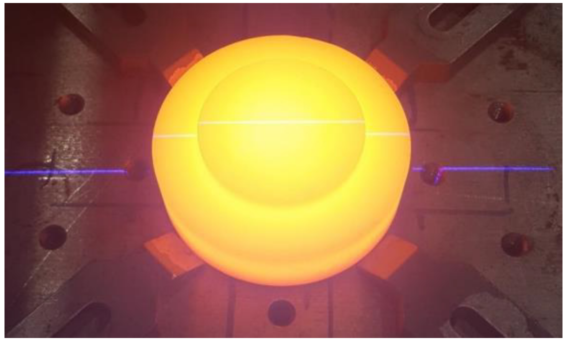


false-colour image taken with thermal camera (CMOS)

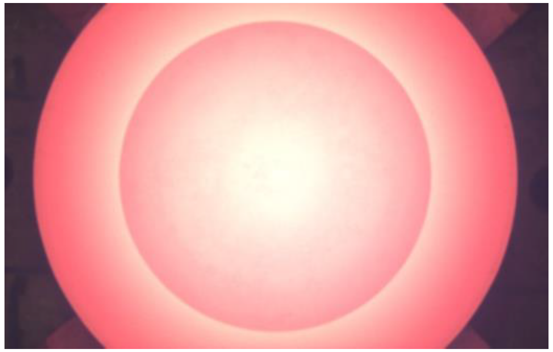
5 Industry 4.0 – Relevance for Forging Industry
Process Monitoring

Measurement of Hot Forgings

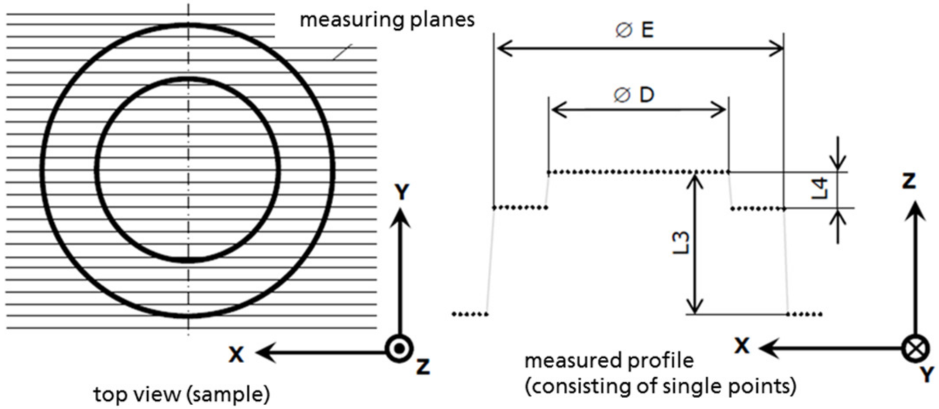
Development of Methodology using Blue Laser
➔ detection of form and dimensional deviations

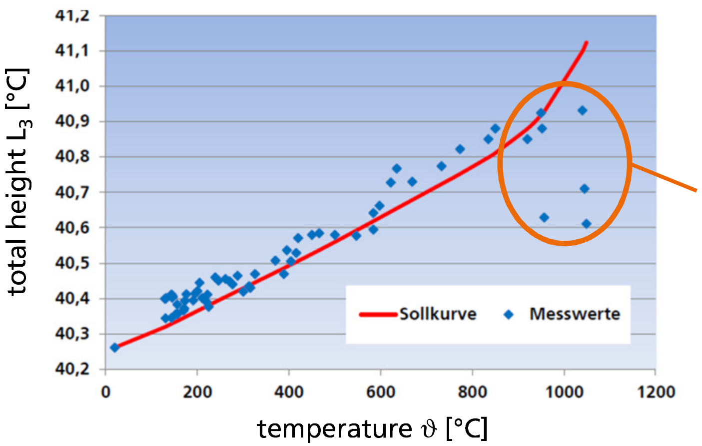


measurement with laser scanner



measurement with camera
with decreasing temperatures additional lighting required





influences of thermal streaks ?
- warming of environment
- gradient of refractive index

