DESIGN AND MANUFACTURING OF PERMANENT MAGNET BEARING RINGS FOR HIGH SPEED APPLICATIONS

2023.JULY.20 TAN TAN

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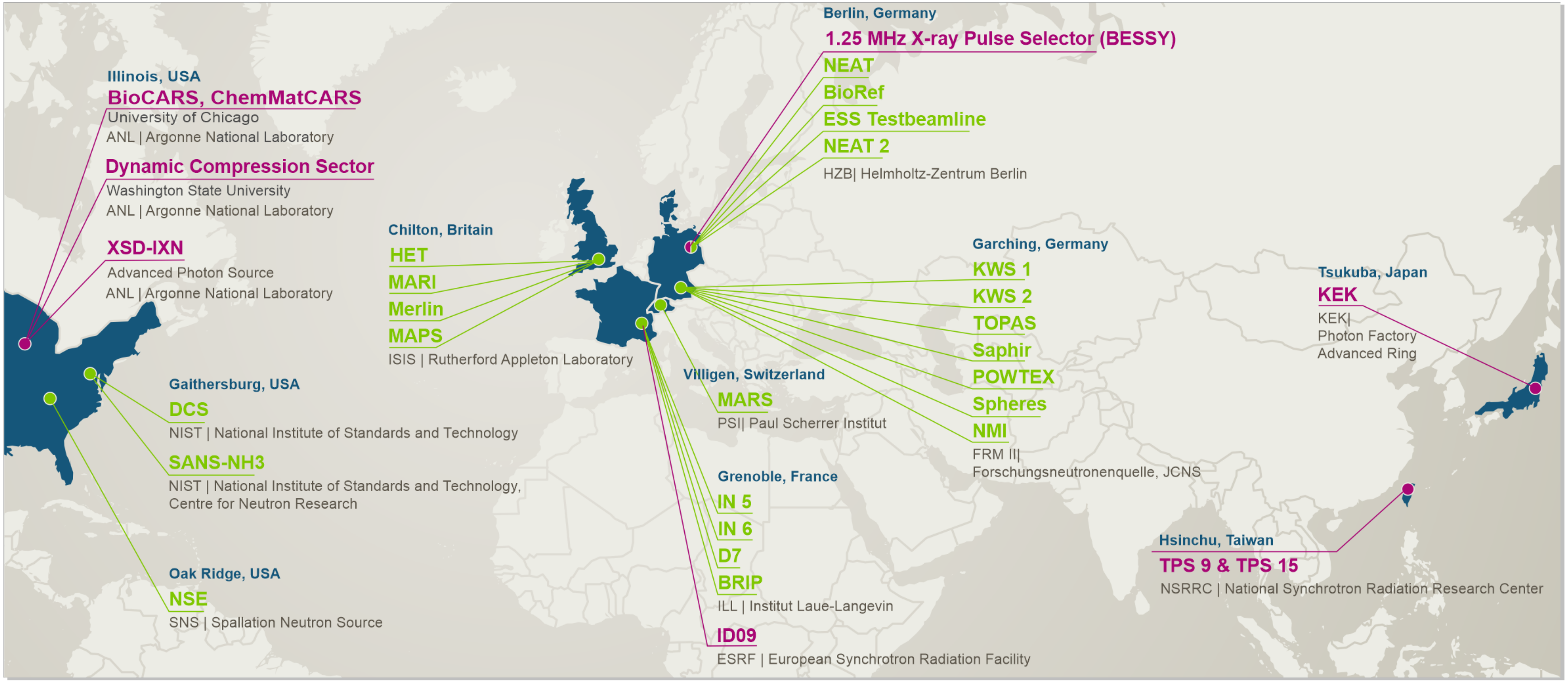
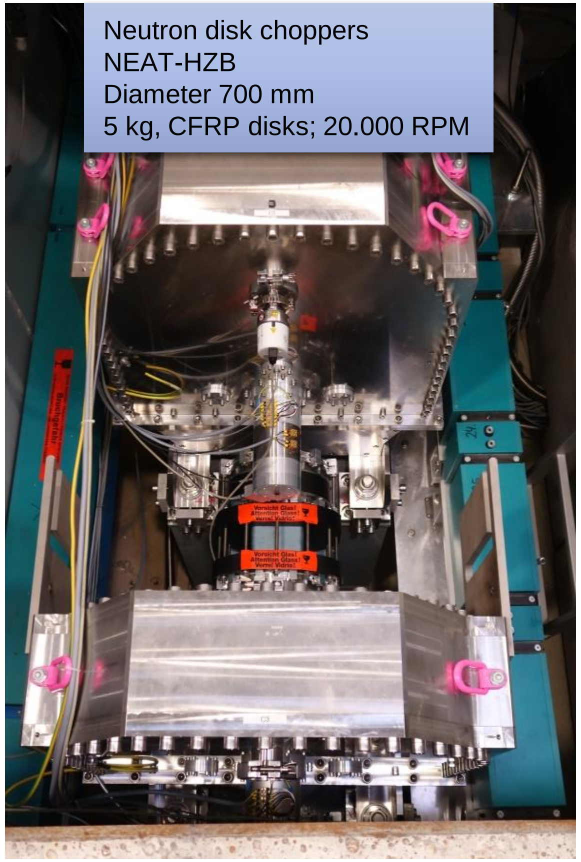
Forschungszentrum

