LIGHTWEIGHT forging

www.LIGHTWEIGHTforging.com

Phase III Hybrid Passenger Car (HEV) and Heavy-Duty Commercial Vehicle (HDV)

2017 – 2018
Automotive Lightweight Design with Forging

Lightweight Forging Initiative
Forging and Steel Industry

- Study of industrial lightweight design potential with 24 partners
  Phase I
  Passenger Car
  2013 – 2014

- Study of industrial lightweight design potential with 28 partners
  Phase II
  Light Commercial Vehicle
  2015 – 2016

- “Lightweight Forging” Research Network
  2015 – 2018

- Study of industrial lightweight design potential with 39 international partners
  Phase III
  Hybrid Car/conv. CV
  2017 – 2018
Automotive Lightweight Design with Forging

- **Phase I (2013 – 2014) – Medium-Sized Passenger Car**
  - 15 forging companies
  - 9 steel manufacturers
  - 42 kg of lightweight design potential

- **Phase II (2015 – 2016) – Light Commercial Vehicle (LCV, up to 3.5 t)**
  - 17 forging companies
  - 10 steel manufacturers
  - 1 engineering service provider
  - 99 kg of lightweight design potential

- **Phase III (2017 – 2018) – Hybrid Passenger Car and Heavy-Duty Vehicle**
  - 22 forging companies
  - 12 steel manufacturers
  - 3 machine manufacturers for forging machines
  - 2 automotive companies
  - International cooperation for the first time (Western Europe, USA, Japan)
  - 93 kg (HEV) und 124 kg (HDV) of lightweight design potential

  - 64 companies from the entire process chain,
    - 4 research associations and 10 research institutes
  - 6 subprojects
  - Goal: to render vehicles lighter using modern steel materials
    as well as through part design and production methods

► Significant reduction in energy consumption and CO₂ emissions through NEW lightweight solutions based on design and material concepts for forged components
Lightweight Forging...

-42 kg Phase I Passenger Car

-99 kg Phase II LCV

-93 kg Phase III Hybrid Passenger Car (HEV)

... in the Powertrain and Chassis
Lightweight Forging...

-124 kg Phase III Heavy-Duty Commercial Vehicle (HDV)

... in the Transmission, Propeller Shaft and Rear Axle
The Cooperation Partners of the Initiative
### Lightweight Research Projects – Public R&D and Metastudies

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Project Motivation: Hybrid Electric Vehicle

Emissions Legislation
- Reduction of CO₂ emissions to achieve the fleet targets → target of the EU by 2020: 95 g CO₂/km
- In order to fulfill global CO₂ legislation, a significant increase in efficiency is required
- Regulation of noise emission and time-dependent noise protection

Entry Restrictions
- Expansion of environmental zones
- Tightening of entry restrictions in cities

Weight Spiral
Increasing requirements:
- Safety [+kg]
- Comfort [+kg]
- Performance [+kg]
- Space [+kg]
- Variability [+kg]
- Quality [+kg]

- Increasing demands led to increasing vehicle mass
- Reversal of the weight spiral through lightweight design
- Suppliers can contribute manufacturing know-how (bottom-up approach)

Megatrends

Electromobility
- Potential for global CO₂ reduction
- Local emissions and noise reduction

Autonomous Driving
- Potential for improved fuel economy
- Potential for fewer accidents
- Reduction of time expenditure

Lightweight Design
- Reduction of fuel consumption
- Environmental protection and contribution to sustainability
- Reduction of resources
- Improved driving experience and increased safety
- Compensation of additional weight due to the electrical powertrain and of the effort involved in vehicle safety
- Payload increase
Emissions Legislation
- In order to fulfill the global CO₂ legislation, a significant increase in efficiency is required
- Emissions standards demand new technologies
- Regulation of noise emission and time-dependent noise protection