5 Industry 4.0 – Relevance for Forging Industry
Process Monitoring

Measurement of Hot Forgings

Conclusions (performed study)

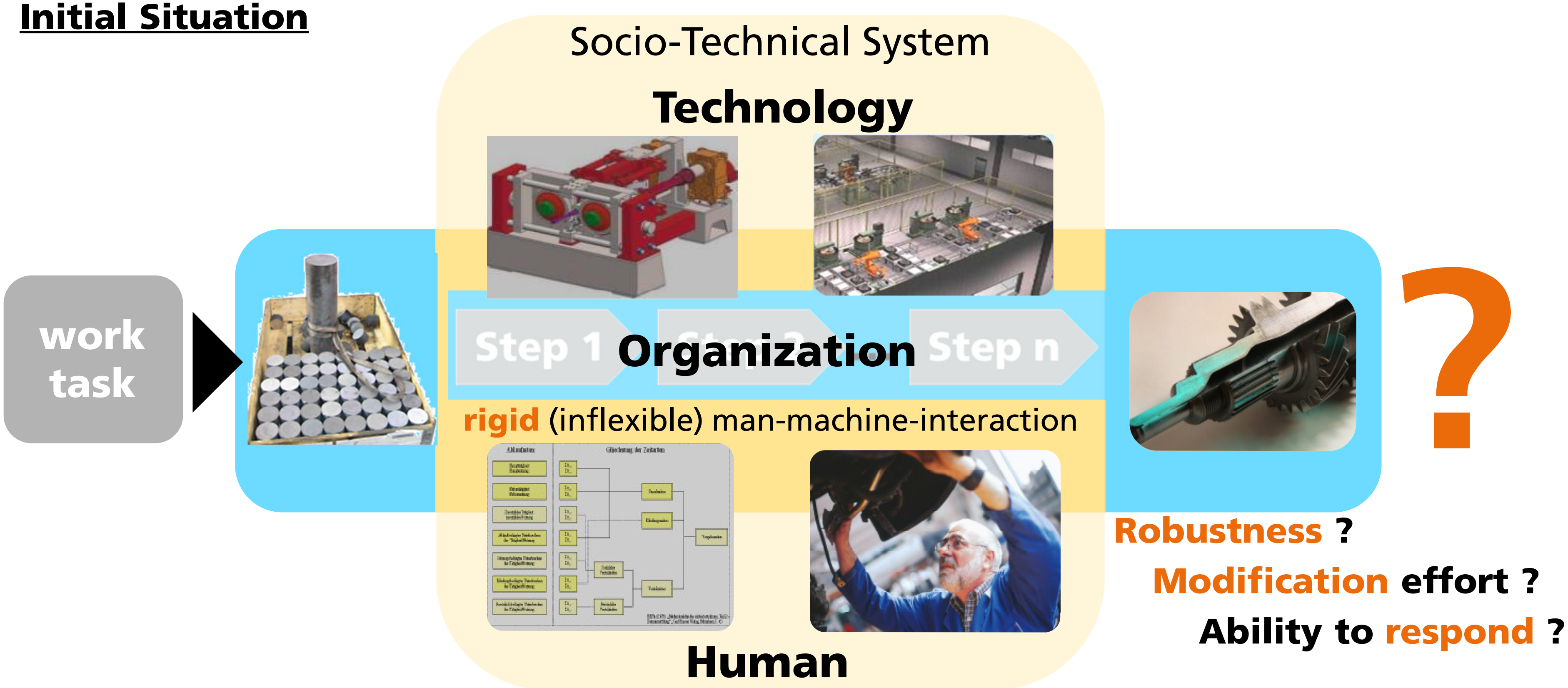
➔ scanner **systems** with **blue laser** **suitable** for measuring red-hot forgings (based on laser triangulation)

➔ **accuracy** requirements can be **guaranteed** within large temperature range
if $\vartheta > 950$ °C:
- occurrence of physical effects (generation of thermal streaks)
- influencing of measuring results
- minimization possible (based on suitable correction algorithm)

