Investigation on the Mechanical and Electromagnetical Performance of a special fabricated Squirrel Cage Copper Rotor for Induction Machines

The 30th International Electric Vehicle Symposium & Exhibition

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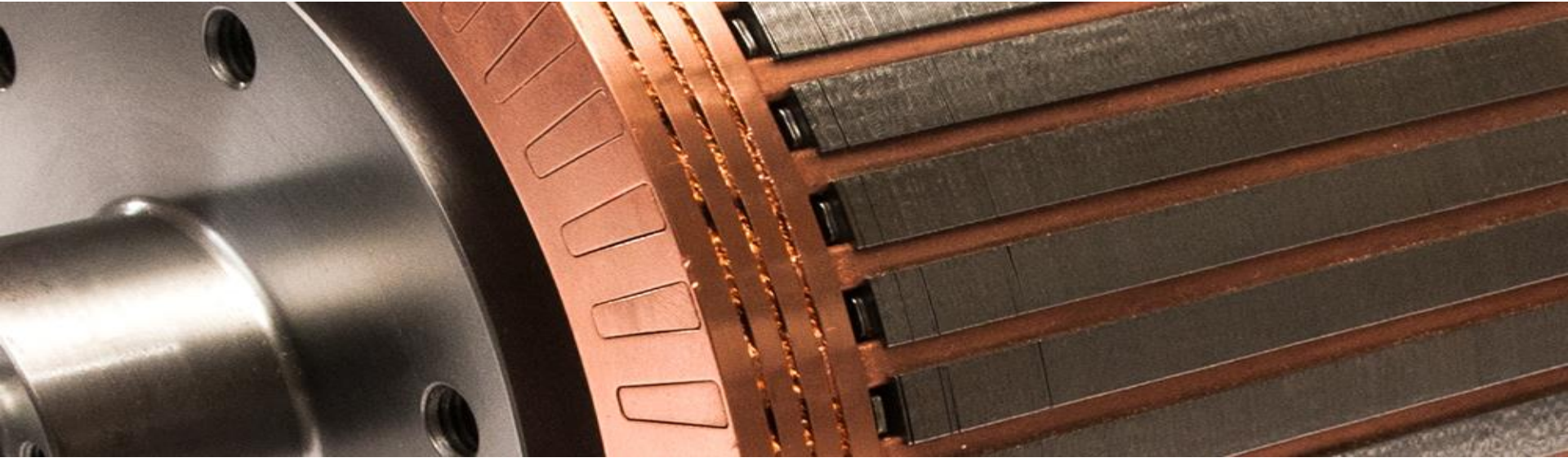
Michael Wolf



- **Short company introduction of Wieland Werke AG**
- Wieland fabricated copper rotor
  - Current copper rotor technologies
  - Manufacturing process of Wieland copper rotors
  - Performance of Wieland copper rotor
- Summary and outlook

- Casting technology since 200 years
- Certified and accredited laboratory
- Development of special copper alloys
- Recycling circuit of internal and external materials

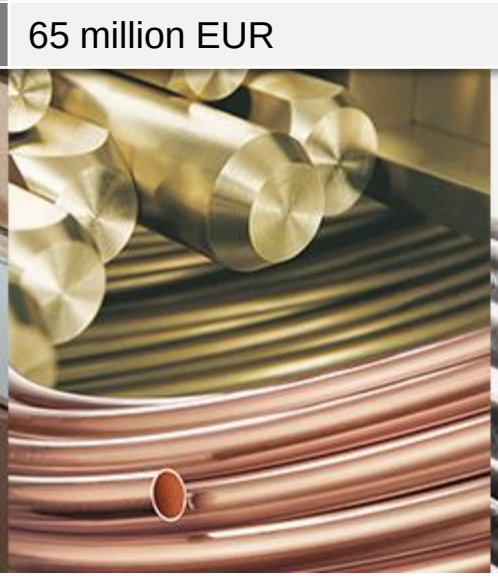
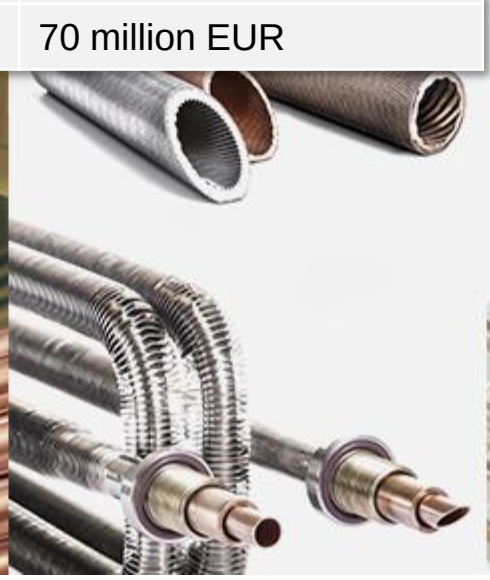
- Pre-material Divisions such as:
- Extruded and Drawn Products
- Rolled Products
- Finned Tubes