Cost Reduction
- In the commercial vehicle sector, TCO is the most important factor
- Innovation to reduce costs of acquisition and/or operating costs
- Lightweight design can increase transport capacity (payload)
- Autonomous driven vehicles could reduce personnel by up to 90%
Method:

Context Analysis
- Trends and drivers of the HEV industry
- Analysis of the developments in the powertrain
- Overview of public research

Benchmarking
- Systematic disassembly and documentation of a reference vehicle
- Generation of an online documentation tool for documentation and evaluation

Workshops
- Holding facilitated workshops on the powertrain and chassis with experts from the Initiative

and in addition…

1. Determining the Overall Vehicle Weight

Reference Vehicle: Compact SUV
- Hybrid drive system, System power: 145 kW (197 PS)
- Battery: 1.6 kWh
- Max. speed: 180 km/h
- Gross vehicle mass: 2,205 kg

2. Disassembly of the Entire Vehicle

ICE
Transmission
HV Battery

3. Listing and Naming all Individual Components

4. Component Analysis
Project Procedure: HEV – 2

...Transmission Modelling
- Transmission model
- Assessment of the influencing variables with the Institute of Product Engineering Karlsruhe (IPEK)
- Development of permissible steel alternatives
- Assessment of hard and soft influencing factors on transmission design

Deriving Lightweight Design Potential
- Identifying the lightweight design potential of forged components in the powertrain and chassis
- Implementation in the form of concrete lightweight design proposals

Documentation
- Accompanying PowerPoint presentation
- Implementation of an online database

5. Weight Distribution of the Assembly Groups

6. Photo Documentation

7. Database Implementation
Project Procedure: HDV – 1

Method:

Context Analysis
- Trends and drivers of the HDV industry
- Analysis of the developments in the powertrain
- Overview of public research

Benchmarking
- Systematic disassembly and documentation
- Generation of an online documentation tool for documentation and evaluation

Workshops
- Holding facilitated workshops on the transmission and powertrain with experts from the Initiative

1. Reference Sub-Systems
- Torque converter:
  - 12-speed transmission
  - 290.34 kg
- Rear axle with differential and propeller shaft:
  - 618.91 kg

2. Disassembly of the Sub-Systems

3. Listing and Naming all Individual Components

4. Component Analysis

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- Transmission model
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Deriving Lightweight Design Potential
- Identifying the lightweight design potential of forged components
- Implementation in the form of concrete lightweight design proposals

Documentation
- Accompanying PowerPoint presentation
- Implementation of an online database

5. Weight Distribution of the Sub-Systems
- Torque converter
- Differential and transfer transmission
- Drive shafts
- Longitudinal and lateral dynamics
- Brake system

6. Photo Documentation
- Gear constant drive 1
- Drive shaft 1

7. Database Implementation
Weight Distribution: HEV

Reference Vehicle: Compact SUV
- Hybrid drive system,
  System power: 145 kW (197 PS)
- Battery: 1.6 kWh
- Max. speed: 180 km/h
- Gross vehicle mass: 2,205 kg

Weight Distribution in Analyzed Vehicle Areas

**Powertrain**
- Internal combustion engine: 8%
- Torque converter: 15%
- Differential and transfer transmission: 26%
- Drive shafts: 26%
- Total: 51%

**Chassis**
- Front axle: 17%
- Rear axle: 27%
- Wheels and tyres: 26%
- Brake system: 24%
- Total: 97%

**Electronics**
- Low-voltage components: 3%
- High-voltage components: 97%
- Total: 99.00 kg

Analyzed Area:
- Powertrain
- Chassis
- Electronics
- Body, interior, electronics, etc.
Weight Distribution: HDV

Reference Sub-Systems:

- **Torque converter**
  - 12 gears
  - 290.34 kg

- **Rear suspension** (incl. propeller shaft)
  - 618.91 kg

![Pie chart showing weight distribution of HDV sub-systems]

