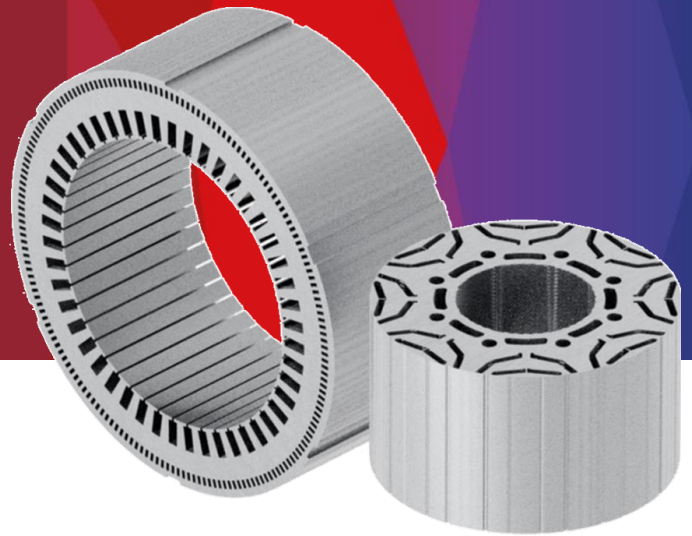

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# Optimization of laminated stacks for electric motors in electrified vehicles

Francis van der Sluis, Benny Seitzinger, Emile Kruijswijk, Sander de Vet, Oleg Alexandrov, Andreas Herzberger

Bosch Transmission Technology / Robert Bosch

CWIEME BERLIN
14-16 MAY 2024
MESSE BERLIN

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# Optimization of laminated stacks for electric motors in (H)EV

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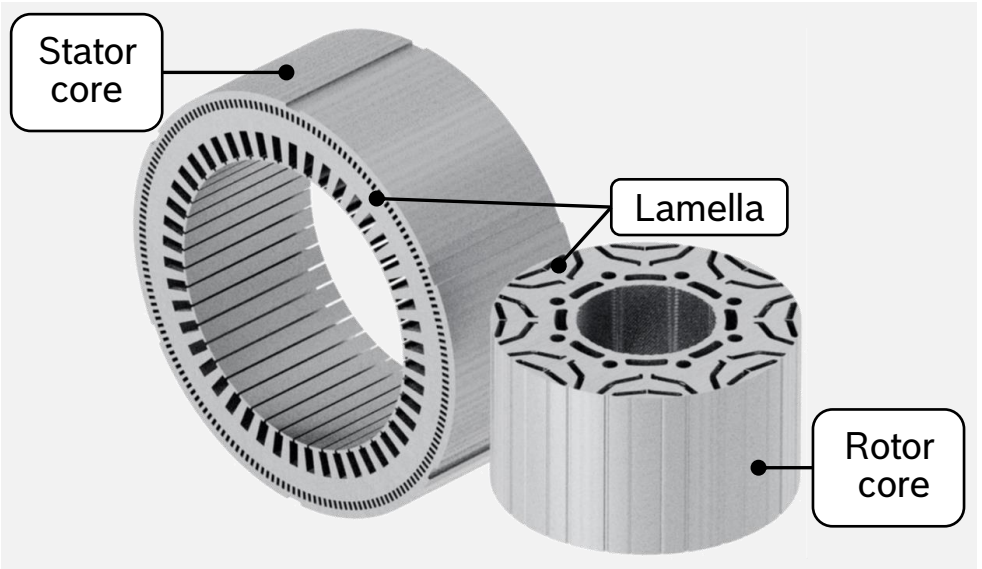
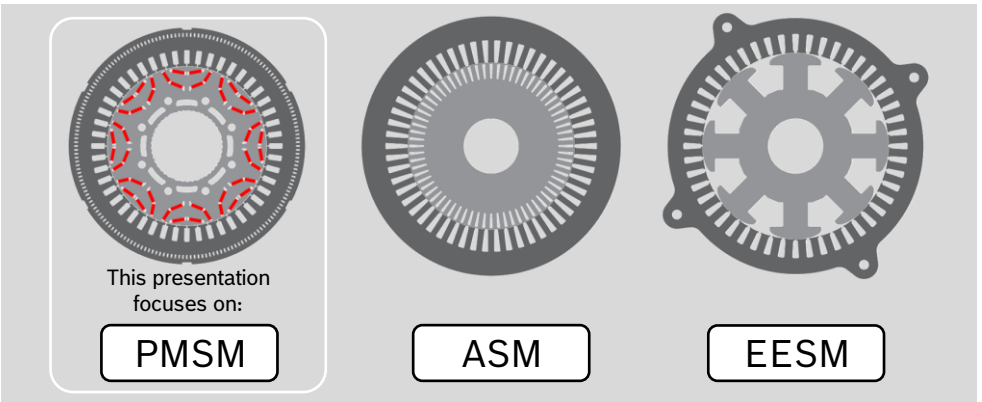
## Content