- Special, customized components
- From prototypes to mass production
- Overall responsibility for component quality

- Assembling, forming, stamping process
- Fully automated processes
- Laser/e-beam welding process with copper material

Key figures Wieland Group

	FY 2014/15	FY 2015/16
Turnover	2,784 million EUR	2,547 million EUR
Sales	443,000 t	464,000 t
Employees	6,780	6,658
Investments	65 million EUR	70 million EUR


Wieland Components for eMobility

Connector Rings

Connector ring components for stators in synchronous motors

HV Parts

High voltage parts for the connection between e-motor and power electronics

Cu Rotors

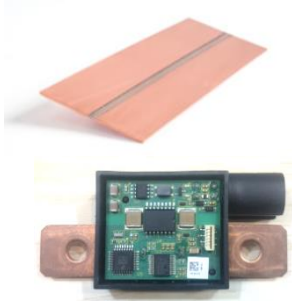
Cu rotors for high performance and high speed induction motors

Cu Rotor components

Cu rotor bars and discs for rotors in high efficient induction motors

Shunt/Resistan and laser cladding

Laser cladding hybrid material and shunts for battery applications



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Die cast copper rotor

Challenges:

- Tooling
- Thermal stress on lamination
- Rotor dimensions and weights

Fabricated copper rotor (brazed)

Challenges:

- Softening of the copper end rings
- Process time
- Thermal stress on lamination

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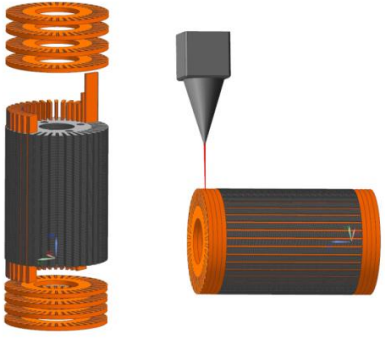
Copper rotor – fabricated, radial laser welded CR

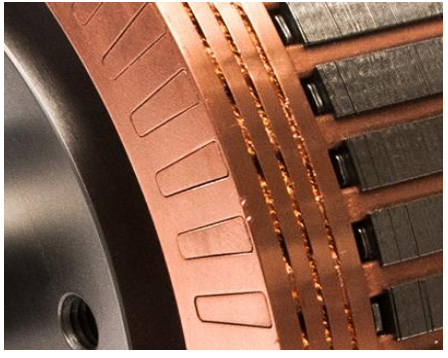
Copper discs for rotor end ring



Radial welding process

This new design enables us to …

- build up an economical, high-volume rotor manufacture
- simple manufacturing of the rotor bars and end ring discs
- ensure a low, only partial influence of temperature
- realize different material combinations in end ring for high speed applications (steel discs)