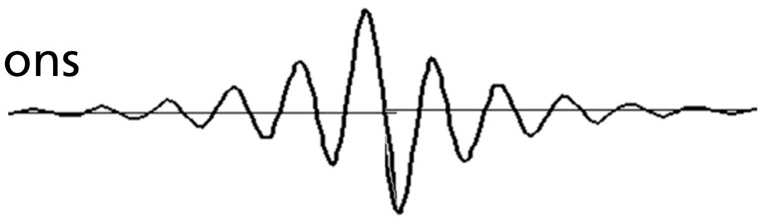
➔ Furthermore
→ **suitability** of **camera systems** for measuring of hot forgings **proven** (2D system was used in finished study)
→ next step: **evaluation** of **3D camera systems** regarding utilizability

5 Industry 4.0 – Relevance for Forging Industry
Intelligent, Flexible Manufacturing Structures

Initial Situation



disturbances, changing boundary conditions and demands…

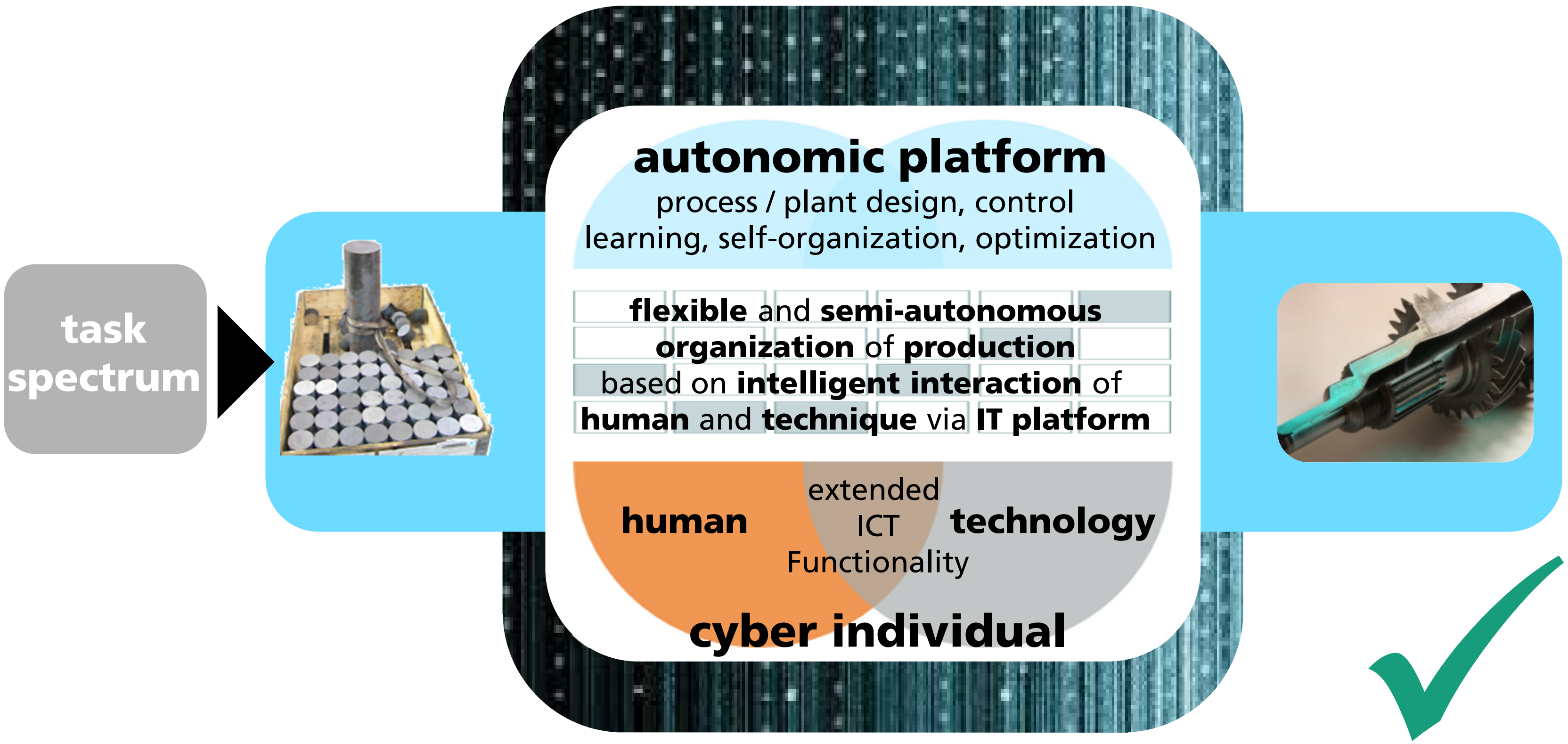


Fraunhofer IWU

5 Industry 4.0 – Relevance for Forging Industry
Intelligent, Flexible Manufacturing Structures

New Demand

decentralized adaption, partially autonomous



Fraunhofer IWU

5 Industry 4.0 – Relevance for Forging Industry
Intelligent, Flexible Manufacturing Structures

<u>Example: Process Route for Hollow Gearshafts</u> <u>(forming-based)</u>

Intelligent, **flexible**, **self-organizing processes** and **process chains**

<u>Challenges</u>

crosslinking, **monitoring**, **closed-loop control** of
- manufacturing process / systems
- logistic processes
- transport systems