**Weight Distribution of the Sub-Systems**

- **Torque converter**
  - Transmission housing: 26%
  - Speed conversion: 1%
  - Drive shafts: 2%
  - Output shafts: 9%
  - Gear change system: 53%
  - Oil supply: 1%
  - Sensors and actuators: 9%
  - Total: 290.34 kg

- **Rear suspension**
  - Differential and transfer transmission: 12%
  - Drive shafts: 47%
  - Rear suspension: 17%
  - Brake system: 12%
  - Total: 618.91 kg
Workshop Overview

- Workshops with 80 experts from 39 companies
- Analysis of 4,067 components from the entire HEV and HDV sub-systems
- Formulation of 983 lightweighting ideas in total, which can be sub-divided into various lightweighting categories
- Main documentation in the benchmarking database

Impressions from the workshops
Evaluation of the Lightweighting Ideas

- **Lightweighting through materials**
  - HEV: 402
  - HDV: 129

- **Lightweighting through design**
  - HEV: 304
  - HDV: 121

- **Lightweighting through manufacturing**
  - HEV: 244
  - HDV: 53

- **Conceptual lightweight design**
  - HEV: 15
  - HDV: 1

*Total Lightweighting ideas = 983*

- **HEV = 732**
- **HDV = 251**

*Lightweight design ideas can often be assigned to various lightweighting categories. The use of a new material may lead to an adapted manufacturing process, for example.*
Portfolio Charts of the Lightweighting Ideas

HEV

Optimum

Group A
"Quick wins"
107 ideas

Group B
"Balanced lightweighting potential"
130 ideas

Group C
"Tough Nuts"
496 ideas

Higher — Manufacturing and Implementation Effort — Lower

HDV

Optimum

Group A
"Quick wins"
18 ideas

Group B
"Balanced lightweighting potential"
20 ideas

Group C
"Tough Nuts"
205 ideas

Higher — Manufacturing and Implementation Effort — Lower

The blue circles show the number of ideas in this point.

Source: fka for Phase III of The Lightweight Forging Initiative
Portfolio Evaluation

HEV

- Reference mass: 816 kg
- Lightweight variant: 724 kg
- Mass reduction: -11.3% (-93 kg)

HDV

- Reference mass: 909 kg
- Lightweight variant: 786 kg
- Mass reduction: -13.6% (-124 kg)

Source: fka for Phase III of The Lightweight Forging Initiative
Selected Lightweighting Proposals

Combustion Engine

1. Conrod
   - **Series**
     - 23MnV53
     - \( m = 572 \text{ g} \)
   - **Lightweighting Proposals**
     - Reduction in cross section of conrod shaft
     - 46MnV55: \( \Delta m = 51 \text{ g} \) (10%)
     - 16MnCrV7-7: \( \Delta m = -75 \text{ g} \) (~15%)

2. Camshaft
   - **Series**
     - Cast solid shaft
     - \( m = 2,400 \text{ g} \)
   - **Lightweighting Proposal**
     - Forming from steel tube with internal pressure
     - \( \Delta m = 1,800 \text{ g} \) (400%)

3. Crankshaft
   - **Series**
   - **Lightweighting Proposals**
     - Material proposals \( \Rightarrow \) estimated \( \Delta m = 1,700 \text{ g} \) (11%
       - SolamB1100
       - Higher strength 46MnV55
       - 46MnV56 or bainite
       - Microalloyed C50
       - Reduced sulphur content
     - Design proposal \( \Rightarrow \) \( \Delta m = 5,100 \text{ g} \) (42%)
       - Forged single parts with pockets or cavities
       - Joined by laser welding using means of hollow bearing pins

Sources: 1 = Georgsmarienhütte, Schmiedetechnik Plettenberg; 2 = Yamanaka Engineering; 3 = ArcelorMittal, Georgsmarienhütte, Saarstahl, Sidenor, TimkenSteel, Trumpf
Selected Lightweighting Proposals

