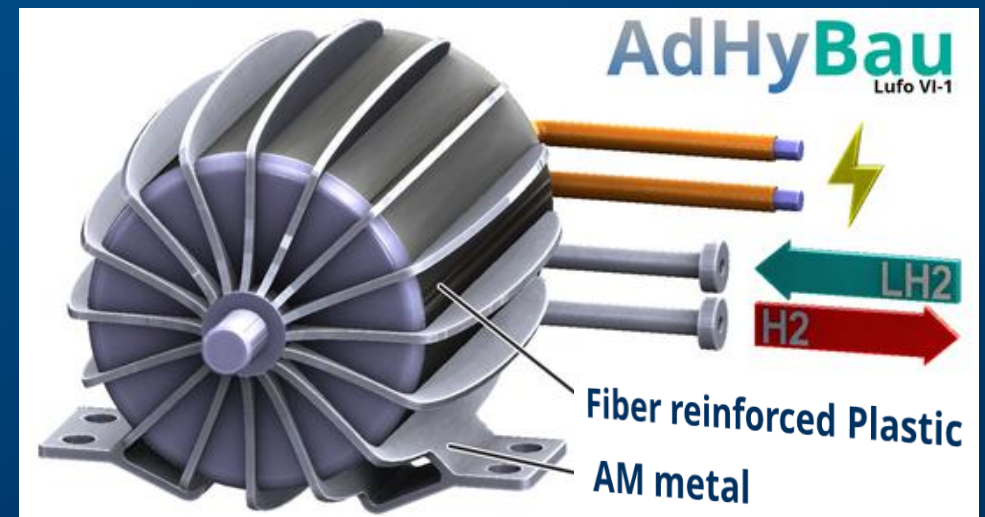


New concept for cryogenic gaseous hydrogen-cooled lightweight electric engine

Martin Pohl, Richard Grothe, Sebastian Spitzer,
Maik Gude, Niels Modler

ICMC2023 // 10th July 2023



VISION

The ILK is the leading international institute for research, development in the field of function-integrative lightweight engineering based on multi-material design



ILK-TEAM

245

employees in a broad interdisciplinary team



70

years of lightweight research in Dresden

YOUNG TALENTS

80

graduates per year



CONTINUOUS RESEARCH AND DEVELOPMENT CHAINS

Material, Modelling, Simulation, Design, Processing, Quality, LCA



>1



Start-Up a year (at present 18)



INDUSTRIAL COOPERATION

with European large-scale industry and regional SMEs



~1.000

Alumni since 1997



35% Basic research

35% Application-oriented research

30% Industrial Development



Promoting initiatives for children, women and young talent
ACL e.V.
juniorING e.V.



INTERNATIONAL NETWORK

among others with partners in UK, Poland, Korea, China, Singapore, Romania, Australia, USA



1. Introduction of the project

Hydrogen-electric propulsion system for aviation

Engineering Design

- Efficient coil design and optimized cooling systems through additive manufacturing for high power density electric machines ► 10 kW/kg
- Cryogenic hydrogen as cooling medium and energy source
- New lightweight design of hybrid structures with fiber reinforced composites and additively manufactured metal components

Simulation

- Digitalization in product development ► design and simulation process based on a digital twin of electric machines

Materials

- Investigation of cryogenic material properties of additively manufactured test specimens
- Influence of hydrogen on additively manufactured materials