- Introduction
  - Market & KPI
  - Effect of stress
- Adapted process chain
  - Main processes (annealing & gluing)
  - Further processes
  - Benefits
- Some test results
- Conclusions




KPI = Key Performance Indicator, PMSM = Permanent Magnet Synchronous Machine, ASM = ASynchronous Machine, EESM = External/Electrically Excited Synchronous Machine

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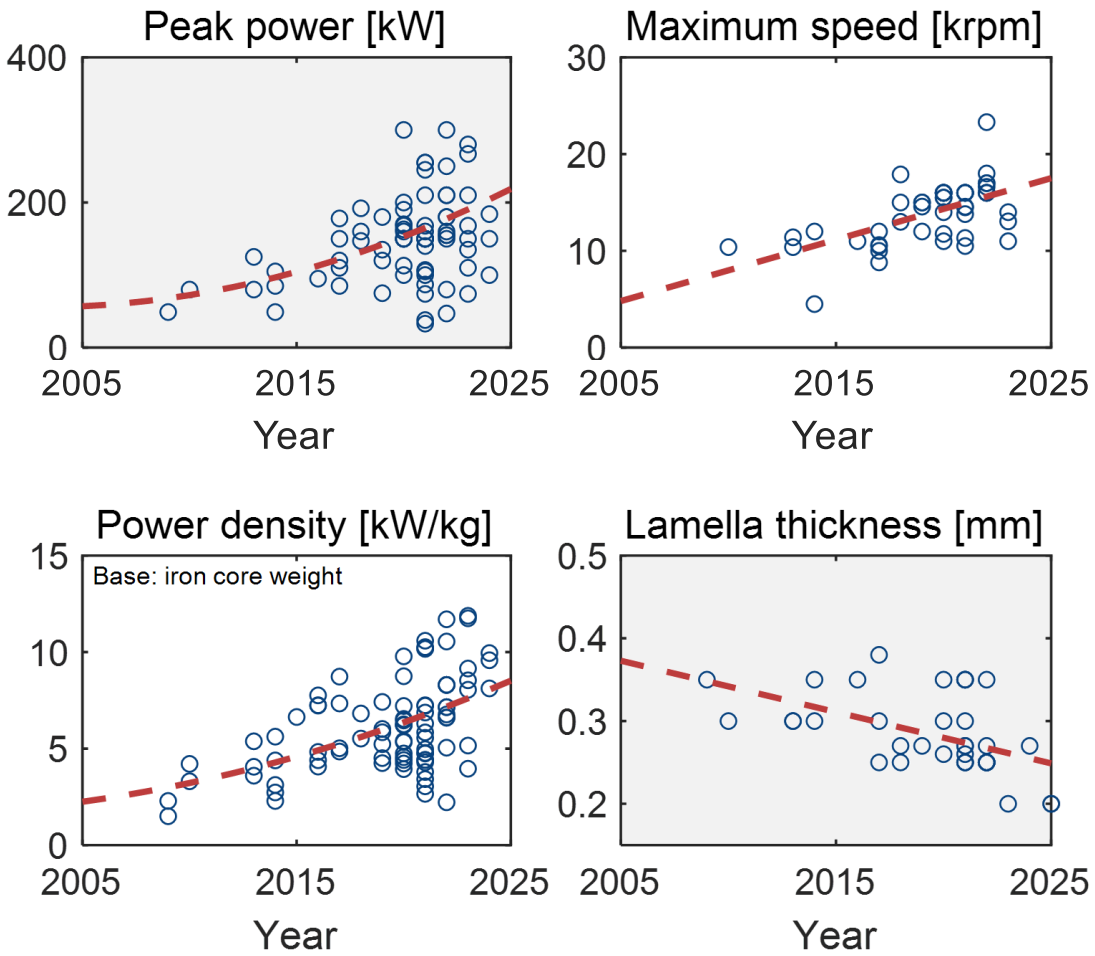
## KPI Trends

- (H)EV motor
  - Power density
  - Efficiency
  - Cost
- Laminated stack
  - Power loss
  - Flux density
  - Size and weight
  - Material and value-add




KPI = Key Performance Indicator, Results based on market data for PMSM applications, (H)EV = (Hybrid) Electric Vehicle