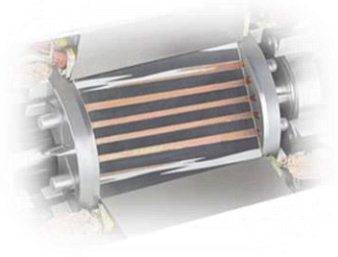


Disc shaped copper rotor

Machining center for copper rotor bars

Fully automated rotor-bar production line with machining centre

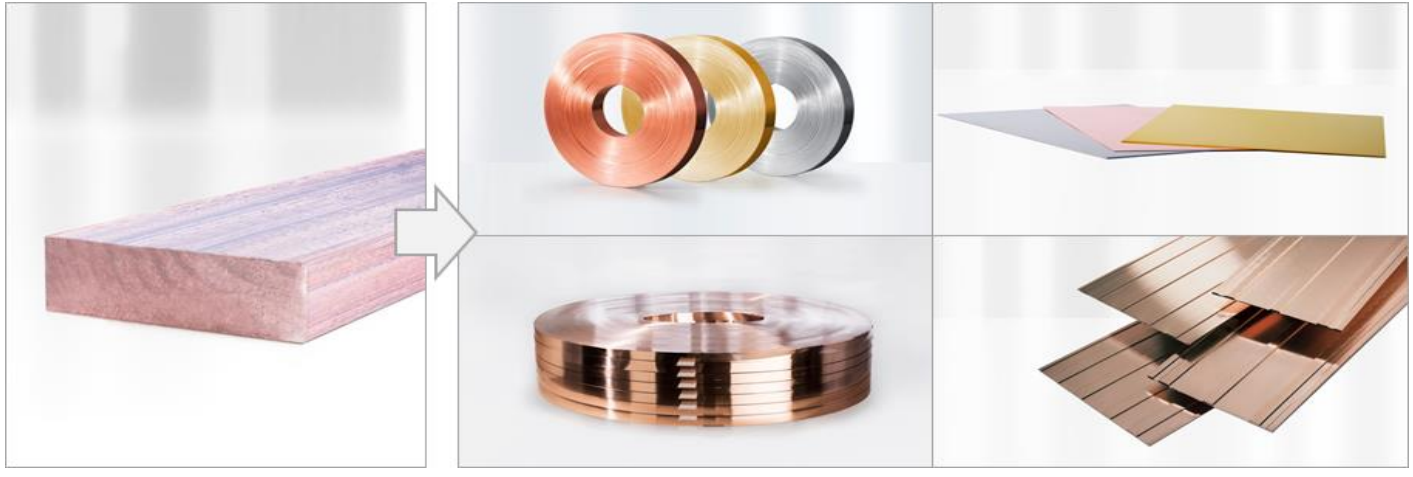
- Cost-efficient and flexible manufacturing process
- Small quantities for prototypes can be manufactured under series conditions.
- Reproducible quality - traceability
- Fully automated manufacture of cut to length rotor bars
- Twisted rotor bars can be manufactured.



Hybrid rotor with copper rotor bar profiles and Al die cast

Stamping of end ring discs

- Fully automated stamping process
- End ring discs out of different Wieland copper alloy material
- Same toolings can be used for different materials
- Material thickness of 4mm and diameter up to 200mm
- High performance Wieland alloys like K60 and K75 for excellent mechanical properties and best softening behaviour at high temperatures



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For high speed rotors, special materials are needed for end ring discs

Requirements are:

- High mechanical strength compared with high electrical conductivity
- Very good softening behaviour at high temperatures
- Usable for laser or e-beam welding process

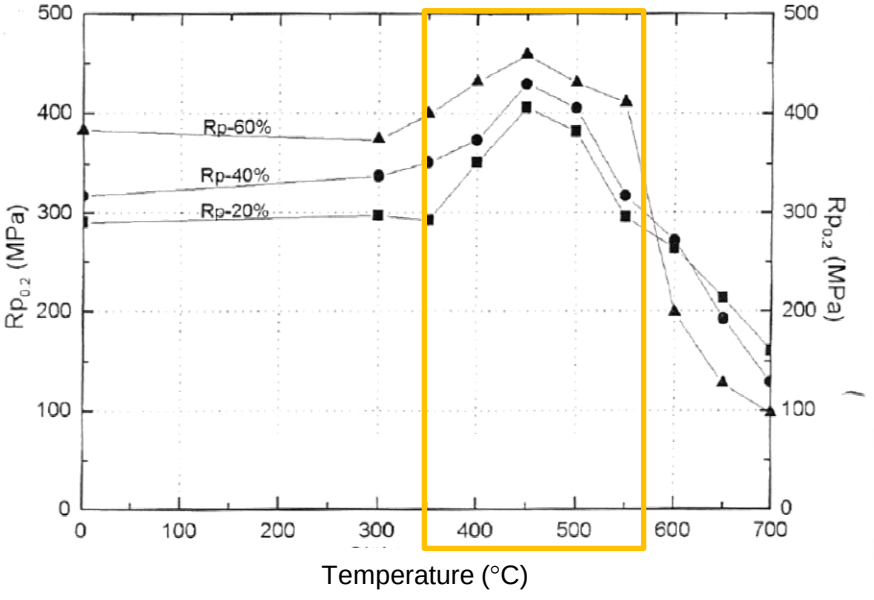
Wieland	EN-Label	Number	Electrical Conductivity		Mechanical Strength
			MS/m	%IACS	MPa
K10	Cu-OFE	CW009A	≥ 58,6	≥ 101	max. 380
K60	CuCr1Zr	CW106A	≥ 43	≥ 74	max. 570
K75	CuCrSiTi (n.g.)	C18070	≥ 45	≥ 78	max. 630
K88	CuCrAgFeTiSi	C18080	≥ 46	≥ 79	max. 620