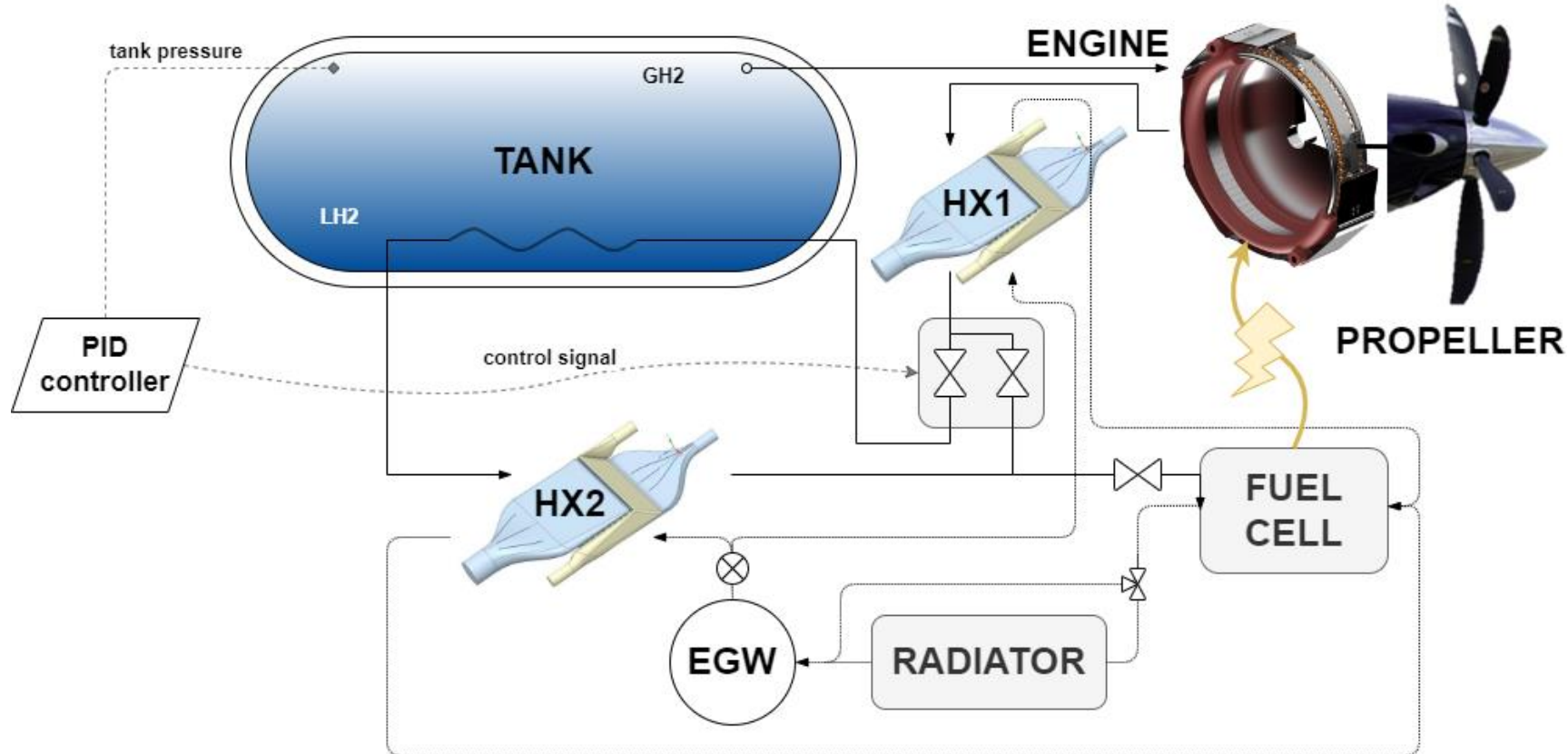
SIEMENS



7. Project partners on CEC/ICMC 2023

Date Time	Room	Title	Speaker	Session ID
Monday 9:30 AM	Emalani 320	Additive Manufacturing and hybrid materials in high power...	Ch. Weidermann	J1 Or 1A
Monday 5:45 PM	Emalani 320	New concept for cryogenic gaseous hydrogen-cooled lightweight electric engine	M. Pohl	M1 Or 3G
Tuesday 11:30 AM	315	Development of additively manufactured cryogenic heat exchangers for hydrogen-ele...	M. Vietze	C2 Or 2B
Wednesday 10:30 AM	318	Cryogenic material testing with gaseous hydrogen for hydrogen-electric aircraft prop...	F. Ebling	M3 Or 1A
Wednesday 11:00 AM	318	Cryogenic thermo-physical properties of additive manufactured...	K.-P. Weiss	M3 Or 1A
Wednesday 11:20 AM	318	Additive Manufacturing of Cryogenic Materials	Olaf Rehme	M3 Or 1A

2. Concept of the power train



electric propulsion engine	
Total mass	50 kg
Nominal power	500 kW
Max. torque	2000 Nm
Max. speed	3000 rpm

LH2	Liquid hydrogen
GH2	Gaseous hydrogen
HX	Heat exchanger
EGW	Ethylene glycol water mixture