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## KPI Improvement

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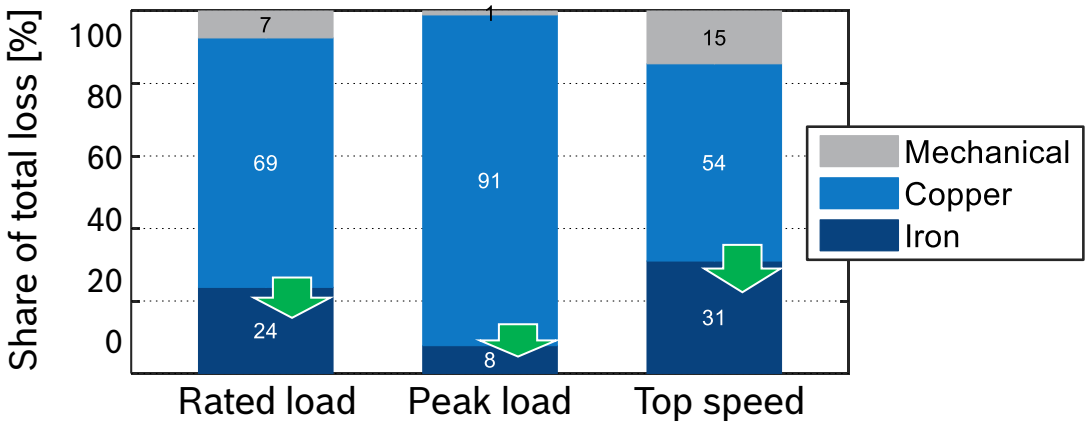
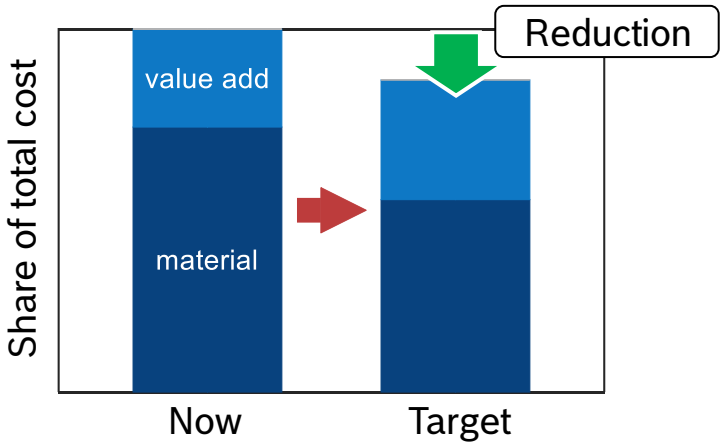
- Target: optimize geometric and material properties
  - Power density – Improve magnetic & mechanical material properties
  - Power loss – Reduce iron loss
  - Cost – Reduce material share

### Loss distribution PMSM




### Cost distribution of stack



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# Optimization of laminated stacks for electric motors in (H)EV

## Effect of Stress

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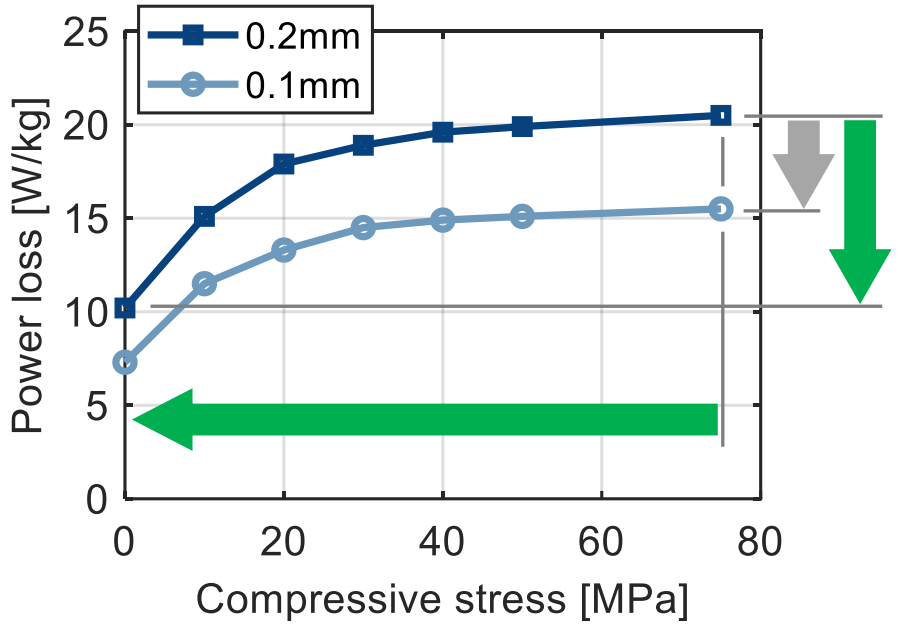
- Stress affects power loss
- Compressive stress is introduced by:
  - Stack manufacturing (blanking, interlocking, welding)
  - Motor assembly (winding, shrink-fit, bolting)

**The reduction of stress decreases power losses**

- Thin lamellae also reduce power loss but the effect can be smaller while cost is higher

Effect of stress on power loss*




* Source: Electronics and Communications in Japan, Vol. 99, No. 12, 2016, Y. Oda et al., Effect of compressive stress on iron loss. Depicted: loss at B=1T, f=400Hz

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# Optimization of laminated stacks for electric motors in (H)EV

