ecoswing

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Status of the Ecoswing project

EUCAS 2017, Geneva

Markus Bauer on behalf of the Ecoswing consortium

THEVA Dünnschichttechnik GmbH, Rote-Kreuz-Str. 8, D-85737 Ismaning, Germany

"EcoSwing has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 656024."
"Herein we reflect only the author's view. The Commission is not responsible for any use that may be made of the information it contains."

Core ambitions

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- Design, develop and manufacture a full scale multi-megawatt direct-drive superconducting wind generator
- Install this superconducting drive train on an existing modern wind turbine in Thyborøn, Denmark
(3.6 MW, 15 rpm, 128 m rotor)
- Prove that a superconducting drive train is cost-competitive
- **Have the generator running in 2017.**

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Platform for technology validation

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- The idea is to replace a PM generator with a superconducting generator

- This includes power conversion and refrigeration equipment.

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Key technical figures

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- **Generator:** Synchronous
- **Drive Train:** Direct Drive
- **Superconductor:** 2G Coated Conductor
- **Refrigeration:** Gifford-McMahon
- **Power Converter:** 4Q-IGBT
- **Turbine:** 2 Bladed, On-shore.

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Key project figures

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- **Program:** EU Horizon 2020
- **Reference:** 656024
- **Start Date:** 2015-03-01
- **End Date:** 2019-03-01
- **Total Cost:** EUR 13,846,594
- **EU Contribution:** EUR 10,591,734.

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Integrated consortium

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- 9 Partners from 5 countries working for a common goal

ENVISION
ECO 5
JEUMONT Electric
DELTA ENERGY SYSTEMS
THEVA
SHI Cryogenics Group
Fraunhofer
UNIVERSITY OF TWENTE.
DNV·GL

- Project web site: www.ecoswing.eu

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Topics of the project

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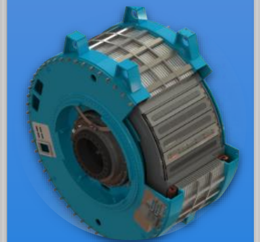
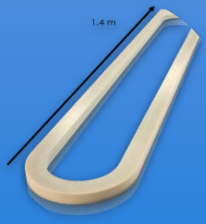
Specs



Design

Materials



Compo-
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Assembly

Testing

Installa-
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Regulatory Oversight

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Topics for this presentation

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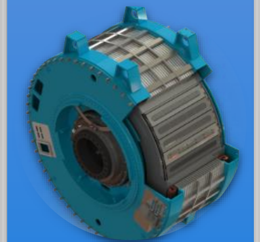
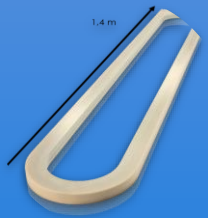
Specs



Design

Materials



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Specifications

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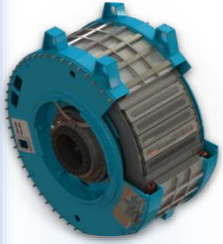

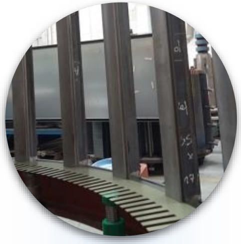


Specs

Design

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General requirements

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- Design according to IEC61400 and IEC60034 series
- 3.600 kW, 2.460 kNm, 690 V, 50 Hz
- Insulation class F
- Max temperature rise class B
- Temperature, external: -20 °C +30 °C
- Altitude: 2000 m
- Humidity <95%, 100% for 10% of life
- Turbine system mechanical load
- Vibrations (Fore-aft, Side-side, Roll, Nod, Yaw)
- Restricted space request for compact design
- Serviceable wear parts
- Service interval minimum 1 year
- Lightning protection IEC61400-24

Same as for conventional generators

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Unique requirements

- Stability of superconductor supply
- Reliable Coil winding
- Robust and proven cryogenics (incremental innovation)
- Risk mitigation through testing of sub components.