Wieland high performance alloys

Wieland high performance alloys (HPA´s) offers all requirements:

- Very high mechanical properties up to 400MPa and very good electrical conditions of 43-46MS/m because of solution annealing at 1000°C and subsequent hardening process
- Homogeneously distributed, intermetallic precipitates create a fine grained and good bendable microstructure
- Materials offers a very good softening behavior at high temperatures

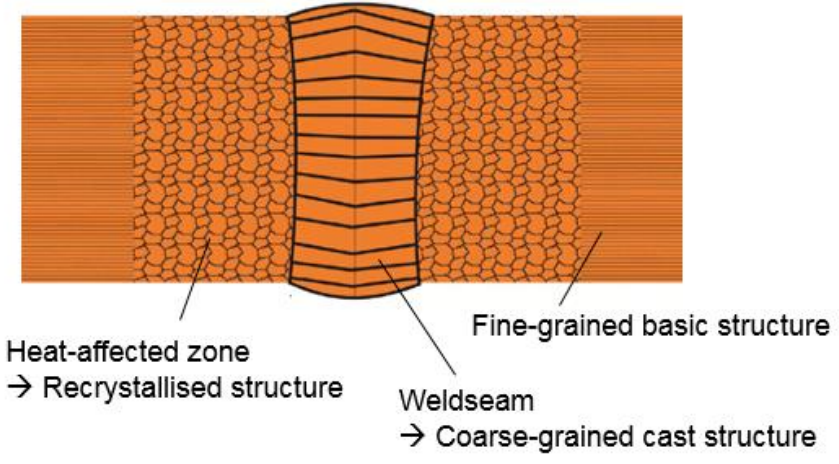
Softening behavoiur of K60 material



→ Are these HPA´s suitable for laser and ebeam welding?

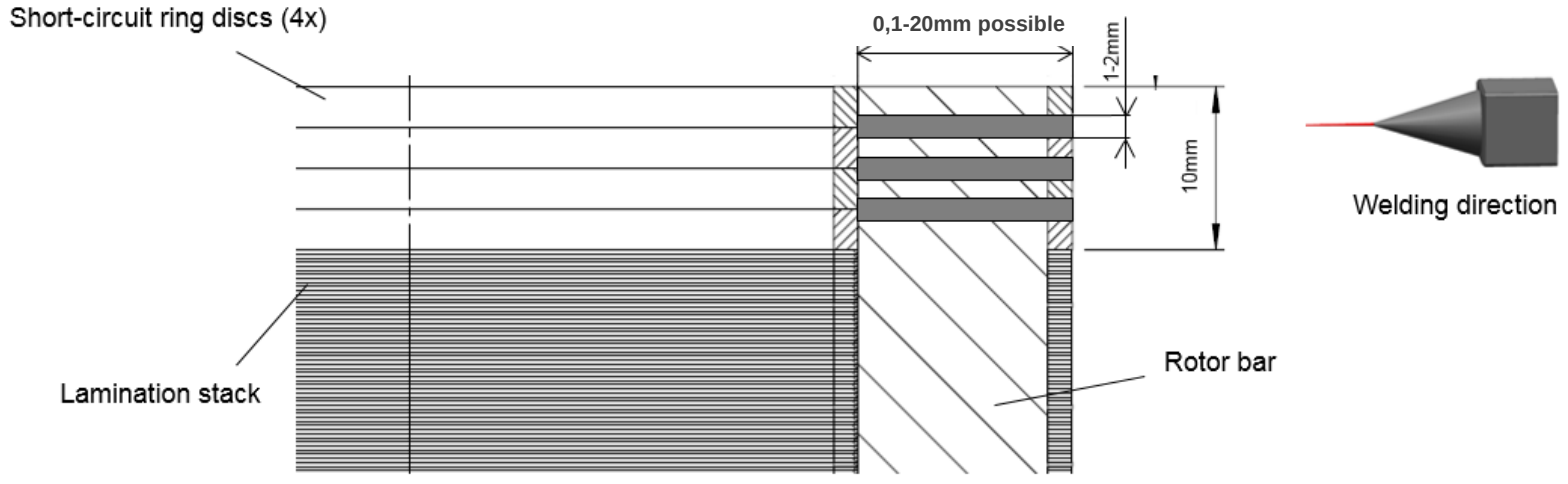
Wielands high performance alloys are suitable for laser and ebeam welding process