## Manufacturing Processes and Residual Stress

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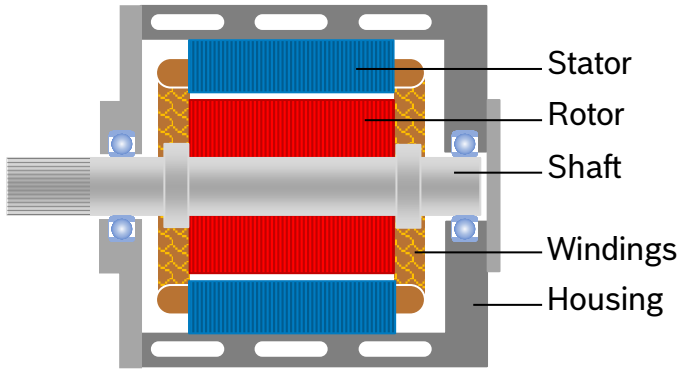
- Stress increase
  - Blanking
  - Interlocking
  - Welding
- Stress relief/neutral
  - Annealing
  - Gluing

| EV traction application | Motor type | Lamella process & thickness [mm] | Lamella joining | | Stack treatment | |
|---|---|---|---|---|---|---|
| | | | Rotor | Stator | Rotor | Stator |
| A | PMSM | blanked/0.25 | interlock+fix | glued | - | - |
| B | PMSM | blanked/0.25 | interlock+fix | interlock+weld | annealed | annealed |
| C | EESM | blanked/0.35 | weld | weld | - | - |
| D | PMSM | blanked/0.25 | interlock+fix | interlock+weld | - | annealed |
| E | PMSM | blanked/0.25 | glued | glued | - | - |
| F | PMSM | blanked/0.35 | interlock+fix | weld | annealed | annealed |
| G | ASM | blanked/0.35 | interlock+cast | interlock+weld | - | - |




Combinations of annealing + gluing are rare for EV



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# Optimization of laminated stacks for electric motors in (H)EV

## Motor Assembly and Residual Stress

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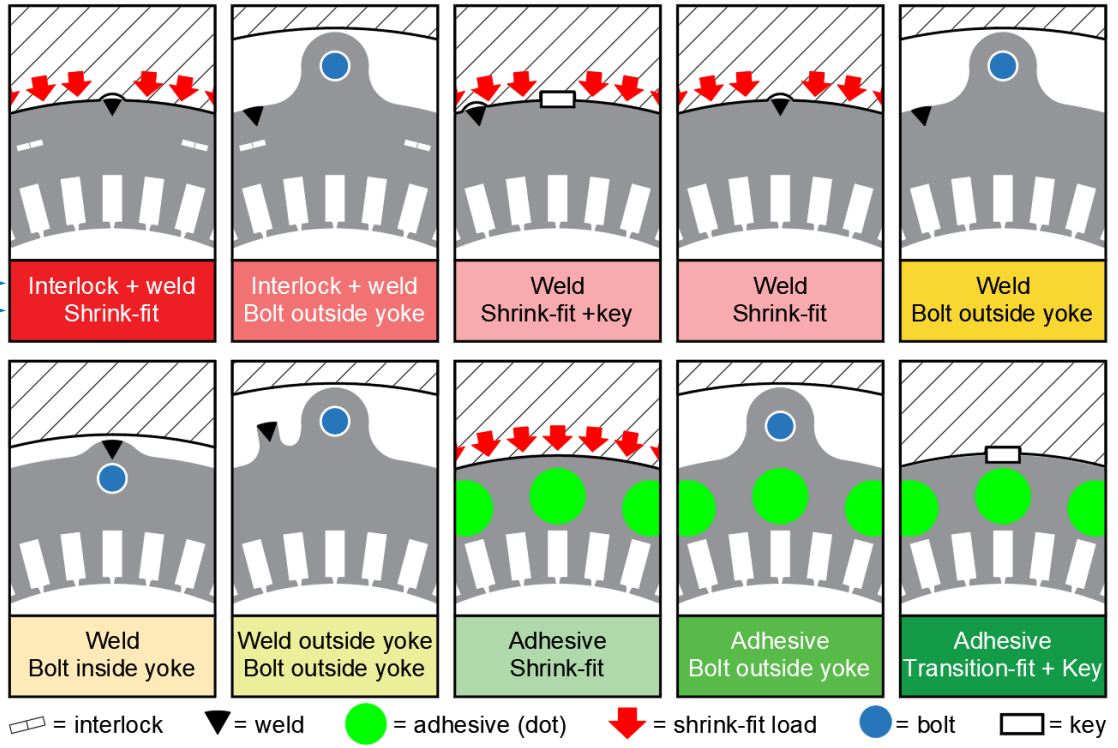
- Stress introduced by assembly (example stator)