Unique for superconductive generators

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Design

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Specs

Design

Materials

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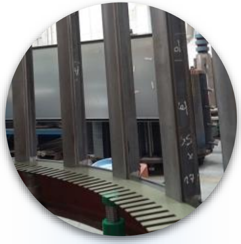

Assembly

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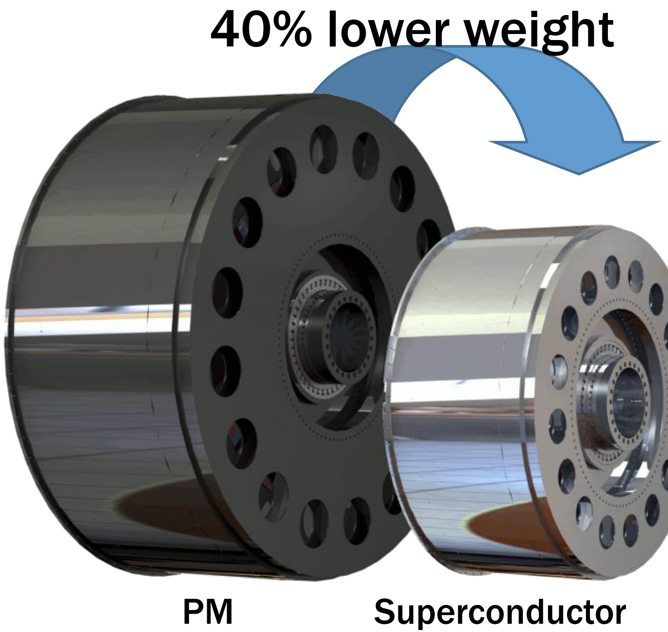
Main design goals



- **All roads capability:** diameter limited to < 4 m
- **Low cost design:** Commercial components for superconductors as much as possible
- **Low weight design:** Optimized for low top head mass
- **Mainstream markets:** 3.6 MW for on-shore and off-shore.

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EcoSwing generator
Design specifications

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	Design Specification
Generator terminal power	3.6 MW
oD generator frame	4,000 mm
Rated speed	15.0 rpm
Stator type	With iron core sheets
Stator primary cooling	Radial air cooling
Stator voltage	710 V
Axial core length	1,142 mm
Stator coils	Form wound copper coils, mica insulation system, VPI, class F
Bearings	2 main
Free mechanical air gap	13 mm
HTS wire dimensions, bare	12 x 0.2 mm^2
Current density in HTS pack	~ 100 A/mm^2
Efficiency (rated)	~ 92%
Current loading	132 kA/m
Cogging torque	< 0.5%
Load torque ripple	< 1.5%
THD stator voltage	~ 1 %

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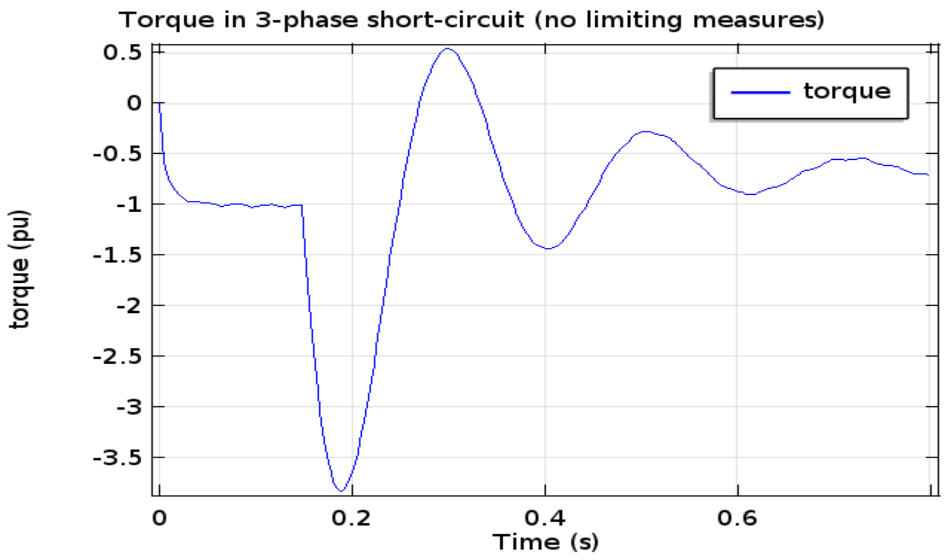
JEUMONT Electric

Short circuit computations

- A short circuit event in the power converter is not very likely—but a potentially disastrous event
  - It can break the generator as well as the hub and the blades
  - In the example (right) it amounts to 4x nominal torque
- Torque-limiting measures needed
  - Overrating for high torque in short circuit events counters the thermal efficiency of the HTS rotor.