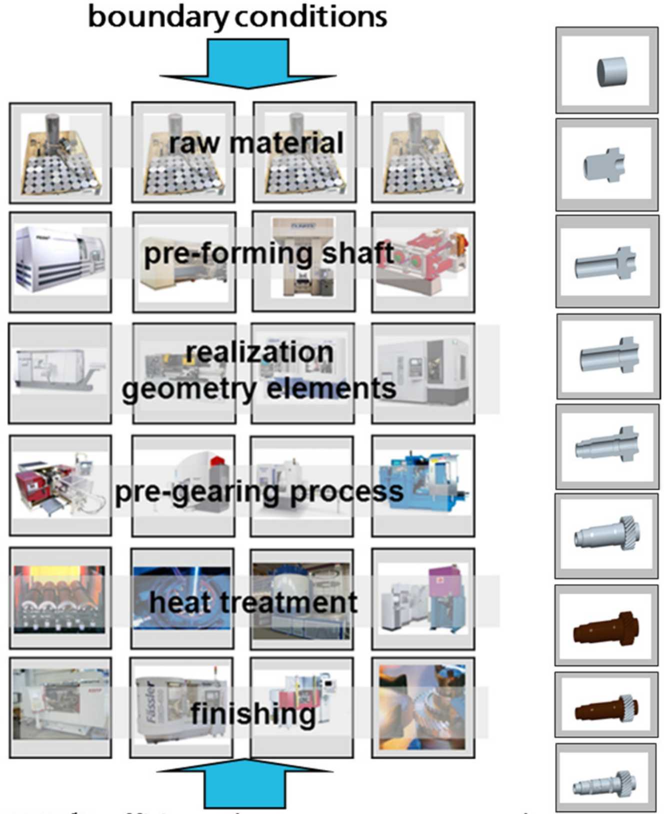
<u>Foci</u>

➔ „**qualification**" of **single steps** / entire **process route**

➔ development and adaption of **interfaces**, **monitoring** / **closed-loop control** strategies (data acquisition, transfer, processing)

➔ adaption / optimization of **work organization** / **process design**

➔ **proof of process capability**



Target: efficiency (costs, energy, resources), quality, part characteristics, lead time, load factor, …

5 Industry 4.0 – Relevance for Forging Industry
Intelligent, Flexible Manufacturing Structures

Future Implementation of Industry 4.0 Measures into Forging Industry (especially SMEs)

Barriers / Restraints

➔ **scepticism** about benefits (management, staff)
- limited human resources
- complex, hardly tangible topic
- measure implementation connected with effort

➔ **production condition** in forging plants

definition of **real objectives** accessible with **manageable effort** !

(considering local conditions)

i = "Industry 4.0" solutions developed by Fraunhofer IWU

Fraunhofer IWU