- Lamella joining options
  - Interlock
  - Weld
  - Adhesive

- Stator assembly options
  - Shrink → transition fit
  - Bolt
  - Key



# Optimization of laminated stacks for electric motors in (H)EV
## An Adapted Process Chain

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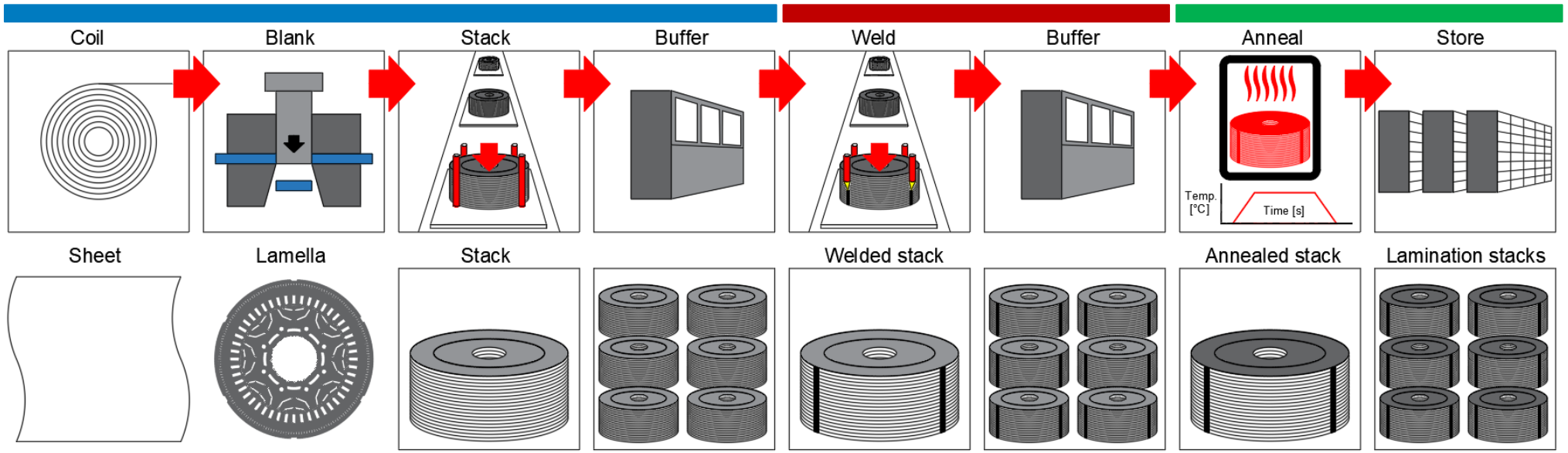
- A typical process chain
  - Blanking & stacking
  - Welding
  - Annealing (optional)



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# Optimization of laminated stacks for electric motors in (H)EV

## An Adapted Process Chain

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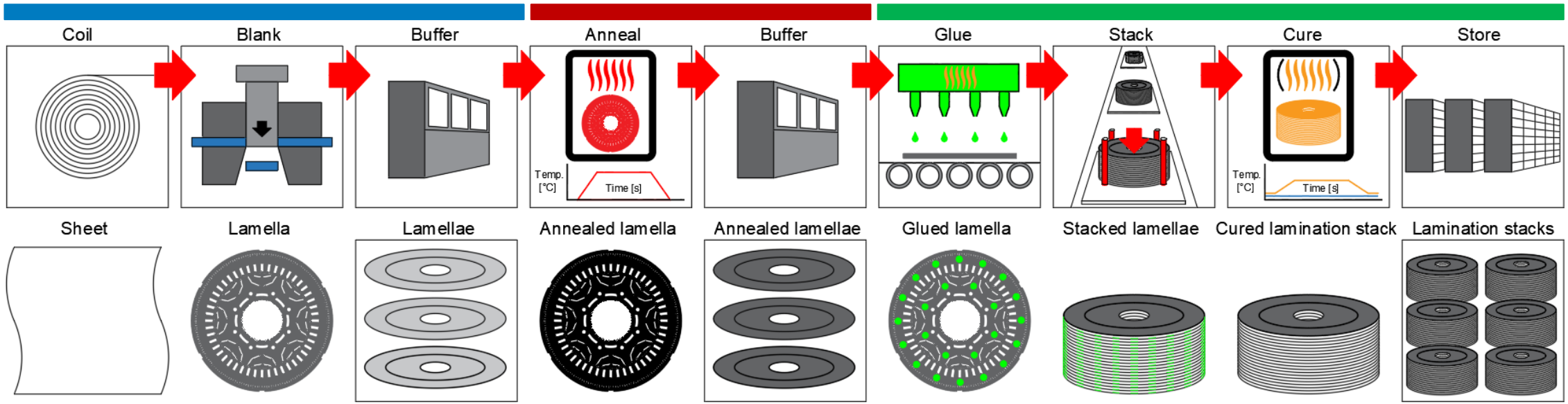
- An adapted process chain
  - Blanking
  - Annealing
  - Gluing & stacking

Optimized combination







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# Optimization of laminated stacks for electric motors in (H)EV