Front Electric Motor and Powertrain

4. Rotor Shaft
- Series
  - Two-part solution: with central shaft press fit into outer part
  - \( m = 3,180 \text{ g} \)
- Lightweighting Proposal
  - Two-part solution
  - Right bearing flange: laser welding or shrinking
  - \( \Delta m = 701 \text{ g} \) (29%)

5. Tripods
- Series
  - Circular on the outside
  - \( m = 957 \text{ g} \)
- Lightweighting Proposal
  - Forged contour on the outside
  - 50CrMnB5-3 (H50)
  - \( \Delta m = 156 \text{ g} \) (19%)

6. Drive Shaft
- Series
  - Machined from bar
  - \( m = 2,160 \text{ g} \)
- Lightweighting Proposal
  - Swaged from tube
  - Spline axially forged
  - Resource-efficient manufacturing
  - Variable wall thicknesses can be produced without machining
  - Internal undercut
  - \( \Delta m = 860 \text{ g} \) (66%)

Sources: 4 = Hirschvogel; 5 = Georgsmarienhütte, Hirschvogel; 6 = Felss
Selected Lightweighting Proposals

Powertrain

7. Differential

Series
- Conventional cast housing
- 4-wheel differential
- \( m = 6,600 \text{ g} \)

Lightweighting Proposal
- 6-wheel differential
- More compact design
- Welded housing
- \( \Delta m = 3,630 \text{ g (122\%) } \)

9. Material for Gears

- Influence of steel cleanliness on fatigue
- Oxidic inclusions, in particular, impair performance
- \( \Delta m = 10 \text{ – 30\%, depending on load case of components and previous cleanliness level} \)

8. Input Wheel

Series
- Conventional round wheel, machined on all sides
- \( m = 1,381 \text{ g} \)

Lightweighting Proposal
- Variable wall thickness below the teeth
- Contoured piercing
- 16MnCrV7-7 (H2):
  - Hardenability ↑ → Tooth width ↓
- \( \Delta m = 353 \text{ g (34\%) } \)

10. Differential

Series

Lightweighting Proposal
- Switch from bolts to laser welding
- Avoids double material layers
- \( \Delta m = \sim 1,000 \text{ g (~13\%) } \)

Sources: 7 = AAM Metal Forming; 8 = Hirschvogel, Georgsmarienhütte; 9 = TimkenSteel; 10 = Trumpf
Selected Lightweighting Proposals

Chassis – 1

11. Steering Rack

Series
- Solid bar
- Teeth produced by machining and induction hardening
- $m = 2,611 \text{ g}$

Lightweighting Proposal
- Production from tube
- Forging of teeth with toothed punch and mandrel
- $\Delta m = 1,338 \text{ g (95\%)}$

12. Wheel Hub

Series
- Induction hardened steel
- $m = 1,637 \text{ g}$

Lightweighting Proposal A
- Contoured shape, not round
- Stiffness-increasing structures
- $\Delta m = 436 \text{ g (36\%)}$

Lightweighting Proposal B
- Direct connection of brake disc to wheel hub
- No hat shape on brake disc
- $\Delta m \approx 400 \text{ g (+ lighter brake disc)}$

Sources: 11 = Yamanaka Engineering; 12 = Linamar Seissenschmidt Forging (A), Hirschvogel (B)
Selected Lightweighting Proposals

Chassis – 2

13. Stabilizer

**Series**
- Tube with constant wall thickness
- \( m = 3,880 \text{ g} \)

**Lightweighting Proposal**
- Tube with variable wall thickness
- Increased thickness in corners
- \( \Delta m = 1,550 \text{ g (66.5 \%)} \)

15. Damper Strut Bearing

**Series**
- Part comprising several steel sheets, joined with rubber bearing
- \( m = 960 \text{ g} \)

**Lightweighting Proposal**
- Aluminium forging
- Crimped rubber bearing
- \( \Delta m = 200 \text{ g (25 \%)} \)

14. Steering Knuckle

**Series**
- Cast iron
- \( m = 5,060 \text{ g} \)

**Lightweighting Proposal**
- Forged aluminium
- \( \text{YS} = 350 \text{ MPa}, \text{TS} = 390 \text{ MPa} \)
- \( \Delta m = 3,320 \text{ g (191 \%)} \)