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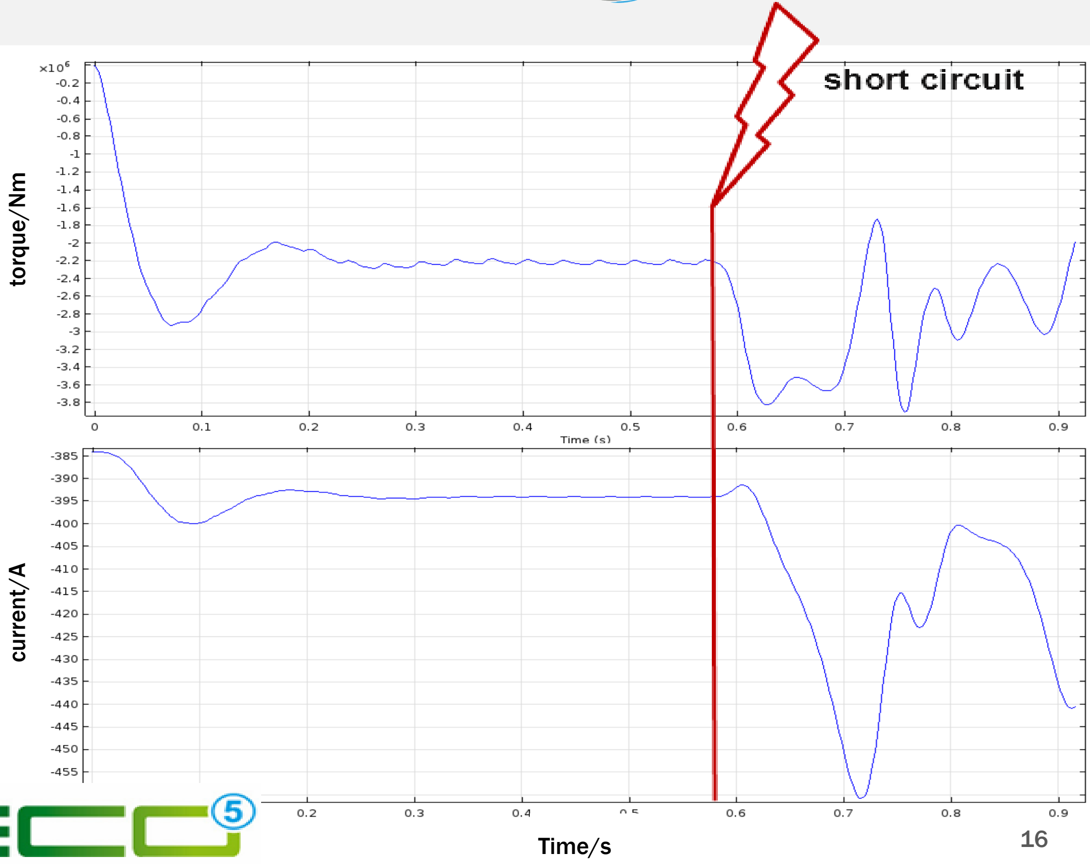
Short circuit computations

- Computation of the short circuit torque is required
  - Makes calculation of entire ring necessary (not just one pole)
  - Must include inertia of rotor and shaft as torsional spring
  - Must include stator and rotor
- Example shown (right)
- Mechanical design was made such that it sustains this short circuit, and the resulting torque levels.



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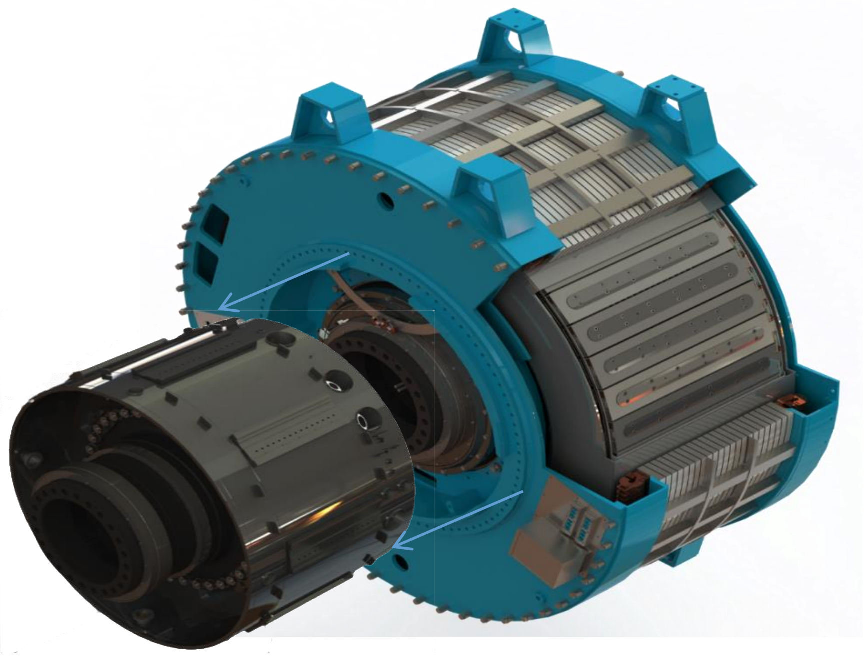
Dual use vacuum chamber

- Cryostat serves two purposes:
  - Thermal insulation
  - Force transmission from shaft to the HTS poles
- Here the cryostat constitutes also the inner structure
  - One piece
  - Lower cost
  - Can be made of low cost steel.