## Annealing – Reduction of Residual Stresses

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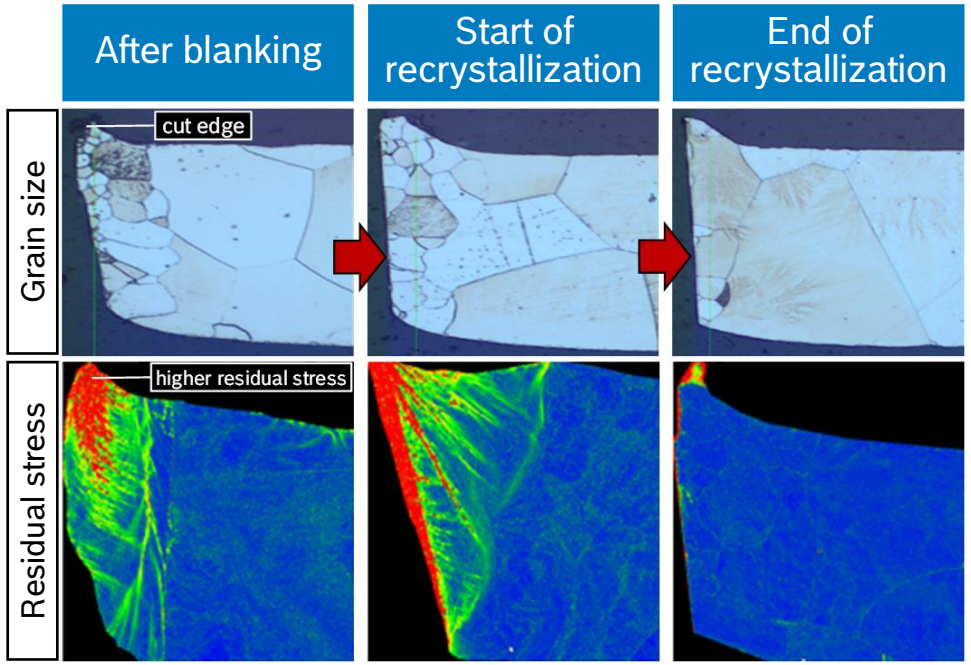
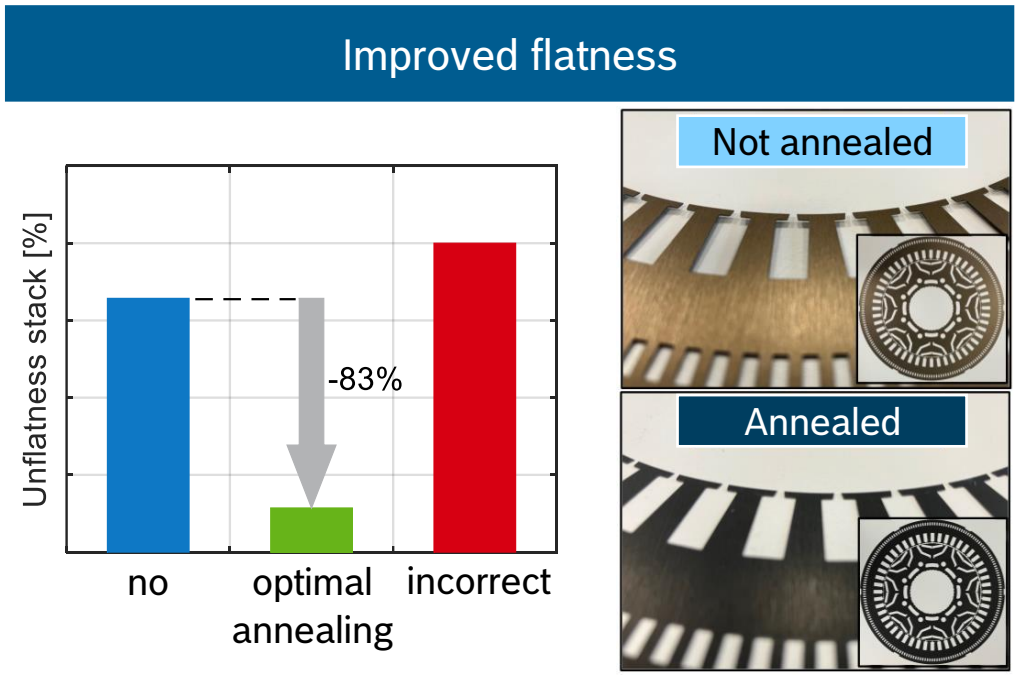
- Benefits
  - Improved power loss & power density
  - Improved shape, e.g., flatness



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# Optimization of laminated stacks for electric motors in (H)EV