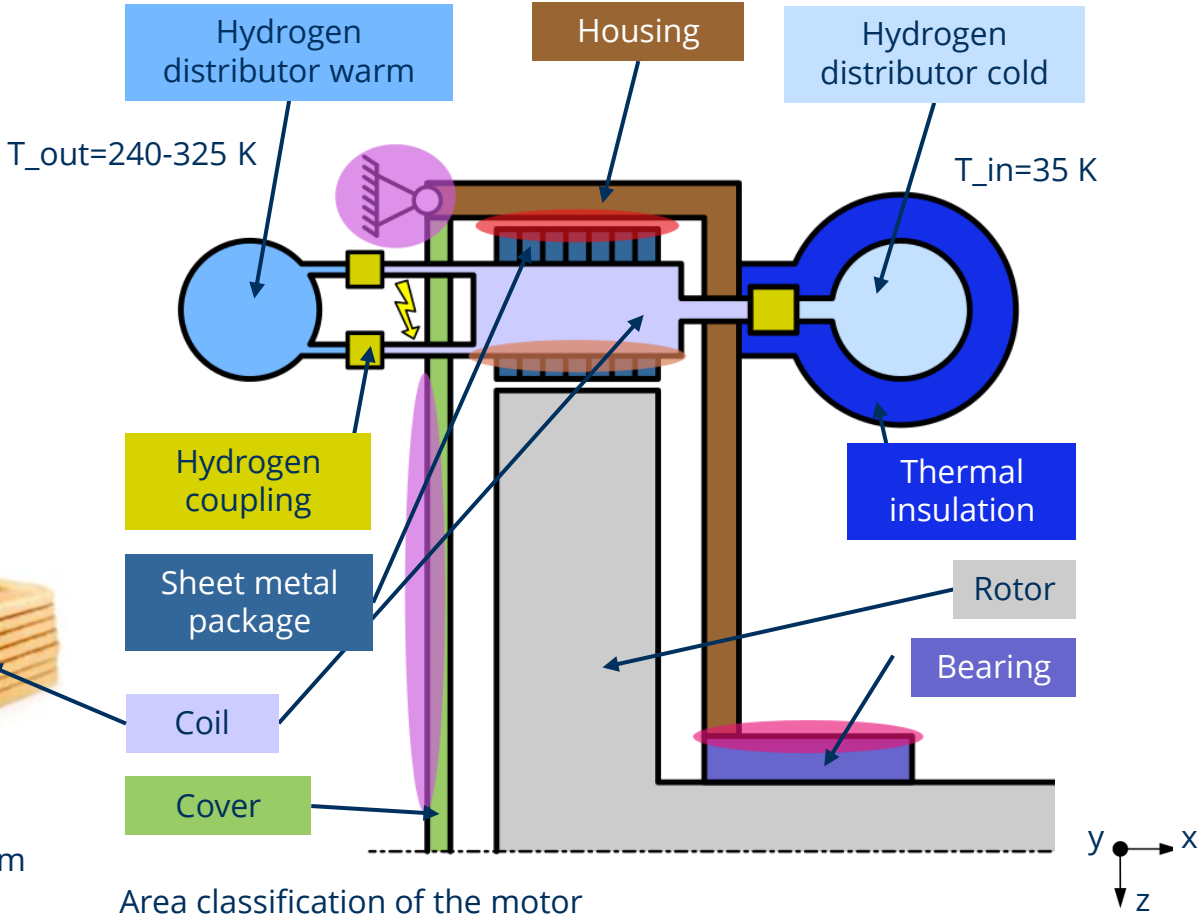
3. Concept of the stator from the motor

- ILK-design path
- Electrical design → SIEMENS
 - permanently excited synchronous machine
 - Operating voltage: 1500 V
 - 78 Coils
 - 52 magnets
 - Outer diameter sheet metal package: 560 mm
 - Length sheet metal package: 50 mm
 - Air gap: 3 mm

Variable requirement	Value
Low mass	40%
Manufacturing effort	27%
Service life	13%
Low volume	11%
Time-to-market	9%



Coil demonstrator, made from AM Copper [SIEMENS]



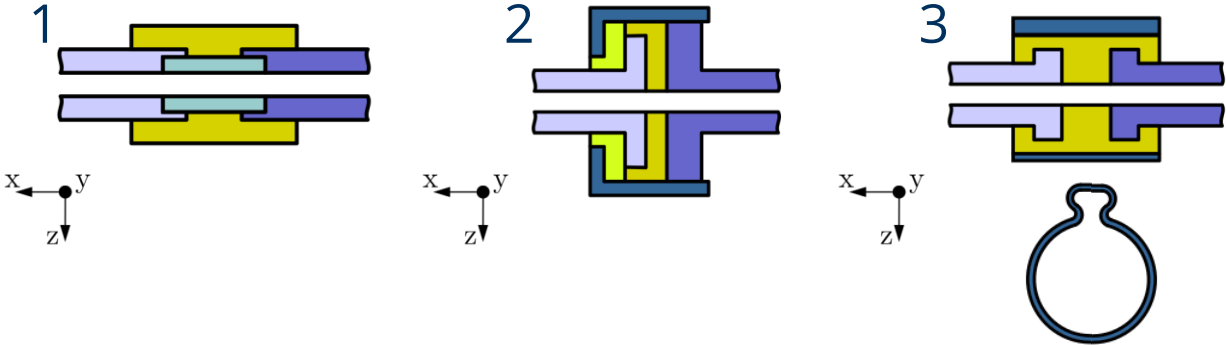
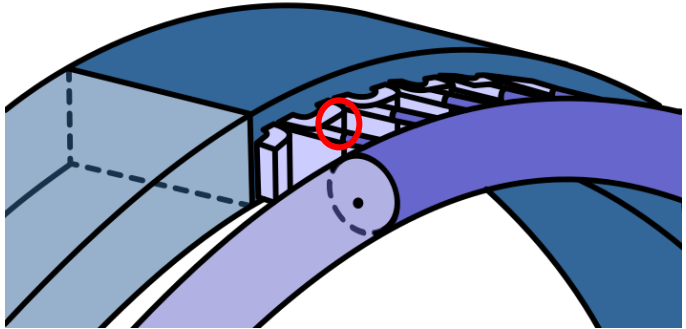
5. Conception hydrogen coupling Overview

Requirements

- Low loss of hydrogen
- electrically insulating

Challenges

- Amount of connections (234 joints)
- Little space for assembly
- Cryogenic conditions



5. Conception hydrogen coupling

Detailed concepts

Electric

- Voltage difference 1500 V
- Gap between metal estimated with Paschens law, with security factor of 2 we need 0,24 mm distance → 1 mm chosen (more practical)