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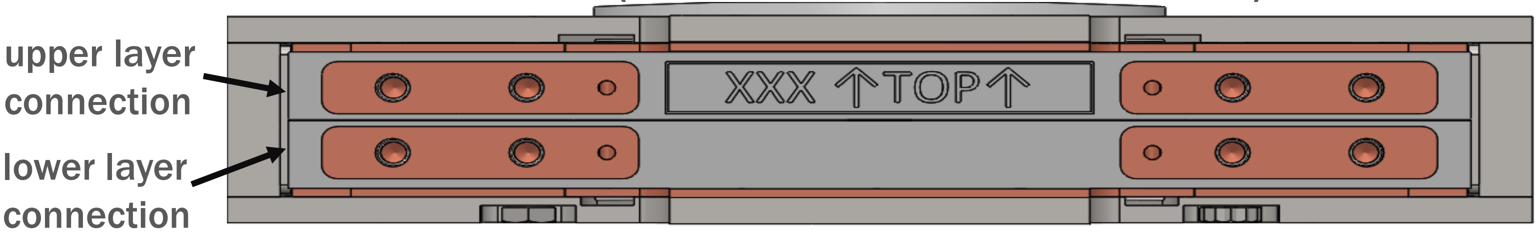
Pole connectors

- HTS coils are all the same (no difference in N and S Pole)



- Connectors are designed such the NSNS Pole arrangement is achieved.

Current feed through

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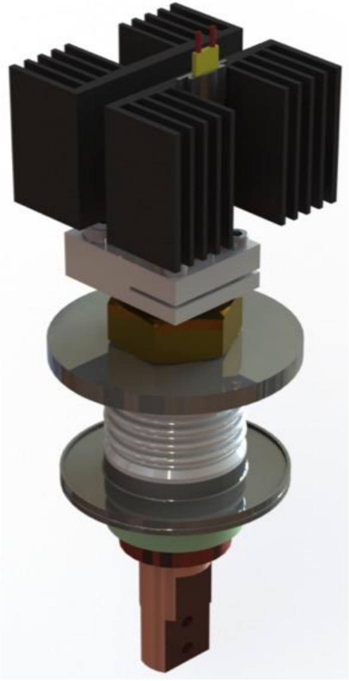
- Commercially available current feed throughs were considered inadequate for use in vibrating wind power environment.
- A robust system was developed allowing high current, industrial metal seals, no ceramic soldered to metal and a large cross-section allowing a small thermal gradient.



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Materials

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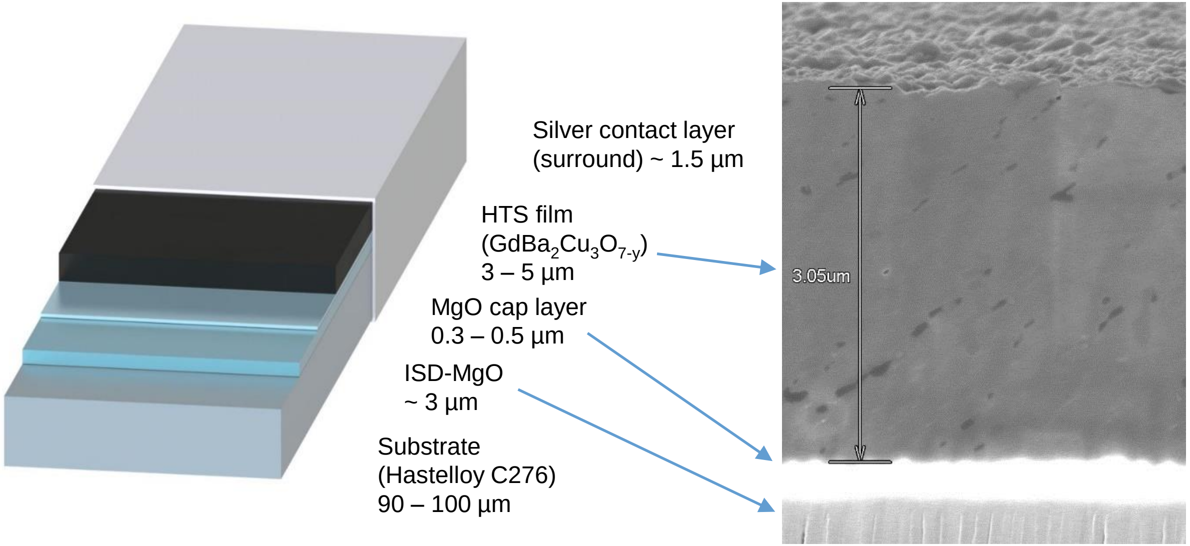
THEVA Pro-Line™