## Gluing – Joining without Introducing Stress

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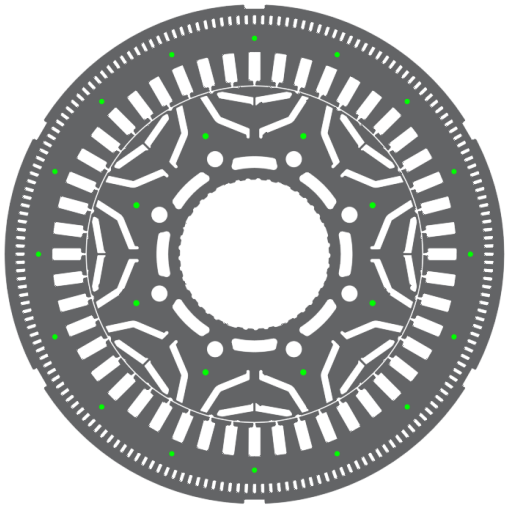
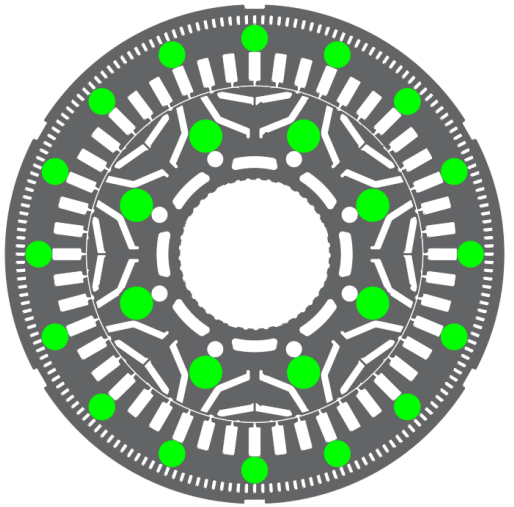
- Benefits of adhesives
  - Bonding - prevents stress
  - Insulating - prevents short circuits
  - Damping - reduces NVH
  - Conducting - equalizes heat
  - Aligning - improves alignment
  - Sealing - seals cooling channels*

Dots applied



After stacking



- Options

| Method | When to apply | Annealing after blanking |
|---|---|---|
| Backlack | Before blanking | No |
| Face gluing | Typically before blanking | No |
| Dot/pattern gluing | Before or after blanking | Yes |

* Depends on gluing and stacking method

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# Optimization of laminated stacks for electric motors in (H)EV

## Test – The Effect of Annealing on Power Loss

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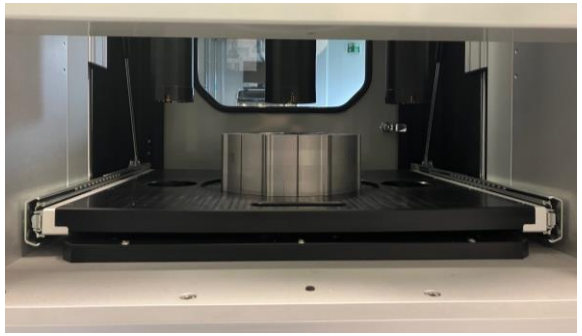
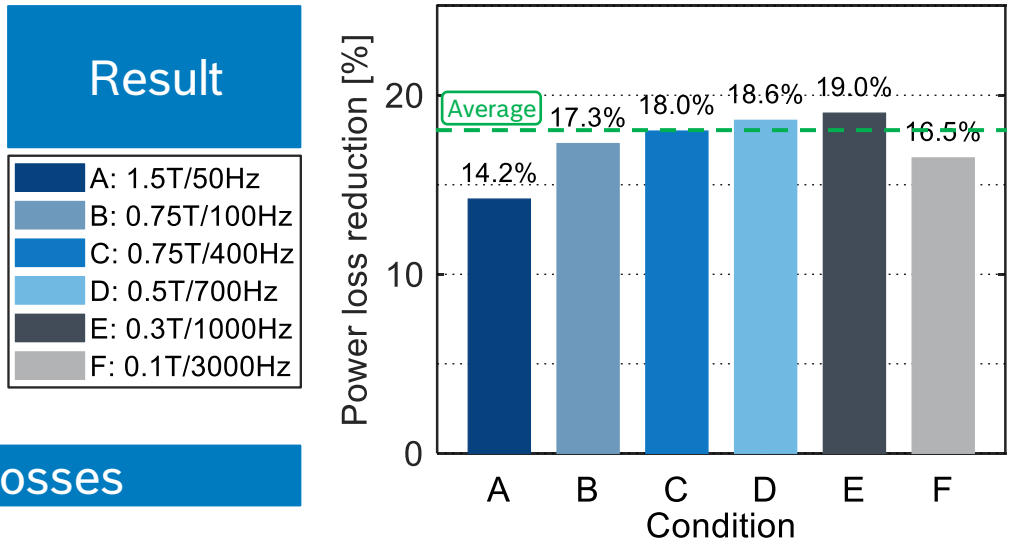
- Power loss testing (stator)
  - Stack level
  - Welded stack
  - Not-annealed vs. annealed
  - Load conditions A to F

**Set-up**



**Result**




**Annealing offers up to 20% reduction of power losses**

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# Optimization of laminated stacks for electric motors in (H)EV