Hydrogen leakage

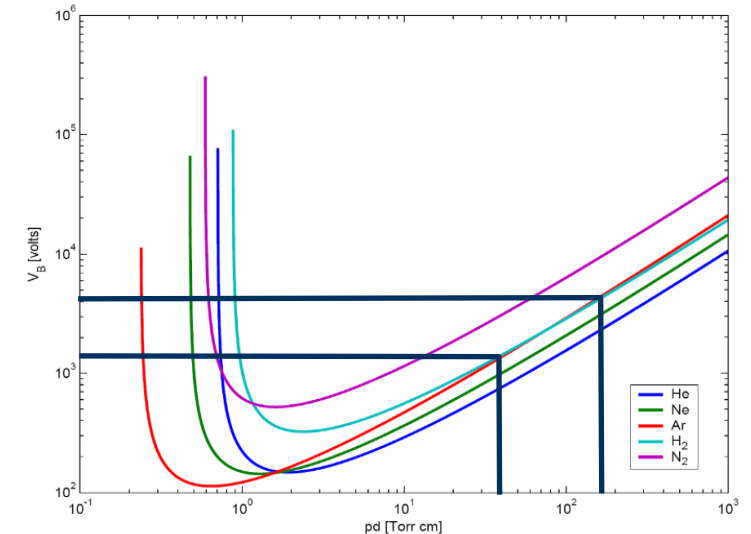
- Allowable permeation of 4,6 ml/h/L to not get an ignitable mixture in a flight cycle
- Comparison of the permeability of different sealing materials → sealing lengths between 0,4 mm and 1,8 mm

Mass calculation

- Use of densities and estimation of the volumes for the coupling concepts

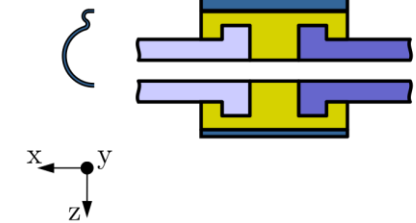
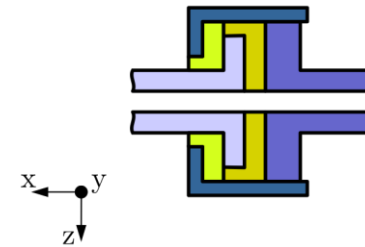
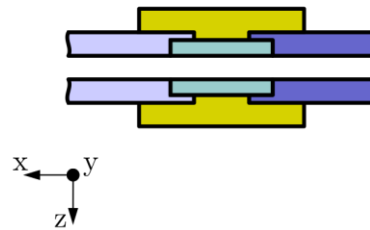
Open question (work in progress)

- Sealing behavior under cryogenic conditions



5. Conception hydrogen connector

Rating and selection

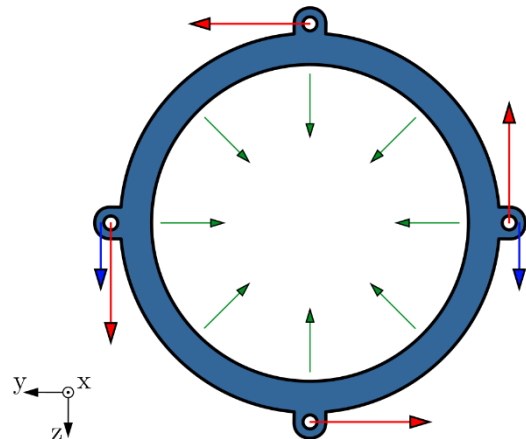


Variable requirement	Value [%]			
Low mass	40	7,5	4,3	10,0
Manufacturing effort	27	8	1	10
Service life	13	0	10	5
Low volume	11	10	10	10
Time-to-market	9	10	10	5
Total	100	7,1	5,3	8,9

6. Conception stator bearing Overview

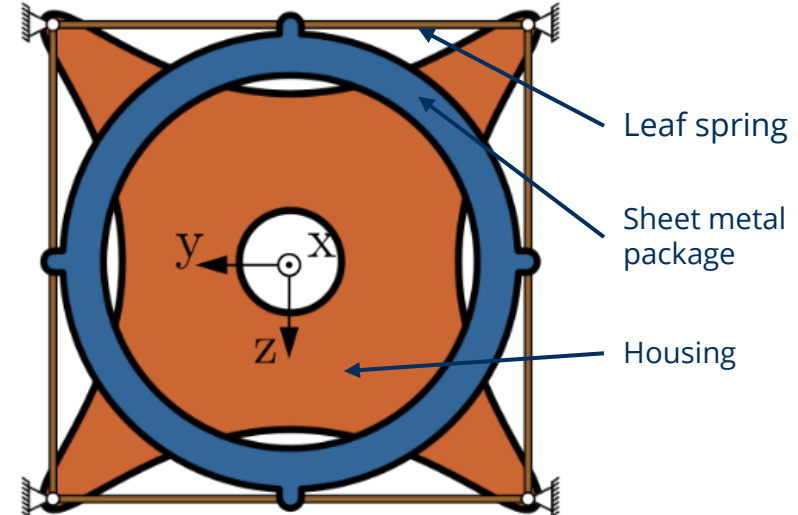
Requirements

- compensate for displacement by cooling the sheet metal package
- Forces due to maneuvering accelerations and torque support must be conducted into the housing