MAGNETIC BEARING CHOPPERS "SYSTEM JUELICH" OPERATING WORLDWIDE

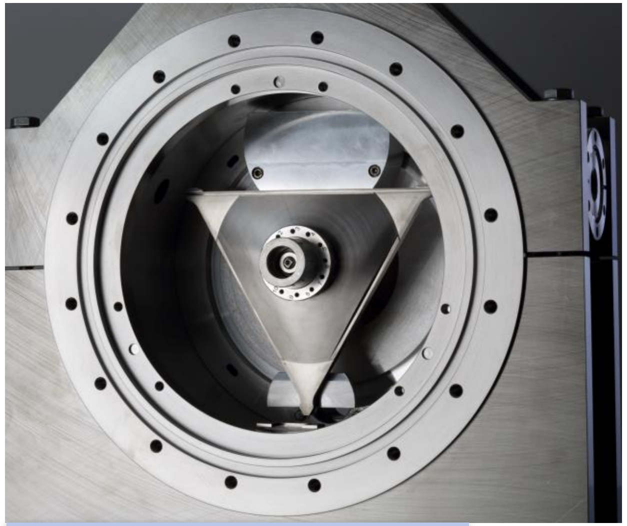


Over 20 years of operation experience

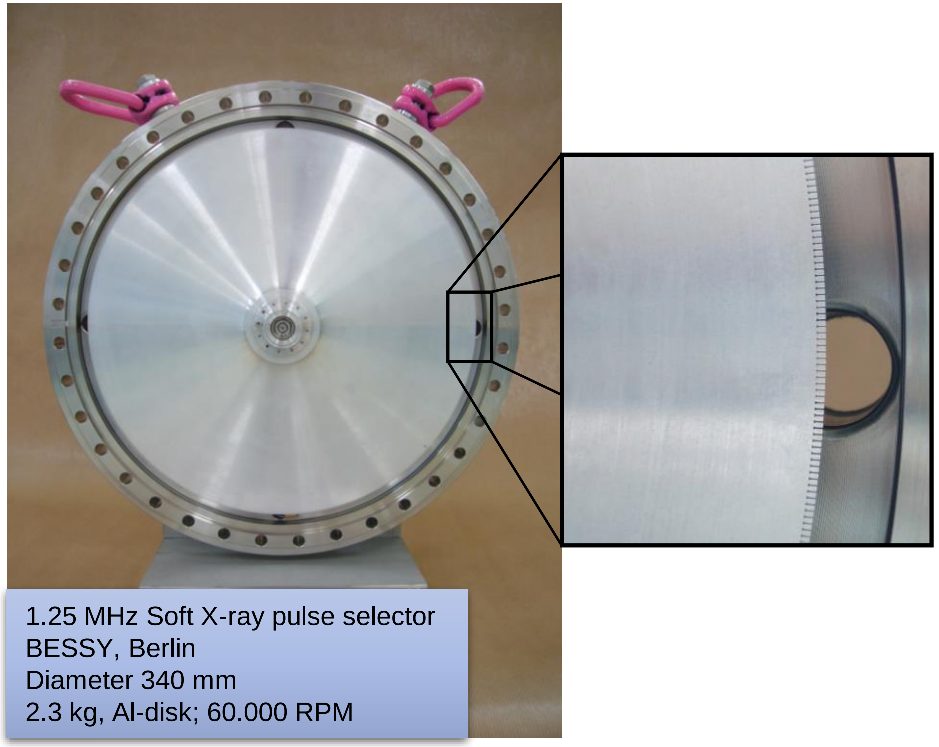
EXAMPLE OF JUELICH CHOPPER SYSTEMS



Neutron disk choppers
NEAT-HZB
Diameter 700 mm
5 kg, CFRP disks; 20.000 RPM



Triangular disk X-ray pulse selector
ANL / ESRF / NSRRC / KEK
Diameter ~200 mm
1.5 kg, Ti-disk; 60.000 RPM



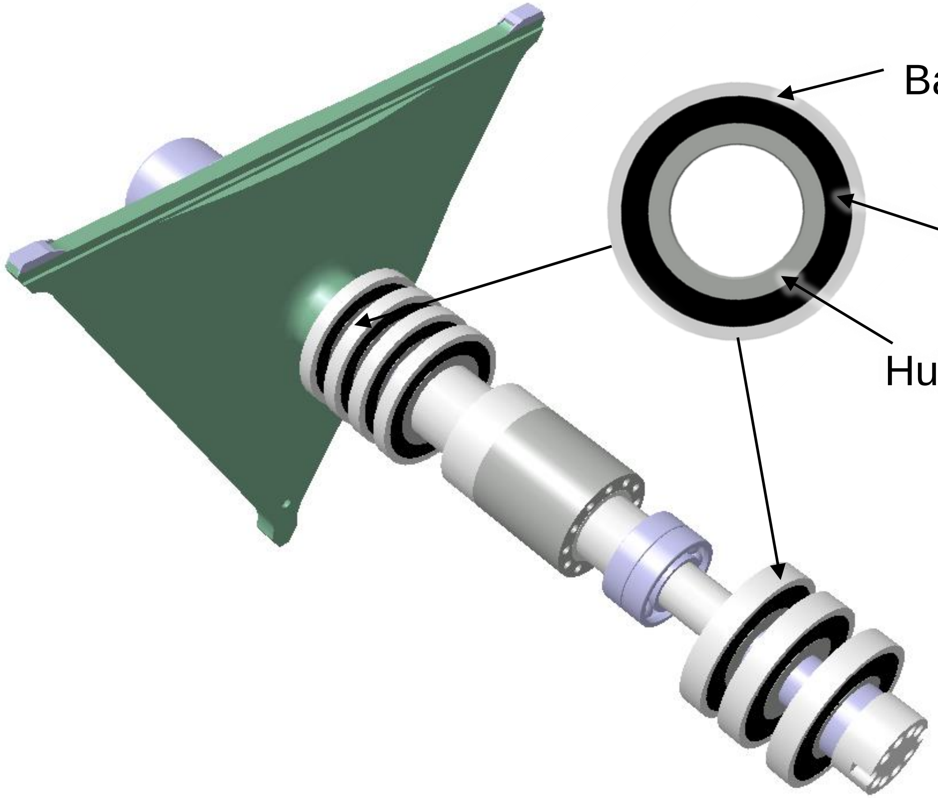
1.25 MHz Soft X-ray pulse selector
BESSY, Berlin
Diameter 340 mm
2.3 kg, Al-disk; 60.000 RPM

BENEFITS OF THE USED BEARING CONCEPT

- Very low power consumption during routine operation (load carried by passive magnets)
- No external cooling necessary
- More compact (smaller size)
- Fewer controllers (radial passive -> only one axis controlled)

  -> Highest reliability

- Compatibility with ultra-high vacuum environments.



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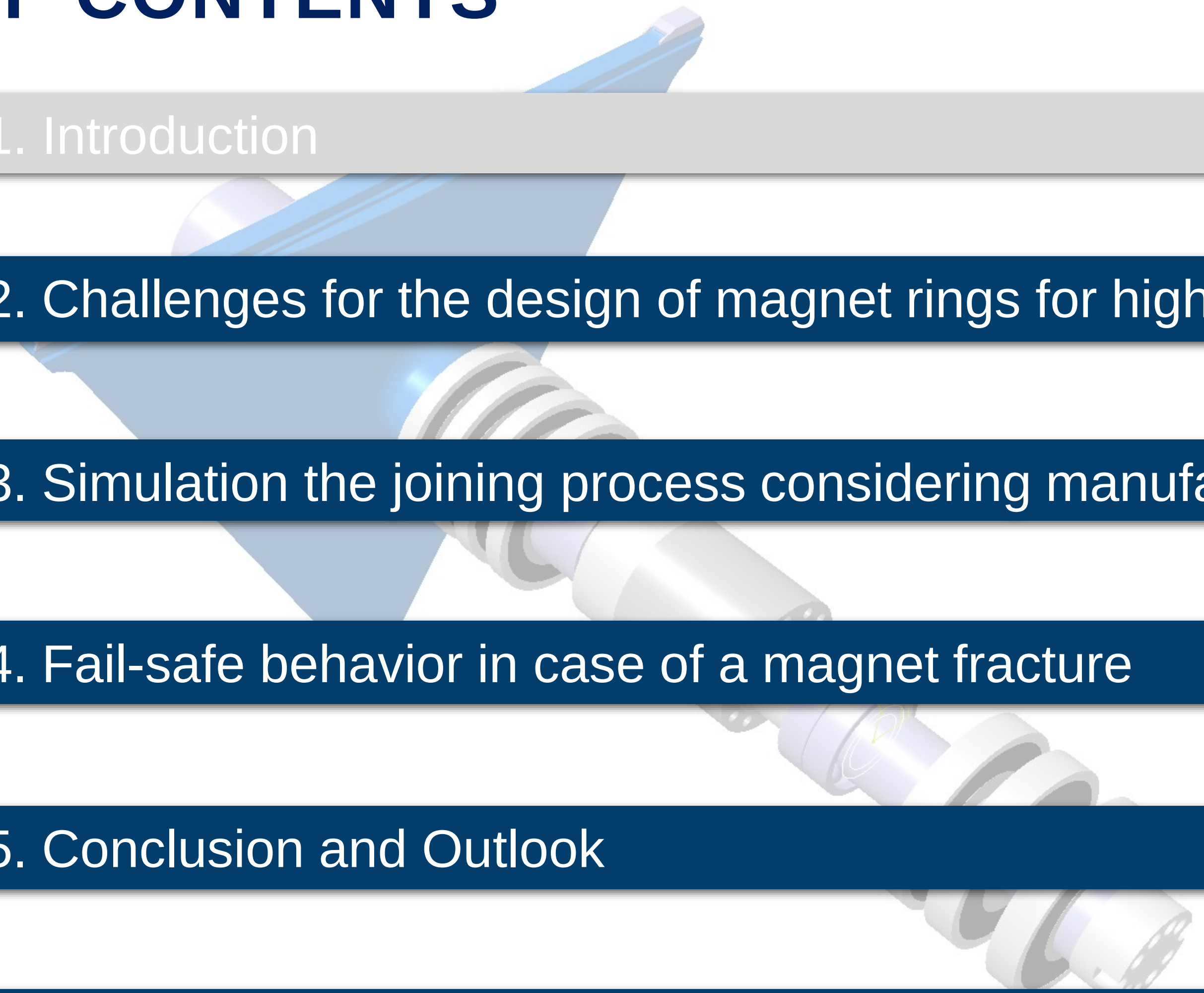
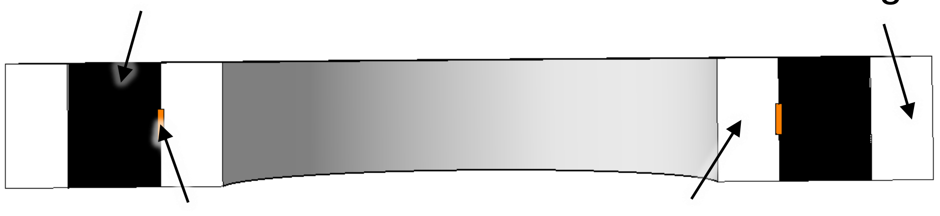