16. Rear Transverse Strut

**Series**
- Welded design from deep-drawn sheet metal and stamped-bent parts
- \( m = 3,080 \text{ g} \)

**Lightweighting Proposal**
- Aluminium forging
- (here still in simplified form)
- Stiffness in longitudinal direction +4 \%
- \( \Delta m = 310 \text{ g (11 \%)} \)

Sources: 13 = BENTELER; 14 = Hirschvogel, Lasco, Leiber, Nissan, Schuler, Setforge; 15 = Leiber, Schuler, Hirschvogel (image); 16 = Hirschvogel
Selected Lightweighting Proposals

Lightweight Potential in the Heavy-Duty Vehicle

17. Brake Carrier: Rear Axle

- Series
  - Forging
  - $m = 10,320 \text{ g}$

- Lightweighting Proposal
  - Forging with filigree structures and piercings
  - $\Delta m = 2,320 \text{ g (29\%)}$

18. Connecting Flange: Propeller Shaft

- Series
  - Series mass
  - $m = 4,000 \text{ g}$

- Lightweighting Proposal
  - Remove material in areas subjected to less load
  - $\Delta m = 420 \text{ g (11.7\%)}$

19. Countershaft Transmission

- Series
  - Solid shaft
  - $m = 23,990 \text{ g}$

- Lightweighting Proposal
  - Swaged hollow shaft starting from tube
  - $\Delta m = 6,540 \text{ g (37.5\%)}$

20. Fasteners

- Series
  - M12

- Lightweighting Proposal
  - Downsizing by strength class 15.9U
  - Lightweight head
  - $\Delta m_{HV} = 5,600 \text{ g}$
  - $\Delta m_{HDV} = 1,600 \text{ g}$

Sources: 17 = Hammerwerk Fridingen; 18 = Buderus Edelstahl; 19 = Linamar Seissenschmidt Forging; 20 = Kamax
Wide Spectrum of Quality and Special Steels –
Steels with High-Strength and High Toughness

- Steel variety leads to application-oriented part design
- Combination of high strength and high toughness leads to lightweighting through materials
- Material family trees enable targeted product-based material selection
Microstructure-dependent strength and toughness of steel bar

- **Martensitic Steel**
  - quenched and tempered (Q+T)
  - Transmission electron microscopy
  - Scanning electron microscopy

- **Bainitic Steel**
  - Cooling from the forging heat

- **Precipitation Hardening Steel + Microalloying**
  - Cooling from the forging heat

**Notch Impact Toughness** vs. **Tensile Strength**

- Light optical microscopy
Material Family Tree “High-Strength Special Steels”*

*Reference values, Ø 20 – 80 mm

Properties achieved by
- Conventional quenching and tempering (Q+T)
- Quenching and tempering directly from the forging heat (Q+T)
- Controlled cooling from the forging heat (AFP/bainite)

Notch Impact Toughness in the Core [J]

Tensile Strength in the Core [MPa]
Material Family Tree “Case-Hardening Steels”*

*Reference values, Ø 35 mm

- 18CrMo4: 1.7243 / 4120
- 20NiCrMo6-5: 1.6757
- 14NiCr18: 1.5860
- 20NiCrMo2-2: 1.6523 / 8620
- 20CrMo3-5: 1.7333
- 20NiCrMoS6-4: 1.6751 / 4320
- 16MnCr5: 1.7168
- 21MnCrMo5: 1.7264
- 21MnCr5: 1.7147 / 5120
- 20CrMo5: 1.7264 / SCM420H
- 18CrNiMo7-6: 1.6587 / 4320H
- 18CrNi8: 1.5920
- 16MnCrV7-7: 1.8195