- Thermal displacement
- Forces due to maneuvering accelerations
- Torque support

Concept



Preliminary design

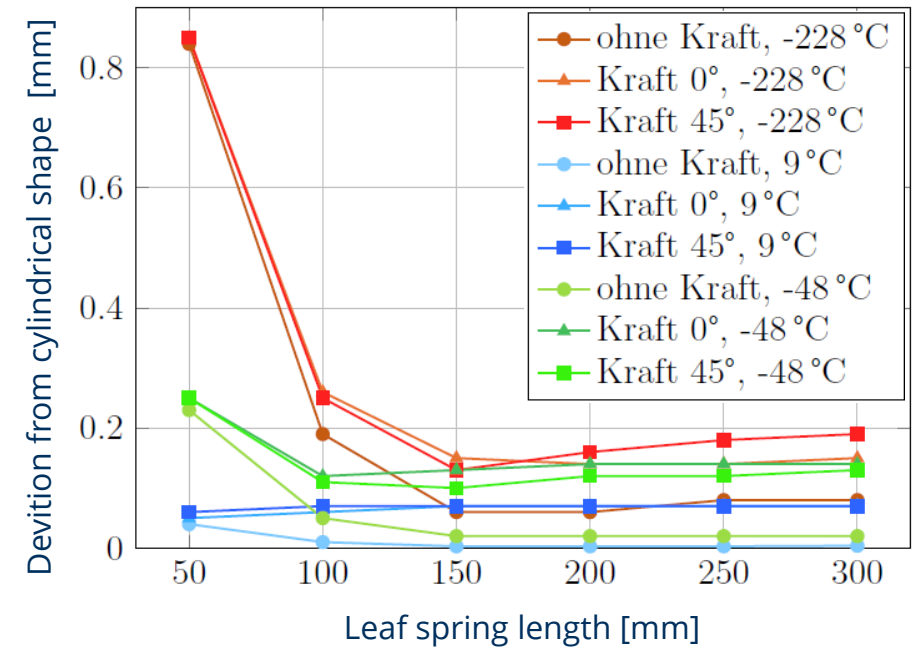
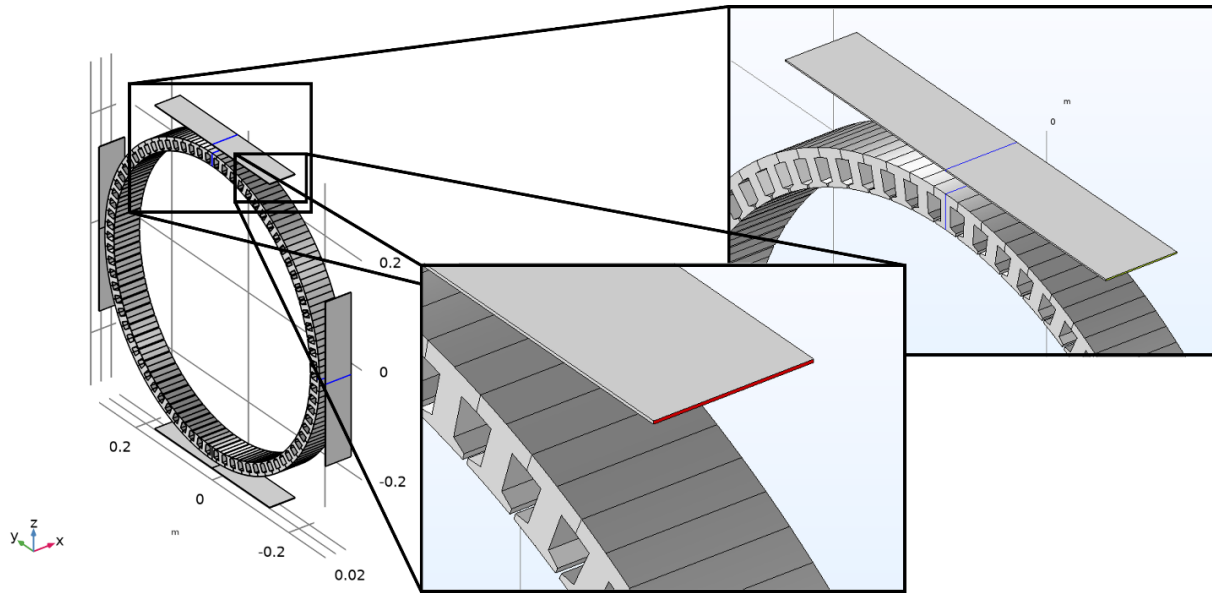
- Thickness for the leafspring: steel 0,5 mm, titanium 1 m, CFRP (canvas fabric) 3,5 mm
- Buckling analysis shows no problems for the investigated lengths of the leaf springs