Welding direction



- Welding width between 1.0 and 2.0 mm and heat-affected zone between 0.05 and 0.5 mm depending on the process
- Temperature of end ring caused by welding process is between 100-150°C (depending on rotor dimensions) this heat-affected zone is about 10-15% of a complete end ring
- Achievable welding depth of up to 20mm

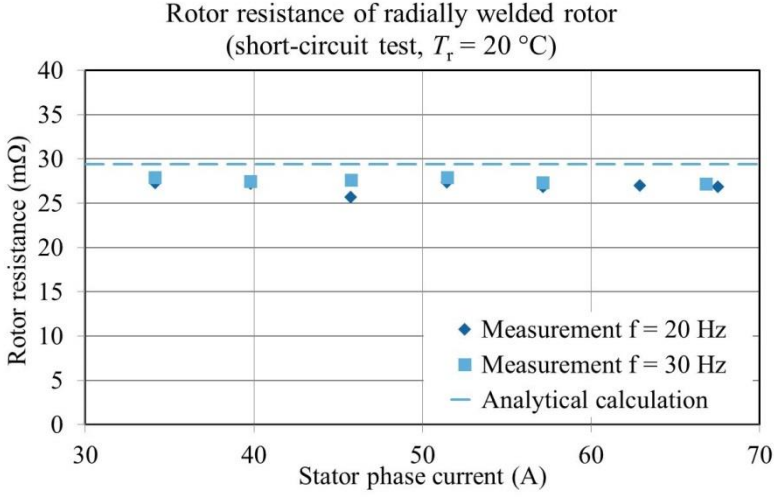
Sectional view of rotor to illustrate cross-section of the connection

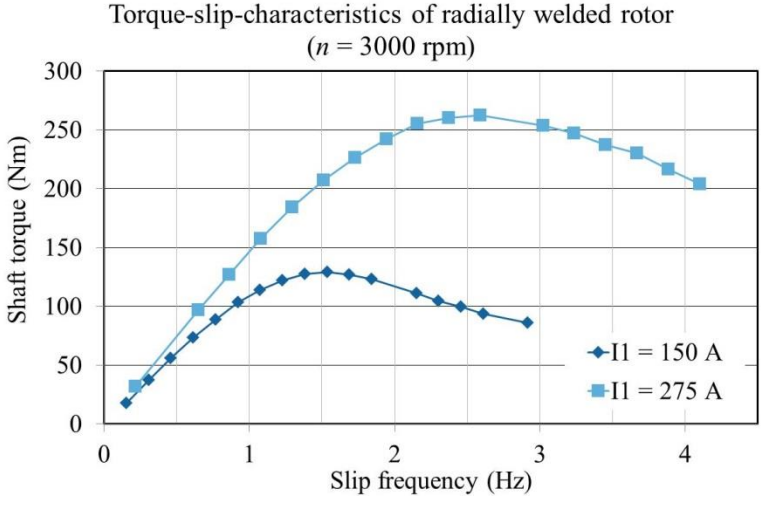


- Full-area connection of the individual rotor bars to the copper discs; therefore very low electrical resistance can be achieved in the short-circuit ring.
- High-purity copper with 100 % IACS makes high electromagnetic rotor performance and energy efficiency possible.