CHALLENGES FOR THE DESIGN OF MAGNET RINGS FOR HIGH-SPEED APPLICATIONS

Magnet rings with suitable bandages



Cross-sectional view of the hub-magnet-bandage assembly

Magnet: NdFeB (Øi=20mm, Øa=26mm, H=4mm)
Bandage and hub: Titanium grade 5
Grooves filled with epoxy resin

- Low tensile strength of sintered NdFeB magnets (80 to 90 MPa, IEC 60404- 8-1:2015)

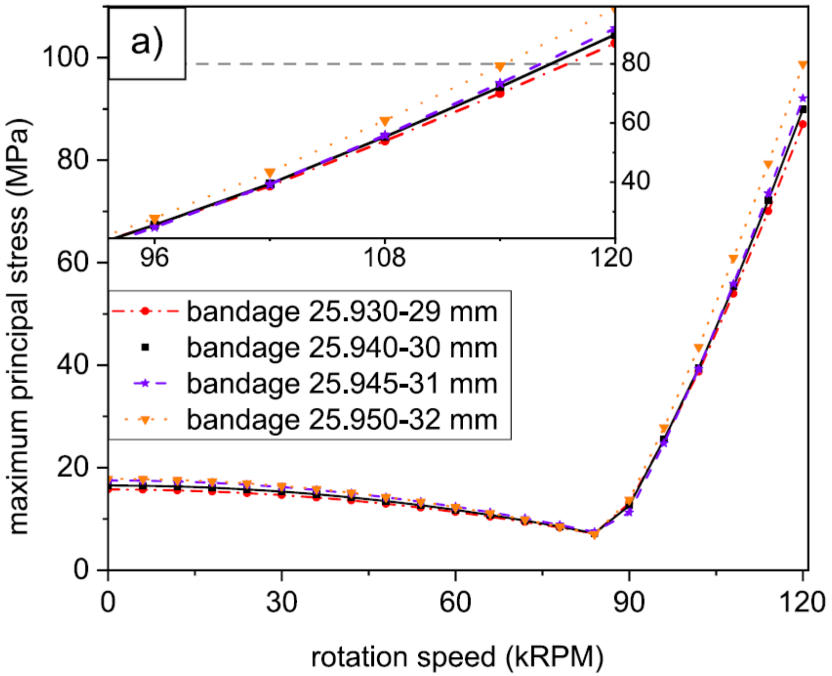
→ Suitable bandages required.

- Press fit requirements

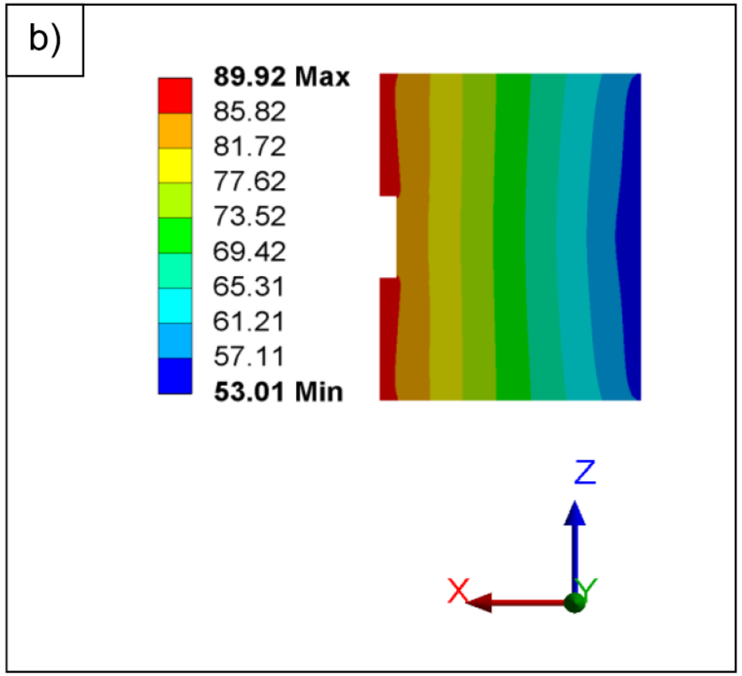
1. Magnet under joint pressure does not break
   →Maximum interference
2. Remaining contact pressure suitable for design rotation speed
   →Minimum interference

SIMULATION PRESS FIT

influence of prestress for the hub-magnet-bandage assemblies



Rotation speed dependent maximum principal stresses of the magnet ring with different bandage outer diameters



Distribution of the maximum principal stress for the magnet ring at 120,000 RPM for the bandage with diameter 25.94-30 mm

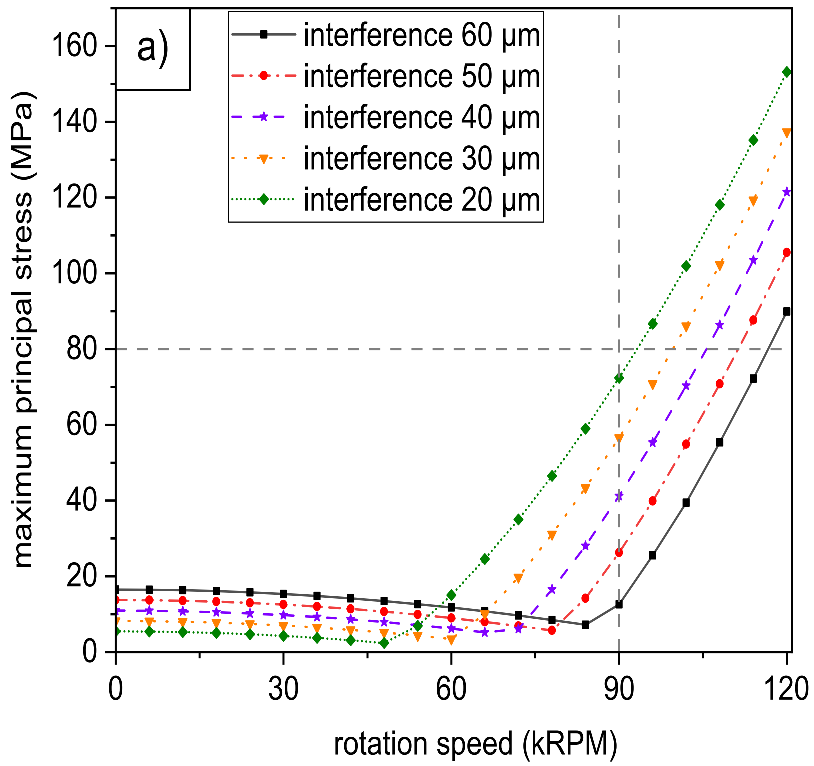
Ideal model without considering any influence of joining, manufacturing tolerance, and magnet ring defect