6. Conception stator bearing

Detailed concepts

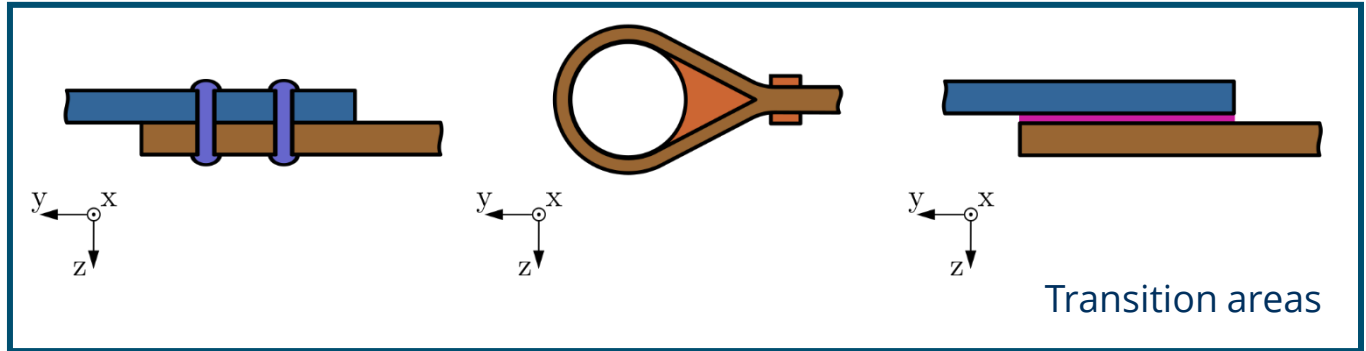
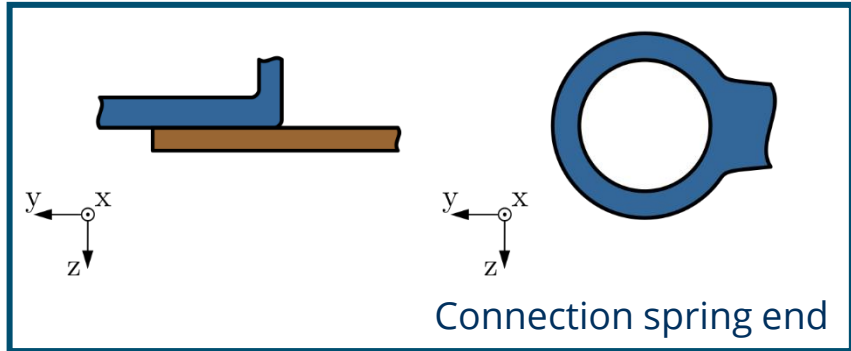
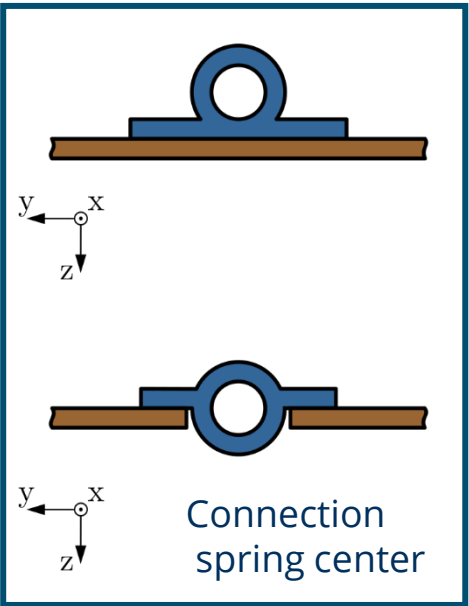
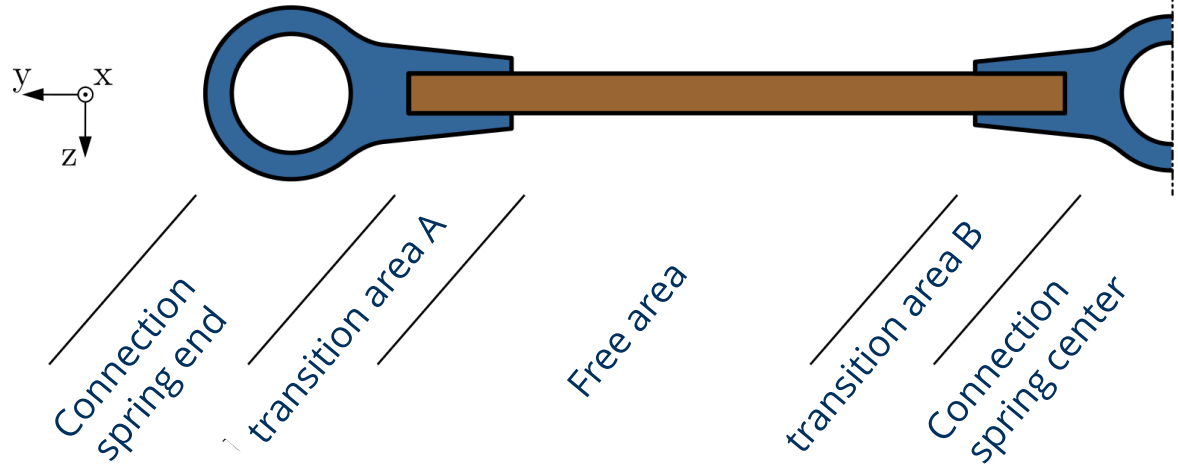
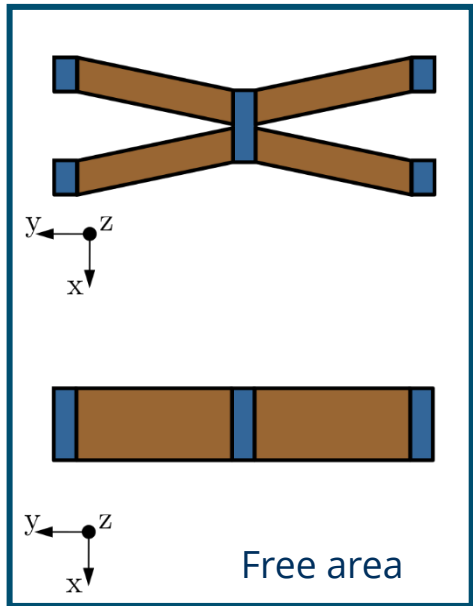
Parameter study - deviation from the cylindrical shape of the sheet metal package depending on the spring length