Direct hardening process:
- Hardening: approx. 920 °C for 40 min.
- Tempering: approx. 200 °C for 2 h
Material Family Tree “Quenched and Tempered Steels”*

*Reference values

**Tensile Strength in Q+T State [MPa]**

- **30CrMoV9** 1.7707
- **30CrNiMo8** 1.6580 / E4340
- **32MnCrMo6-4-3** 1.7910
- **34CrNiMo6** 1.6582 / 4340
- **42CrMo4** 1.7225 / 4140 / SCM440RCH
- **51CrV4** 1.8157 / 6150
- **8CrMo16** 1.8524

**Hardening Depth [mm]** (Jominy value at which hardness has gone down by 5 HRC compared to J 1.5)

- **37Cr4** 1.7034 / 5135 / Scr440
- **41Cr4** 1.7035 / 5140 / Scr440
- **34CrMo4** 1.7220 / 4137 / SCM435RCH
- **25CrMo4** 1.7218 / 4130 / SCM430RCH
- **C45E** 1.1191 / 1045 / S48C
- **C35E** 1.1181 / 1035 / S38C
- **38Cr2** 1.7003 / 1541H

**Q+T Process**

- **Forging**
- **Hardening**
- **Tempering**
- **Straightening**
- **Stress-relief annealing**
Lightweighting with High-Strength Steels

1. Drive Shaft Differential

Series
- Case-hardening steel SCR420H
  - m = 1,182 g

Potential
- High-strength case-hardening steel 16MnCrV7-7 (H2) and improved manufacturing enable reduction in cross section
  - m = 875 g
  - Δm = 307 g (35%)

2. Shock Absorber

Series
- Steel tube e.g. E235 (1.0308)
  - Wall thickness 2.8 mm
  - m = 1,054 g

Potential
- High-strength tube FB590
  - Wall thickness 2.0 mm
  - m = 804 g
  - Δm = 250 g (31%)

3. Wheel Carrier: Front Left

Series
- Cast iron (TS = 400 – 600 MPa)
  - m = 5,060 g

Potential
- Steel forging made of ferritic-pearlitic or bainitic steel
  - TS = 1,100 MPa
  - m = 4,100 g
  - Δm = 960 g (23%)

4. Conrod

Series
- 23MnVS3
  - m = 572 g

Potential
- High-strength steel 36/46MnVS6Mod → Δm = 35%
- Other high-strength steels:
  - 27/30/38 MnVS6 or similar; 16MnCrV7-7, S40C + P

Sources: 1 = Hirschvogel, Georgsmarienhütte; 2 = BENTELER; 3 = ArcelorMittal; 4 = TimkenSteel, Nissan Motor, Deutsche Edelstahlwerke, Nippon Steel & Sumitomo Metal, Schmiedetechnik Plettenberg, Georgsmarienhütte, Saarstahl, ArcelorMittal
Lightweighting Potential of High-Performance Steels

Software Tool

- Vehicle Parameters
  - Speed
  - Torque
  - Transmission design
  - Component connections

- Manufacturing Process

- Material Data
  - Yield strength
  - Torsional stiffness
  - Surface pressure
  - Surface hardness
  - Young’s modulus
  - Poisson’s ratio
  - ... 

- Material Properties

- Software-Tool
  - Shafts
  - Bearings
  - Gears
  - Synchro.
  - Tooth root strength
  - Pitting resistance
  - Cylindrical interference fit
  - Torsional and bending strength

- Housing

- Mass
- Inertia
- Assembly space

- Dimensioning of the shafts according to DIN 743
- Dimensioning of the gears according to DIN 3990
- Dimensioning of the planetary gear according to VDI 2157
- Dimensioning of cylindrical interference fit according to DIN 7190

Source: Institute of Product Engineering Karlsruhe (IPEK)
Lightweighting Potential of High-Performance Steels