a) maximum achievable speed decreases with increasing bandage thickness

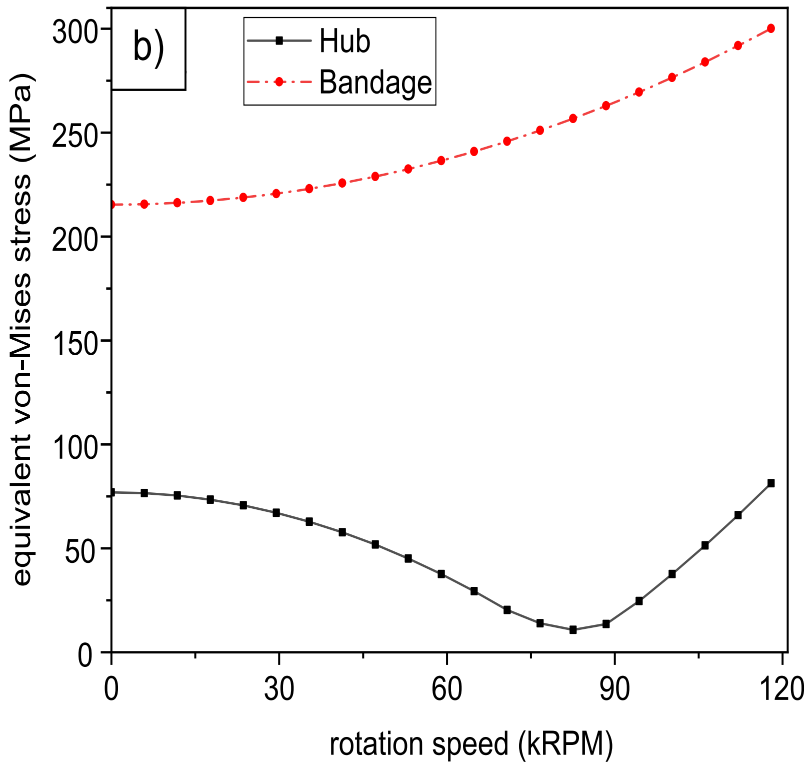
b) The maximum is located in the area of the grooves.

SIMULATION PRESS FIT

suitable tolerance windows



Rotation speed dependent maximum principal stresses of the magnet ring for different interferences between 20 µm and 60 µm



Equivalent von-Mises stresses of hub and bandage for 2 mm bandage thickness and 60 µm interference

- Tolerance windows for Ideal model at 90,000 RPM : 20 – 60 µm
- Every reduction of the interference by 10 µm →reduction of the permissible speed of about 6,000 RPM
- Bandage and Hub: uncritical for all analyzed cases (Rp0.2 = 828 MPa, safety factor of 2)

MANUFACTURING OF HIGH-SPEED MAGNET BEARINGS

magnet rings with suitable bandages with interference fit

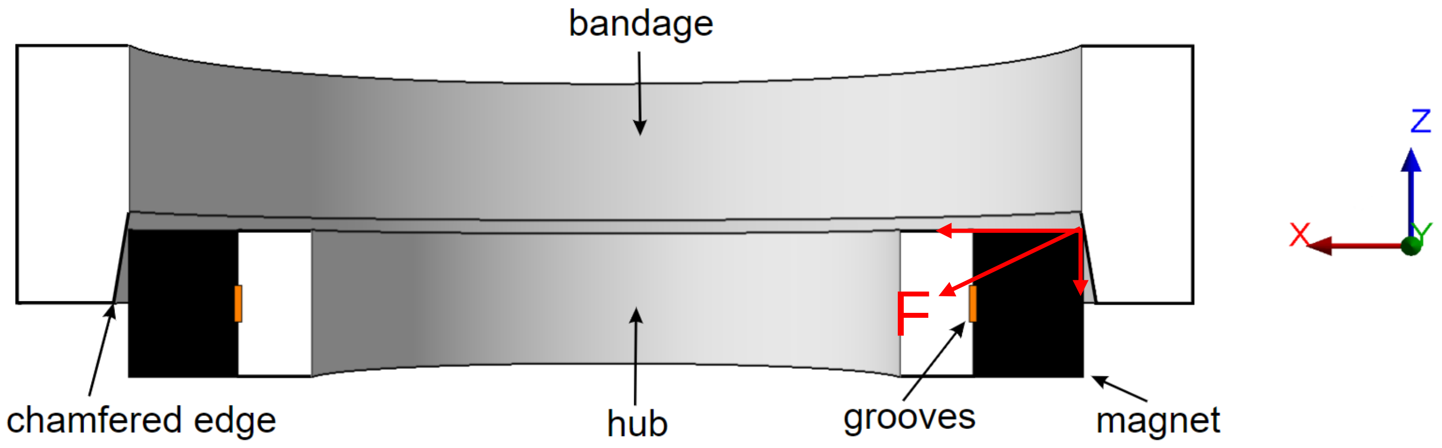
- Interference fit is necessary → shrink-fitting or press-fitting

- Problems for shrink-fitting

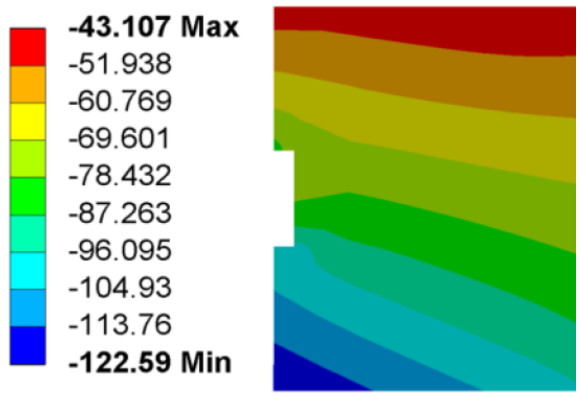
1. NdFeB magnets: anisotropic thermal expansion.
2. Heat sensitity of magnet → Risk of partial demagnetization

SIMULATION THE JOINING PROCESS

The model



Cross-sectional view of the hub-magnet-bandage assembly during the axial press-fit process