- Variable lengths between 50 mm and 300 mm
- Loads from Torque an flight maneuvers like accelaration or flight of a curve
- Temperature of the sheet metal package



6. Conception stator bearing

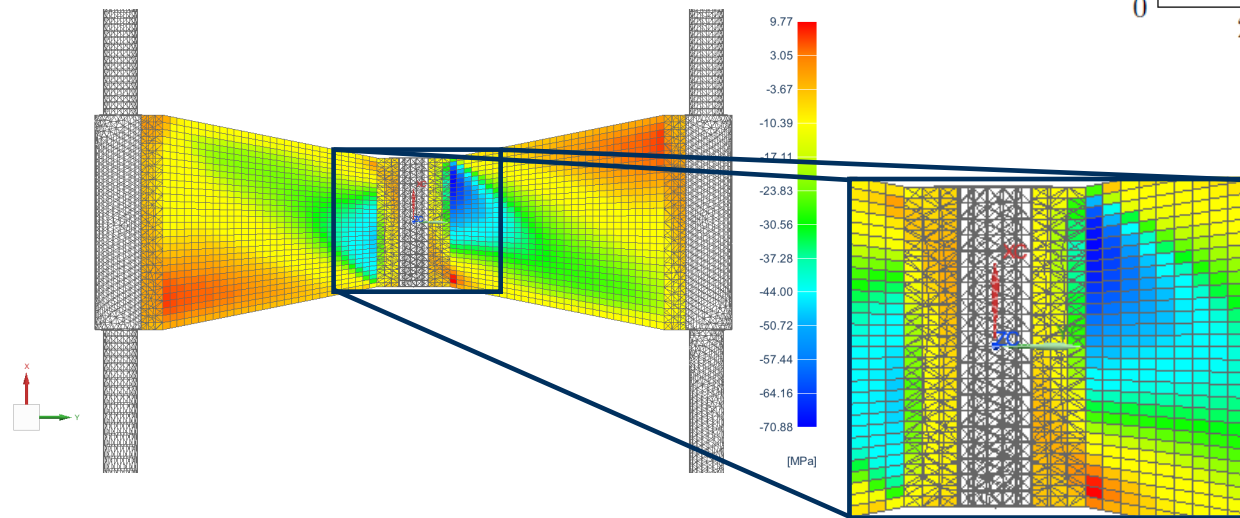
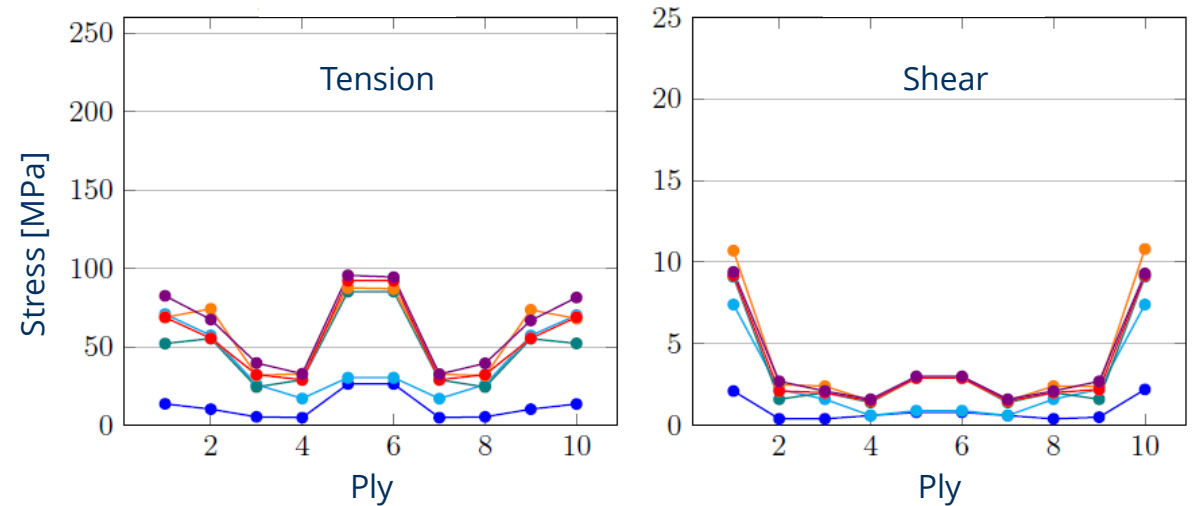
Area classification and concepts for leaf spring