Software Tool

- Development of a model for rough design/calculation of transmission design and mass
- Model created and verified for:
  - e-hybrid CVT, SCr420H, SCM420H (similar to 25CrMo4)
  - 12-speed truck transmission, 25MoCrS4, 30MnSiV6, 20MoCrS4
- Evaluation of the influencing variables of the material characteristics for transmission dimensioning
- Examination of the real influences of high-strength steels
- Evaluation of the “soft influencing factors” from the transmission standard ISO 6336, Part 5

Source: Institute of Product Engineering Karlsruhe (IPEK)
Software Tool: e-hybrid CVT

<table>
<thead>
<tr>
<th>Dimension gear wheels</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>( \varphi_{\text{w}} )</td>
<td>Permitted pitting resistance</td>
</tr>
<tr>
<td>( \varphi_{\text{t}} )</td>
<td>Permitted tooth strength</td>
</tr>
<tr>
<td>( \varphi_{\text{f}} )</td>
<td>Permitted fatigue strength</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dimension gear shafts</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>( \tau_{\text{w}} )</td>
<td>Permitted shearing torsional tension</td>
</tr>
<tr>
<td>( \tau_{\text{f}} )</td>
<td>Permitted bending fatigue strength</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Engine parameters</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Power combustion engine</td>
<td>114 kW</td>
</tr>
<tr>
<td>Power electric engine</td>
<td>105 kW</td>
</tr>
<tr>
<td>Input torque: petrol engine</td>
<td>265 Nm</td>
</tr>
<tr>
<td>Input torque: electric engine</td>
<td>125 Nm</td>
</tr>
<tr>
<td>Input speed at maximum power of the combustion engine</td>
<td>1250 rpm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total weight of the gear box</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight of the reference gear box</td>
<td>104 kg</td>
</tr>
<tr>
<td>Weight of the optimized gear box</td>
<td>94 kg</td>
</tr>
<tr>
<td>Weight saving in %</td>
<td>10%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Inertia of the shafts and gear wheels</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Inertia of the reference gear box</td>
<td>0.0210 kg·m²</td>
</tr>
<tr>
<td>Inertia of the optimized gear box</td>
<td>0.0200 kg·m²</td>
</tr>
<tr>
<td>Inertia saving in %</td>
<td>5%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Shaft length</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>V001-shaft</td>
<td>113 mm</td>
</tr>
<tr>
<td>M011-shaft</td>
<td>103 mm</td>
</tr>
<tr>
<td>M021-shaft</td>
<td>103 mm</td>
</tr>
<tr>
<td>M021-shaft outside</td>
<td>103 mm</td>
</tr>
<tr>
<td>Hollow wheel shaft</td>
<td>143 mm</td>
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<tr>
<td>Intermediate shaft</td>
<td>163 mm</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Gear wheel width</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference gear box</td>
<td>100 mm</td>
</tr>
<tr>
<td>Optimized gear box</td>
<td>95 mm</td>
</tr>
<tr>
<td>Width savings</td>
<td>5 mm</td>
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</table>

<table>
<thead>
<tr>
<th>Gear wheel mass</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference gear box</td>
<td>1.05 kg</td>
</tr>
<tr>
<td>Optimized gear box</td>
<td>1.00 kg</td>
</tr>
<tr>
<td>Mass savings</td>
<td>0.05 kg</td>
</tr>
</tbody>
</table>

Source: Institute of Product Engineering Karlsruhe (IPEK)
IPEK Transmission Study – Rear Axle Transmission

**Material Strength**

**Change in weight depending on material properties**

**Change in dimension depending on material properties**

<table>
<thead>
<tr>
<th>Tooth flank strength/MPa</th>
<th>Tooth root strength/MPa</th>
<th>Pulsating torsional strength/MPa</th>
<th>Bending fatigue strength/MPa</th>
<th>Δ Weight/g</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,500 → 1,800</td>
<td>1,000</td>
<td>270</td>
<td>450</td>
<td>129</td>
</tr>
<tr>
<td>1,500 → 1,800</td>
<td>1,000 → 1,200</td>
<td>270</td>
<td>450</td>
<td>-1,216</td>
</tr>
<tr>
<td>1,500 → 1,800</td>
<td>1,000 → 1,200</td>
<td>270 → 324</td>
<td>450</td>
<td>-1,722</td>
</tr>
<tr>
<td>1,500 → 1,800</td>
<td>1,000 → 1,200</td>
<td>270 → 324</td>
<td>450 → 450</td>
<td>-1,875</td>
</tr>
</tbody>
</table>