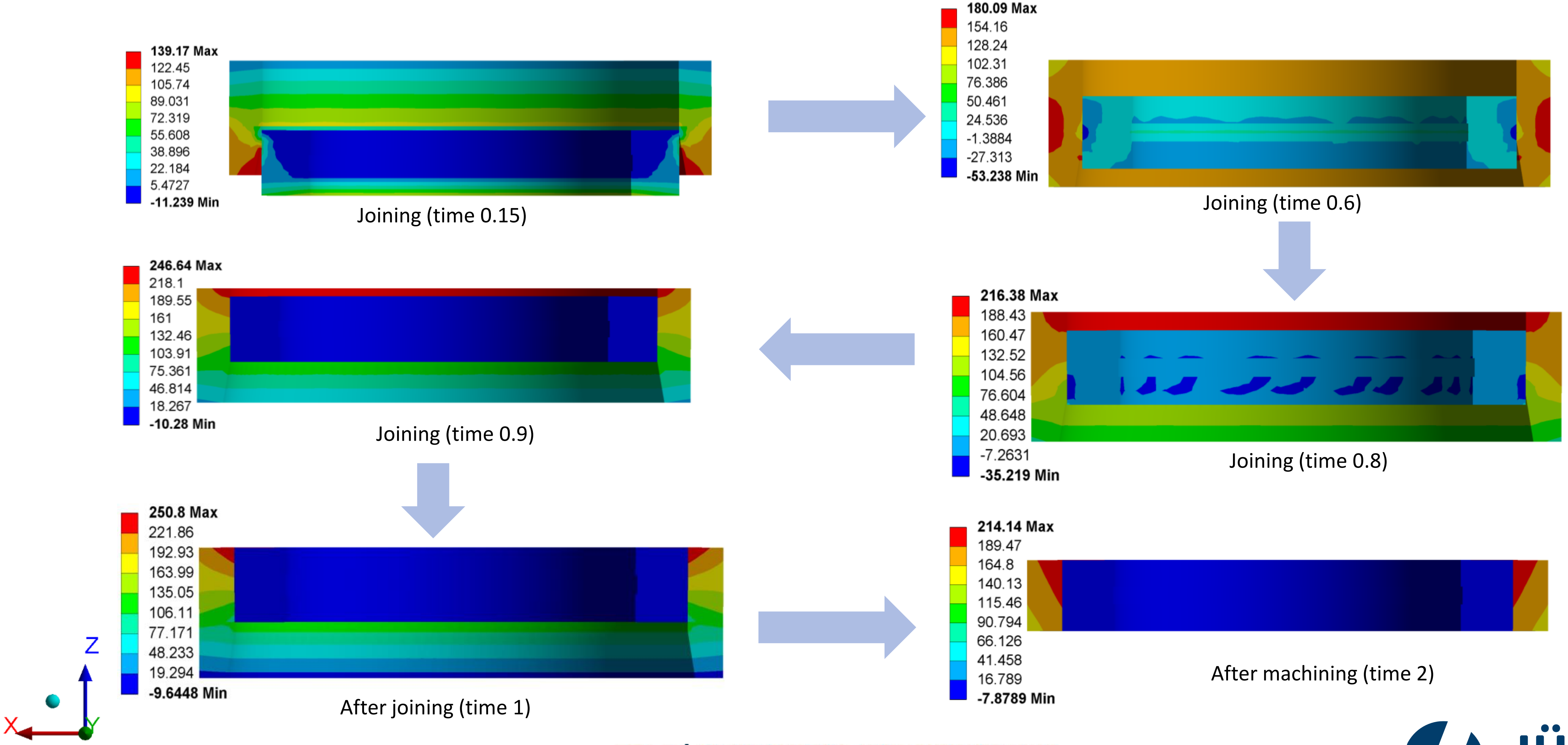
Distribution of the minimum principal stress on the magnet ring after joining (machining)

- Simulation Step

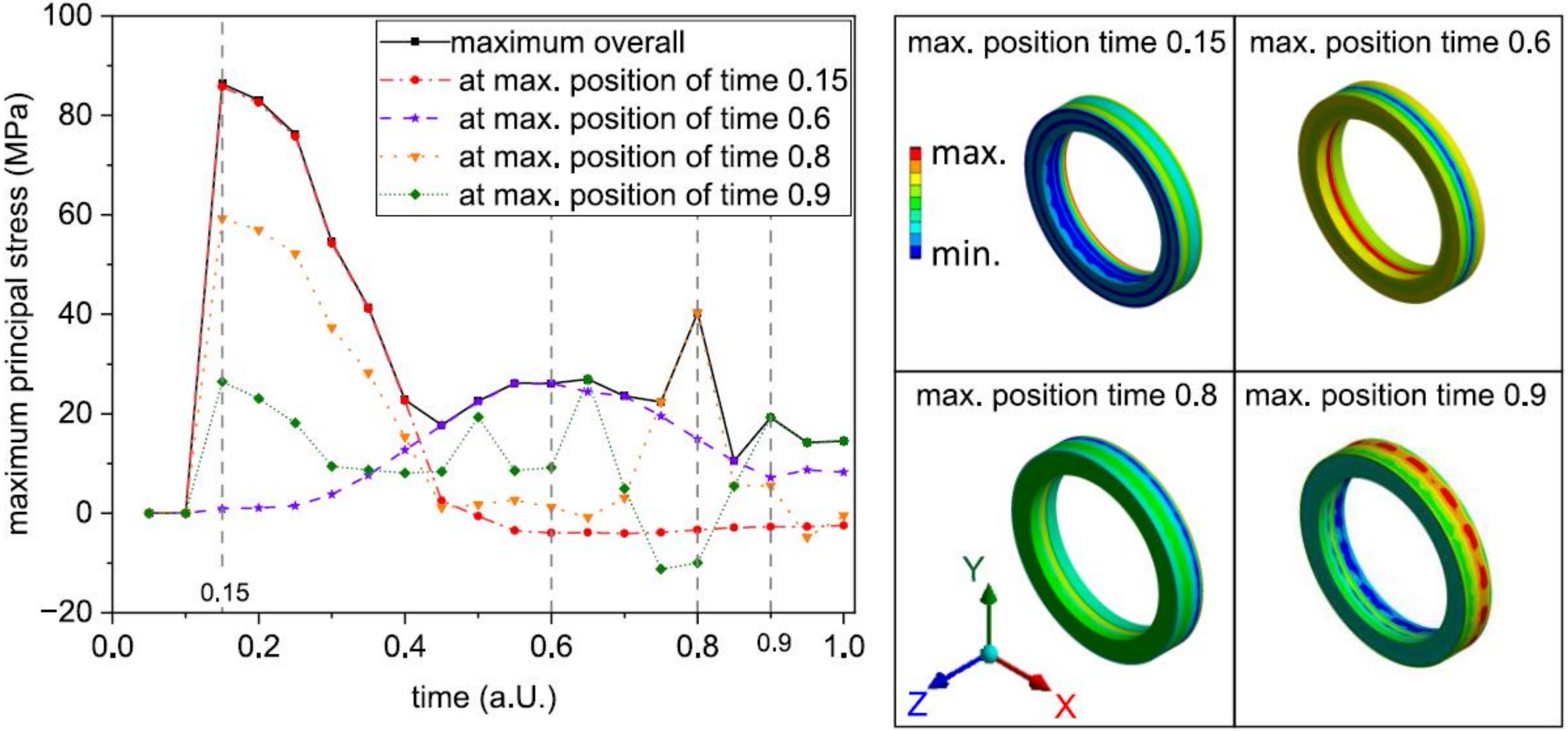
1. Press-fit assembling of the bandage
2. Removal of the excess bandage part with the chamfered edge
3. Acceleration of the assembly to rotation speeds up to 120,000 RPM