6. Conception stator bearing

Results of numerical clculation

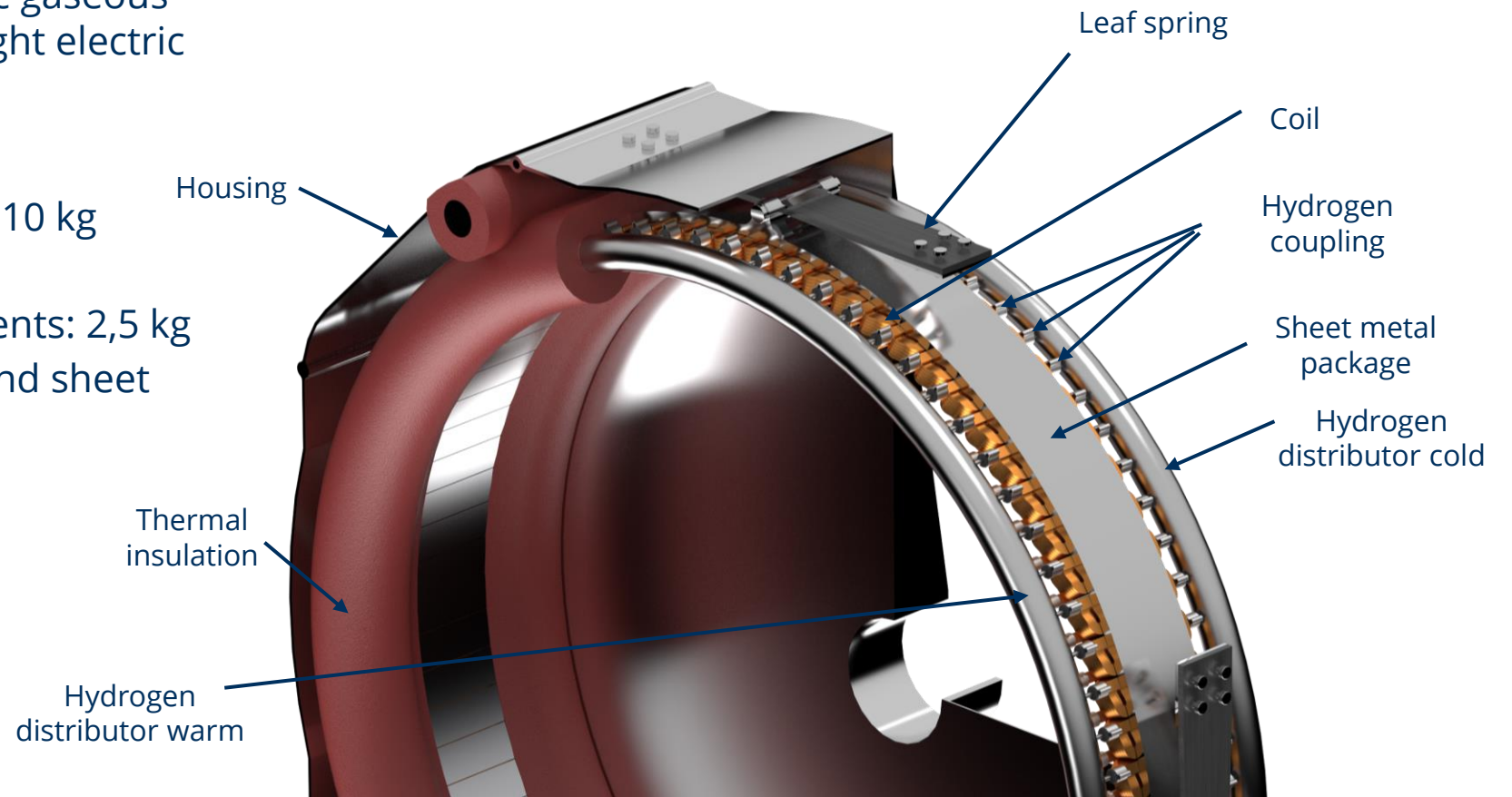
- Relatively lightly loaded component
- Dimensions are rather dominated by practicable handling



- Maneuver-x
- Maneuver-x + shrinkage
- Maneuver-x + torque
- Maneuver-x + torque + shrinkage
- Maneuver-y + torque
- Maneuver-y + torque + shrinkage

7. Summary

- New concept for cryogenic gaseous hydrogen-cooled lightweight electric engine described
- Estimated masses
 - Sheet metal package: 10 kg
 - Cu coils: 7,1 kg
 - Other stator components: 2,5 kg
 - Rotor with magnets and sheet metal package: 12 kg
 - **Total: approx. 32 kg**



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Supported by:



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by the German Bundestag

Thank You! Questions?

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