Test bench results of Wieland Copper Rotor tested in IAV´s Drive Pack EV80:

→ Compact drive module for electric axle including induction machine, transmission, differential
→ Induction machine (peak power 80 kW, peak torque 300 Nm, max. speed 8000rpm)
→ Integrated power electronics



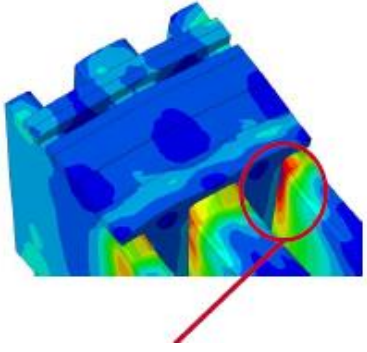


- Measurement of the rotor resistance by means of short-circuit test (locked rotor) R= 29,4mΩ at 20°C
- Shaft torque is measured at constant speed and varying slip frequency for constant stator current amplitude
- Radially welded rotor reached a top performance in IAV´s Drive Pack unit with an best efficiency of 92%

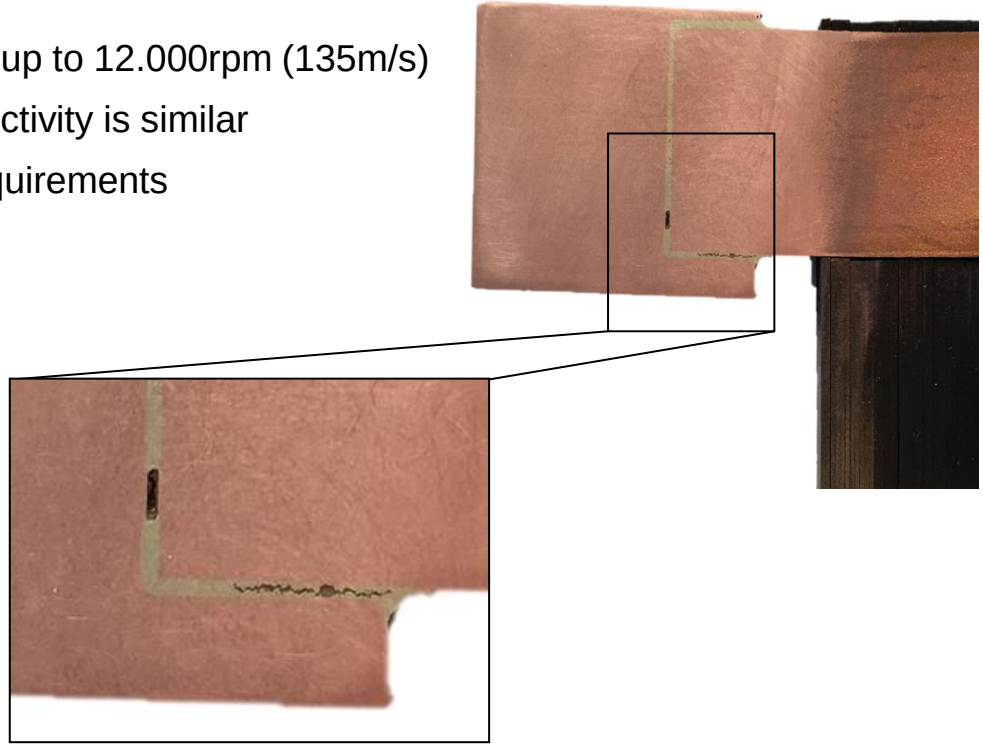
Customer requirements regarding high speed performance can be fulielled !

- Speed and burst testing shows that with pure copper at room temperature over **170m/s** circumferential speed is possible
- We secured the mechanical stability of IAV rotor up to 12.000rpm (135m/s)
- Compared with brazed end ring, electrical conductivity is similar

  but mechanical stability is not given for IAV´s requirements



Red areas are high
stressed positions highlighted in end ring



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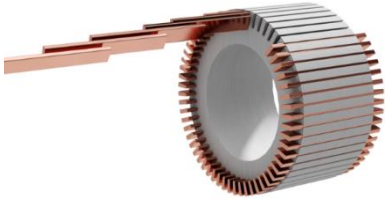
Wieland

Summary regarding Wieland copper rotor:

- Very flexible rotor design and dimensions can be realised.
- Cost-efficient manufacture for larger quantities
- Simple manufacture of the individual parts (rotor bar/discs)
- Minimal thermal influence on the copper material through joining technology
- Different material combinations make high-speed applications without additional containment ring possible



Outlook:

- Using laser roll bonded materials in the end ring
- Realising assembly and testing technologies
- Setting up a partly automated production line for copper rotors
- Realising high twist angles for industrial rotor solutions

Thank you very much for your attention!

Please note: Visit us at booth 1D35