SIMULATION THE JOINING PROCESS

Maximum principal stress on bandage and magnet

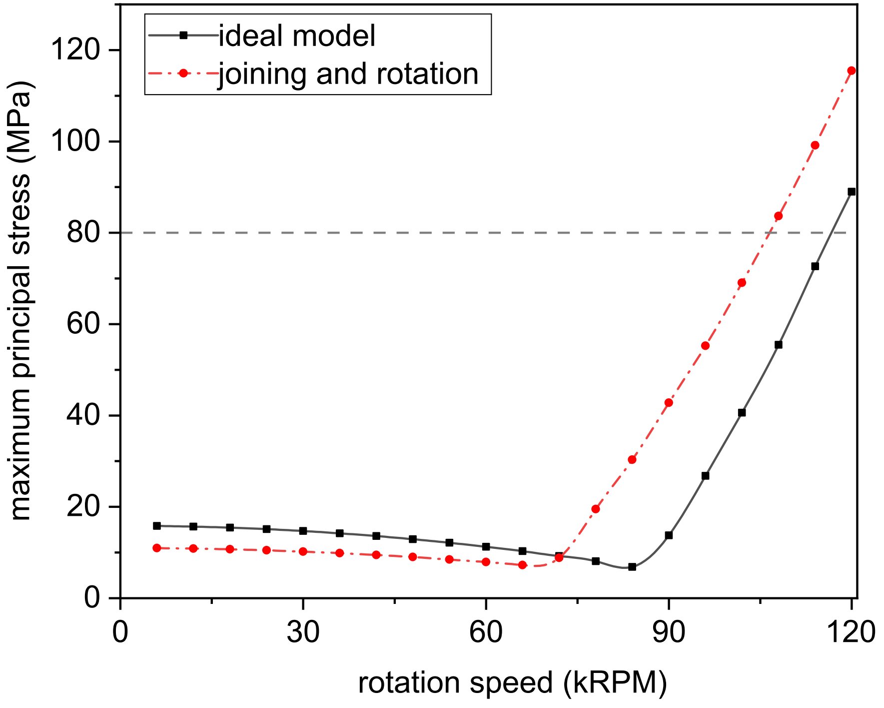


SIMULATION THE JOINING PROCESS



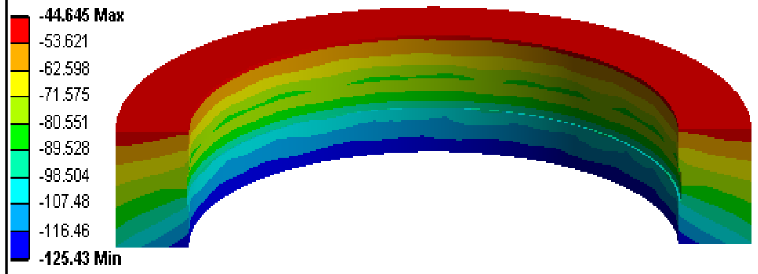
Maximum principal stress on the magnet ring for 2 mm bandage thickness and 60 µm interference and local max. stresses in the magnet ring during the joining process

SIMULATION THE JOINING PROCESS

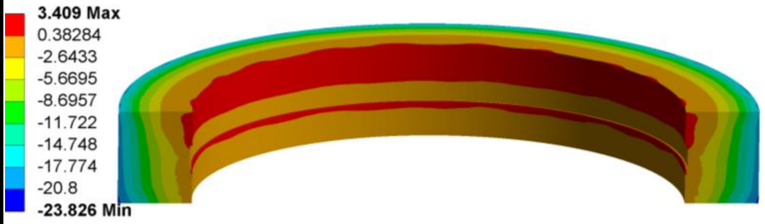


Rotation speed dependent maximum principal stresses of the magnet ring after joining compared with the ideal model

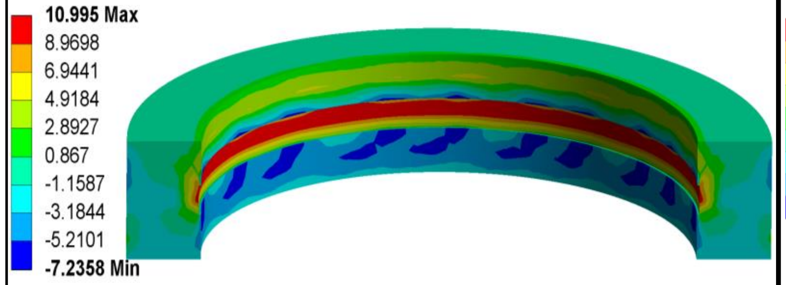
Distribution of the minimum principal stress on the magnet ring after joining (machining)



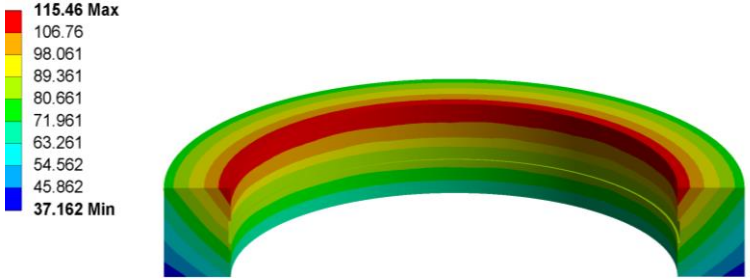
Distribution of the minimum principal stress on the magnet ring at 120,000 RPM



Distribution of the maximum principal stress on the magnet ring after joining (machining)

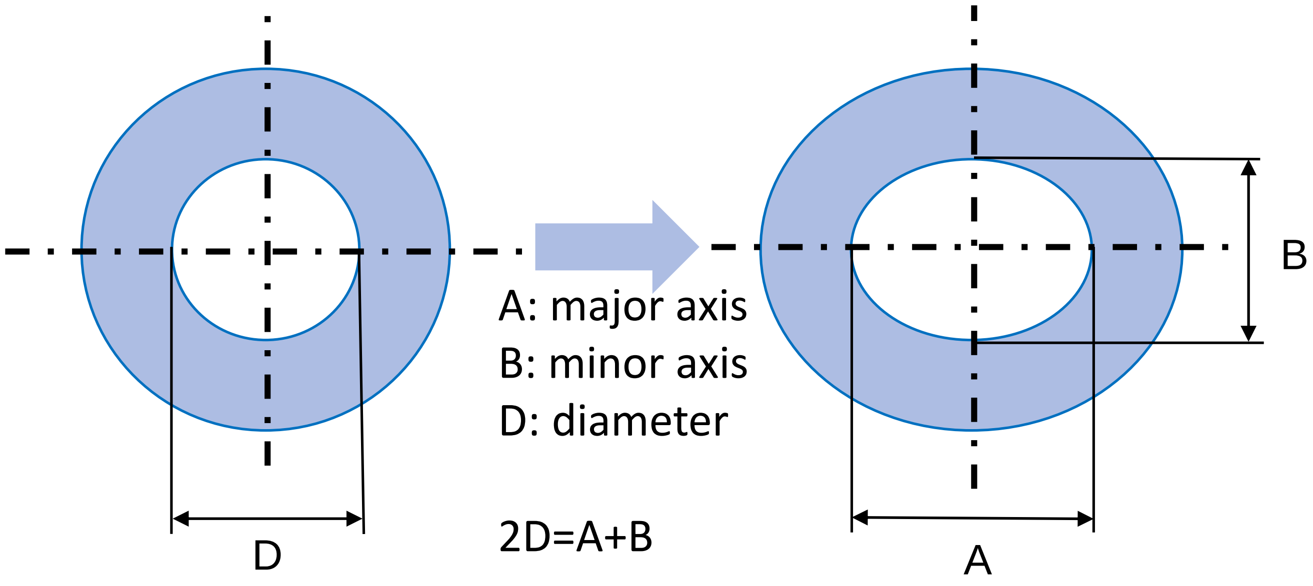


Distribution of the maximum principal stress on the magnet ring at 120,000 RPM



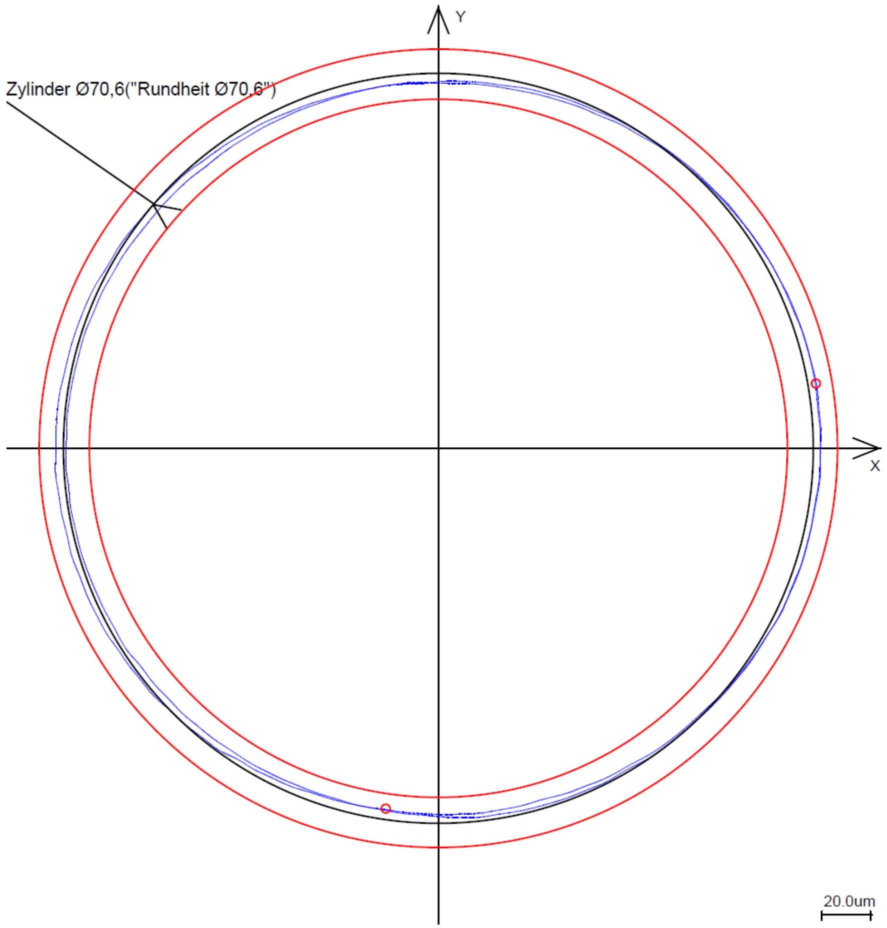
JOINING PROCESS CONSIDERING MANUFACTURING TOLERANCES