Source: Institute of Product Engineering Karlsruhe (IPEK)
Functional Layout of the HDV Transmission

Source: Institute of Product Engineering Karlsruhe (IPEK)
Software Tool: HDV Transmission

Source: Institute of Product Engineering Karlsruhe (IPEK)
Results

- Through optimization of the material properties by 10%, the lightweight potential could be:
  - up to approx. 3.5 kg for the e-hybrid CVT
  - up to approx. 17 kg for the 12-speed truck transmission

- The model also shows that:
  a further increase in the material strength
  of the gear wheels and shafts
  may lead to additional weight savings
The “Lightweight Forging” Research Network

The Research Network entitled “Lightweight Forging – Innovation Network for Technological Progress in Part, Process and Material Design for Forged Parts in Automotive Technology” was generated from the idea competition “Leading Technologies for SMEs” held by the Industrial Collective Research program (IGF) of the Federal Ministry for Economic Affairs and Energy (BMWi) via the German Federation of Industrial Research Associations (AiF).

Goal: To use new steel materials, part designs and production methods to also make the car powertrain – from the engine to the transmission and wheel bearings – even lighter, while still fulfilling the stringent requirements with regard to service life.
Multi-Component Gearwheels

Material
- 18CrNiMo7-6
- Fully machined solid body
- Turned

Geometry
- 0 %
- 794 Nm* / 889 Nm**

Production process

Weight reduction

Torque (static)

- -25 %
- 192 Nm*
- 333 Nm*

Material
- DC04 (sheet metal)
- Lightweight structure
- Deep-drawn

Geometry

- -44.5 %
- 433 Nm**

Production process

Weight reduction

Torque (static)

- -30.5 %
- 627 Nm* / 776 Nm**

Material
- 18CrNiMo7-6
- Circumferential groove
- Turned/milled

Geometry

- -25 %
- 192 Nm*
- 333 Nm*

Production process

Weight reduction

Torque (static)

- -30 %
- 1,200 Nm

*Joined during quenching / **Joined during tempering
The Research Associations

The Research Network has been financed since 01.05.2015 and will continue to be financed until 31.10.2019...

Research Association for Steel Application (Forschungsvereinigung Stahlanwendung e.V. – FOSTA), which serves as the lead institution

Heat Treatment and Material Engineering Association (Arbeitsgemeinschaft Wärmebehandlung und Werkstofftechnik e.V. – AWT), Bremen

Research Association for Drive Technology (Forschungsvereinigung Antriebstechnik e.V. – FVA), Frankfurt

Research Association of Steel Forming (Forschungsgesellschaft Stahlverformung e.V. – FSV), Hagen

...from funds of the Federal Ministry for Economic Affairs and Energy (Bundesministerium für Wirtschaft und Energie – BMWi) via the German Federation of Industrial Research Associations (Arbeitsgemeinschaft industrieller Forschungsvereinigungen “Otto von Guericke” e.V. – AiF).

Building on the results from Phase I and II, further lightweighting potential is expected in approx. two years. Additional results can only be ensured by scientifically verifying the dynamic load of the new materials from the five research projects that commenced in May 2015. The Lightweight Forging Initiative expects that new weight optimization possibilities shall emerge from the Research Network.
Transfer of Findings

- Current information at www.LIGHTWEIGHTforging.com
- Publications
- Presentation events and exhibitions
- “Lightweight Forging” TechDays at automotive companies and system suppliers

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