## Test – The Effect of External Load on Power Loss

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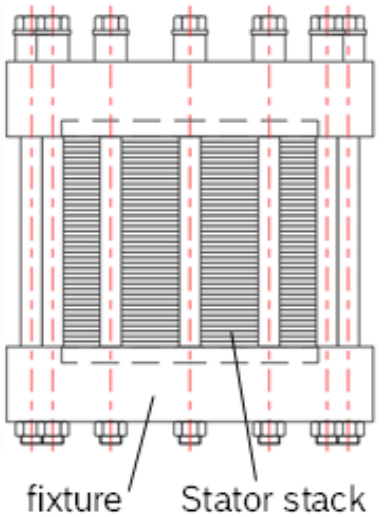
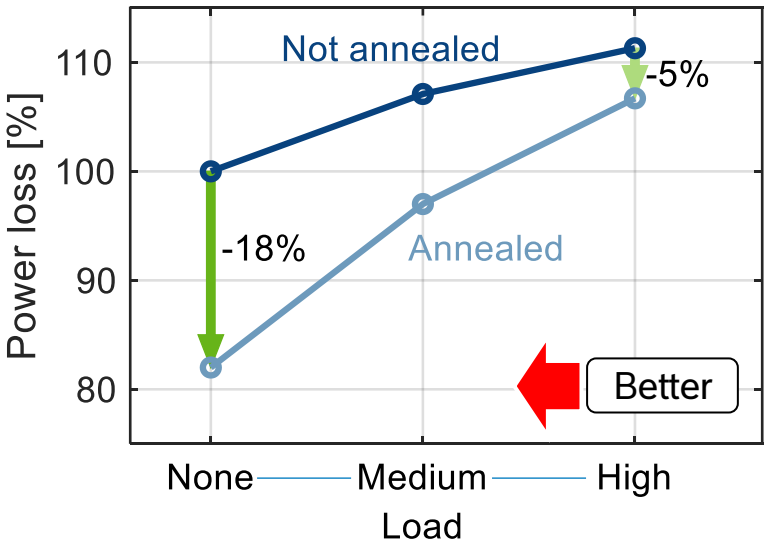
- Power loss testing (stator)
  - Stack under axial load (bolts)
  - Not-annealed vs. annealed
- 5 to 18% power loss reduction

**Set-up**




**Result**




**Prevention of external loads reduces power losses**



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# Optimization of laminated stacks for electric motors in (H)EV

## Test – The Effect of Annealing and Gluing

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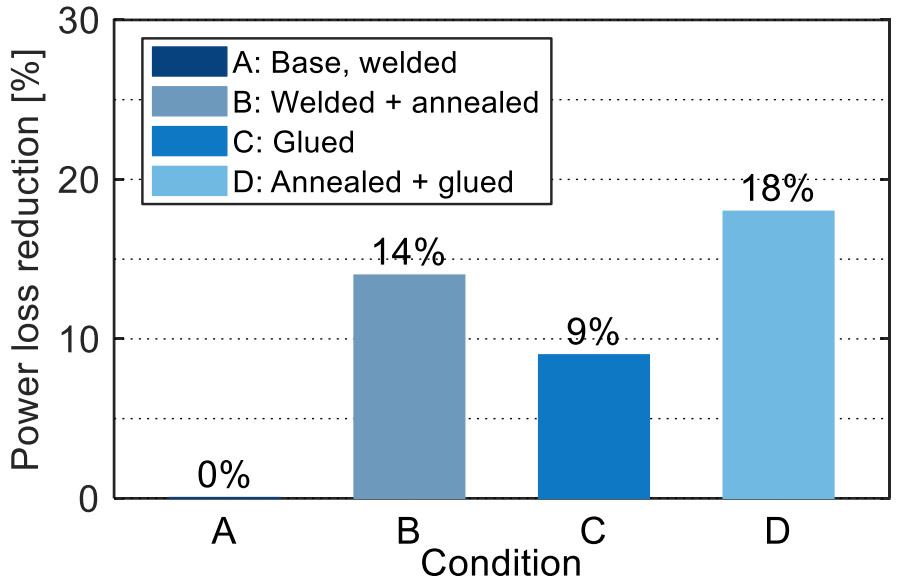
- Power loss testing (stator)

Variants:

A. Base stack, welded, not annealed
B. Welded and annealed
C. Not annealed, glued
D. Bosch annealing and gluing




**The combination of annealing + gluing shows best result**

* Results from averages over 6 operating conditions

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# Optimization of laminated stacks for electric motors in (H)EV
## Conclusions

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- Annealing of lamellae reduces power losses in laminated stacks
- Gluing of lamellae prevents negative effects of interlocking and welding

- Annealing plus gluing provides efficiency and power density benefits that improve EV mileage or cost

- Bosch developed a process chain that combines annealing and gluing

# Optimization of laminated stacks for electric motors in (H)EV

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## Contact Information

Thank you for your attention. For more info, visit us at our stand 62B44.


Francis van der Sluis
Francis.vandersluis@nl.bosch.com
+31 13 4640 440

Matthijs Roorda
Matthijs.Roorda@nl.bosch.com
+31 13 4624 953

Dirk van den Heuvel
Dirk.vandenHeuvel@nl.bosch.com
+31 13 4640 354

Bosch Thin Metal Technologies
Dr Hub van Doorneweg 120
5026 RA, Tilburg
The Netherlands
estacks@bosch.com





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