Bandage ovalization



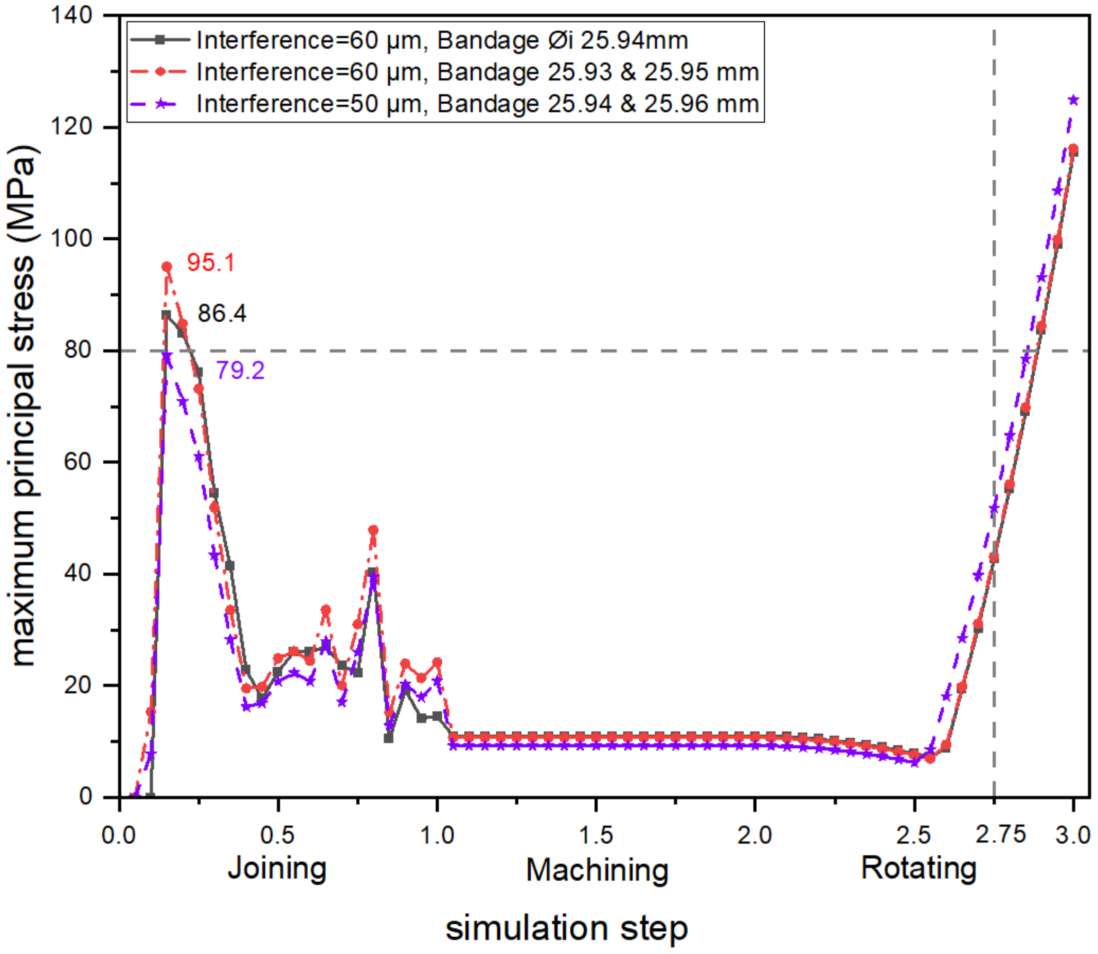
A: major axis
B: minor axis
D: diameter

2D=A+B



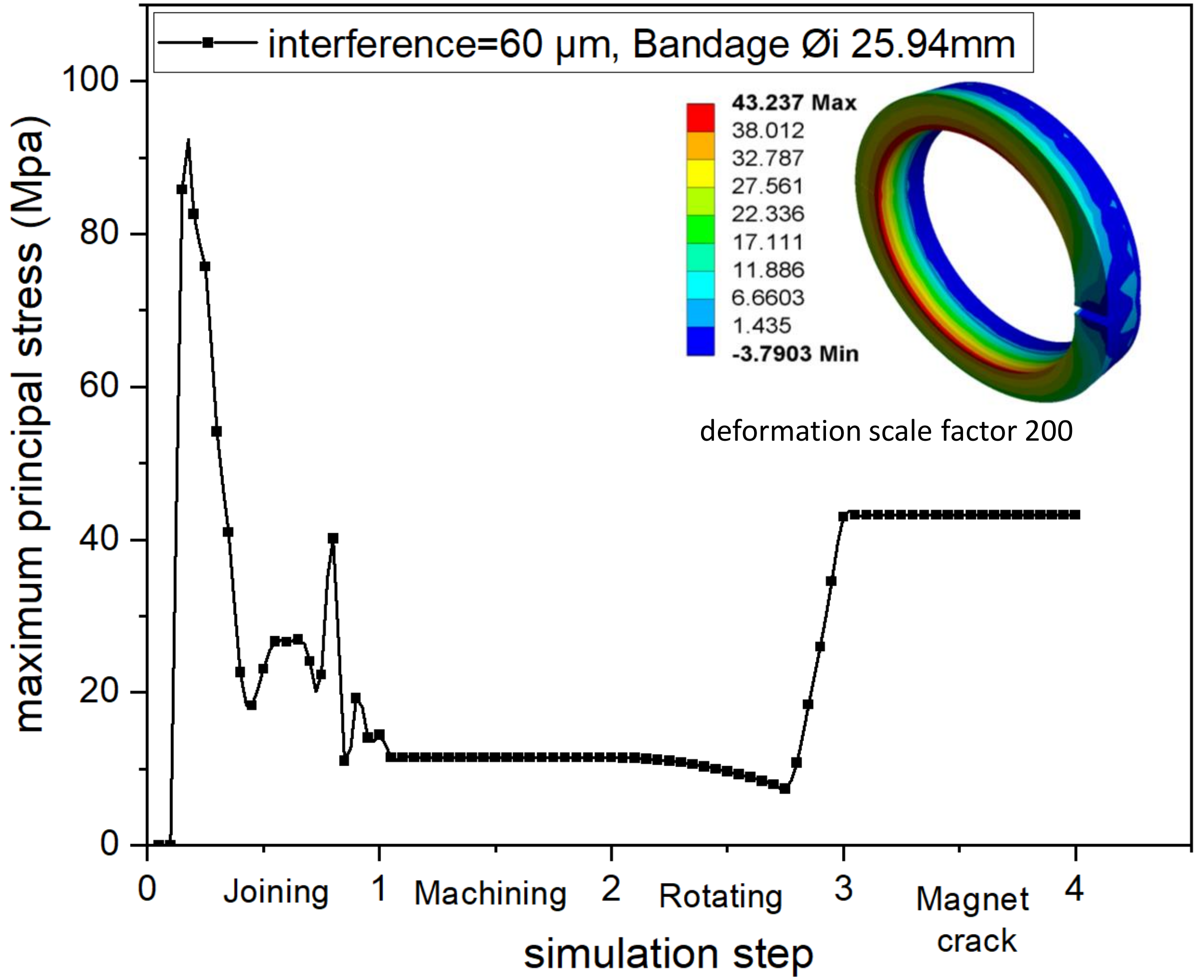
Measurement result bandage Øi=70.6mm

SIMULATION THE JOINING PROCESS CONSIDERING MANUFACTURING TOLERANCES



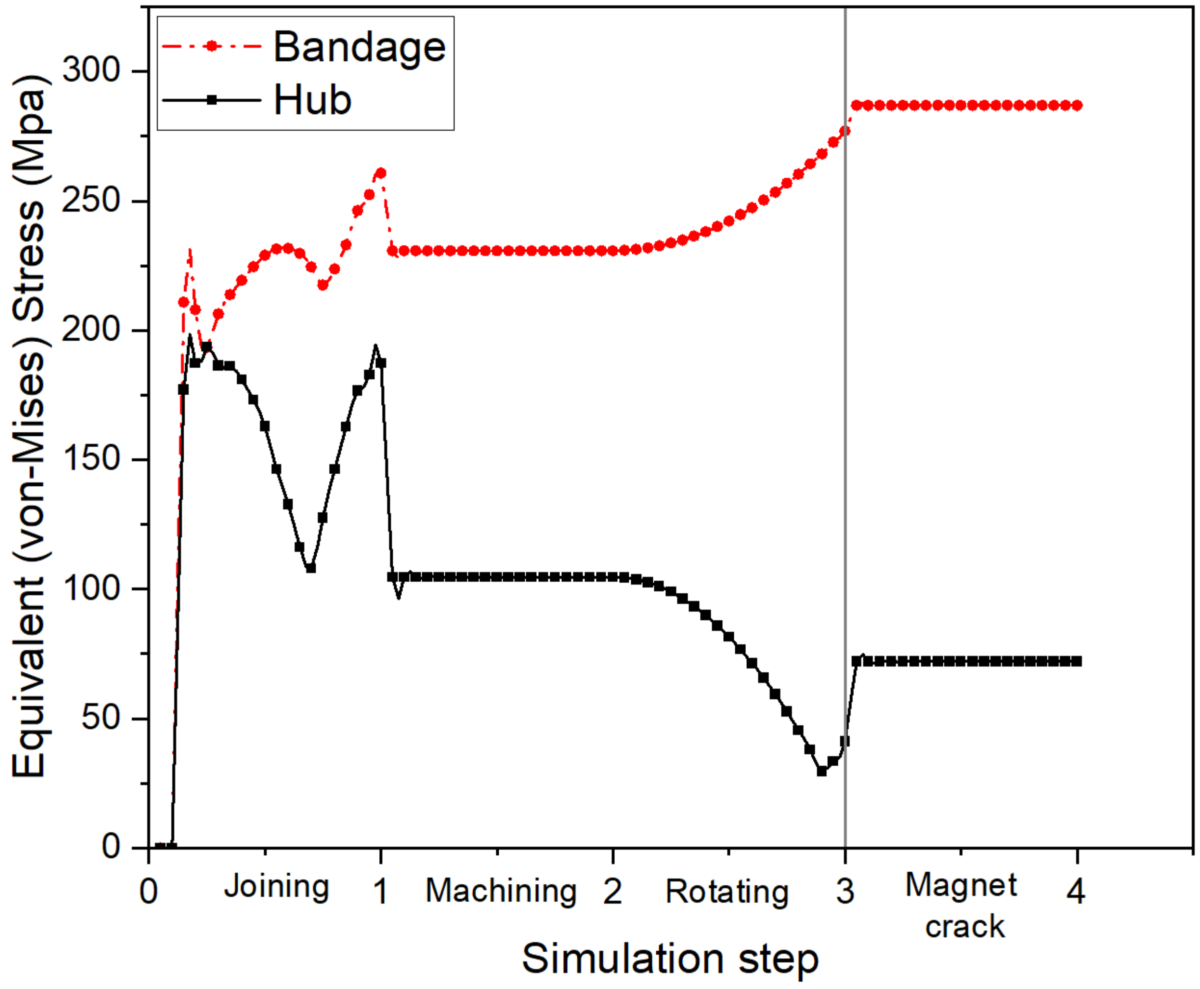
- Stress maximum increases from 86 MPa to 95 MPa by 10 µm ovalization
- The ovalization does not significantly influence the stresses during rotation
- Decrease allowable tolerances and allowable speed

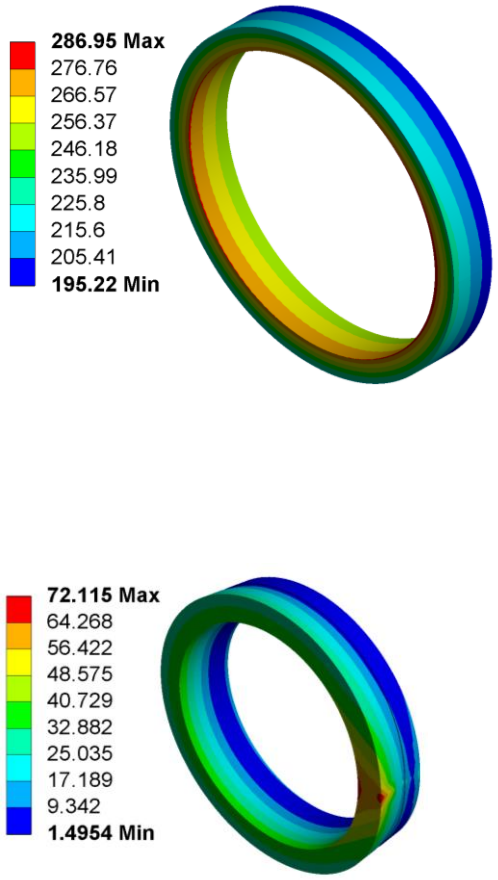
FAIL-SAFE BEHAVIOR IN CASE OF A MAGNET FRACTURE



- Undetected magnet defects due to manufacturing flaws or local damage during the joining process→ Crack of magnet
- At 90,000 RPM. With a tensile stress of 43 MPa
- Maximum principal stress on the undamaged part of the magnet ring increases only marginally by less than 1 MPa

FAIL-SAFE BEHAVIOR IN CASE OF A MAGNET FRACTURE





- Hub: equivalent von-Mises stress increases after cracking from 41 MPa to 72 MPa.
- Bandage: equivalent von-Mises stress increases from 277 MPa to 287 MPa.
- All stress increase after cracking is uncritical.
- Contact pressure between bandage and magnet of 27 MPa

CONCLUSION

- Stresses on the magnet are the limiting factor of the rotation speed.
- Idealized system: bandage thickness and the required rotation speed define suitable tolerances.
- press-fit joining process and ovalization effects of the bandage decrease allowable tolerances and allowable speed
- Safety analysis shows that the hub-magnet-bandage assemblies analyzed here are safe with respect to magnet cracking even at high speed.

OUTLOOK

- Measurements for joining process→determine the coefficient of friction for unlubricated joining, lubricated joining and joining with adhesive.
- Microsections of magnets and bandages before and after joining →changes of the roughnesses at the contact surfaces and analyze consequences of localized tensile stress above the magnet's strength limit during the press-fitting.
- Simulations and experiments for bandages made of carbon fiber-reinforced polymers.


Q&A