- High performance 2G HTS tape
- Simple layer architecture
- Contains 20 years of R&D
- Unique approach –
  all IP owned by THEVA



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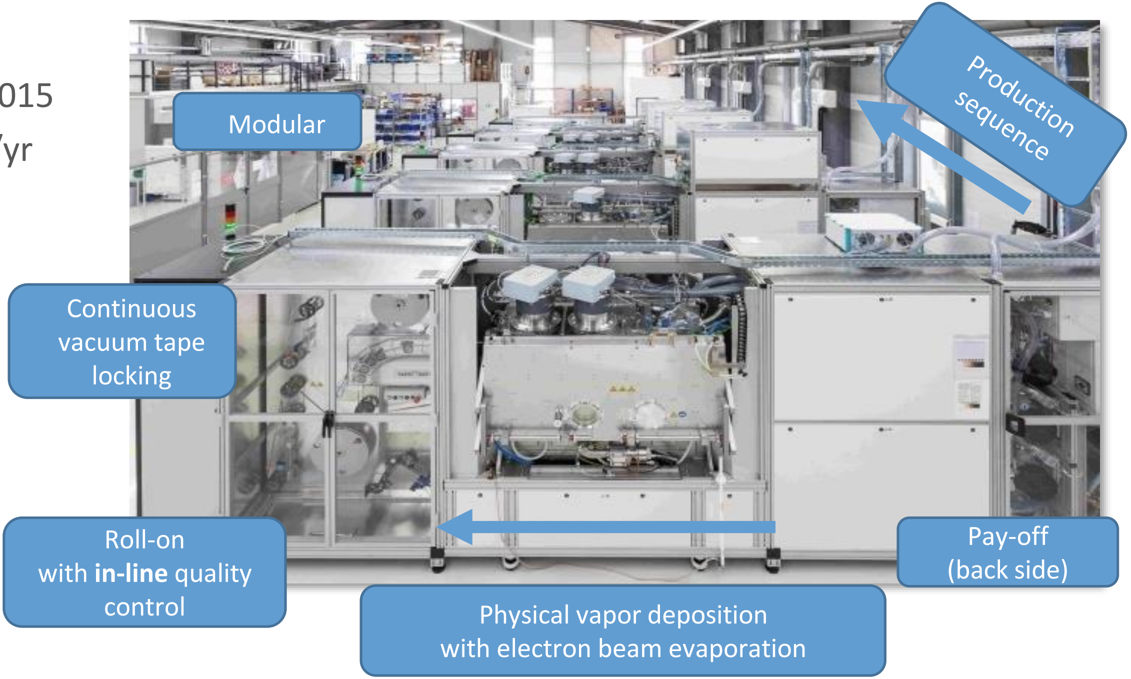
HTS Tape production

Production Features

- Built 2012-2014, commissioned end of 2015
- Maximum production capacity: 150 km/yr (@ 12 mm-width)
- Production tape length: 300 m, up to 600 m demonstrated!

Goals

- Cost efficient production
- Robust process allowing high yield
- Implementation of industrial standards
- Proof of production: high quality tape



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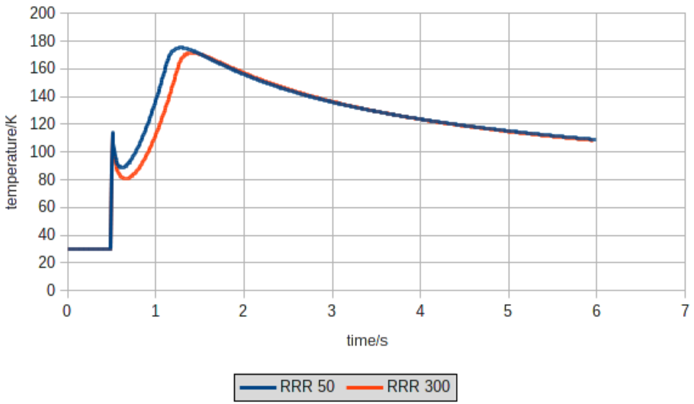
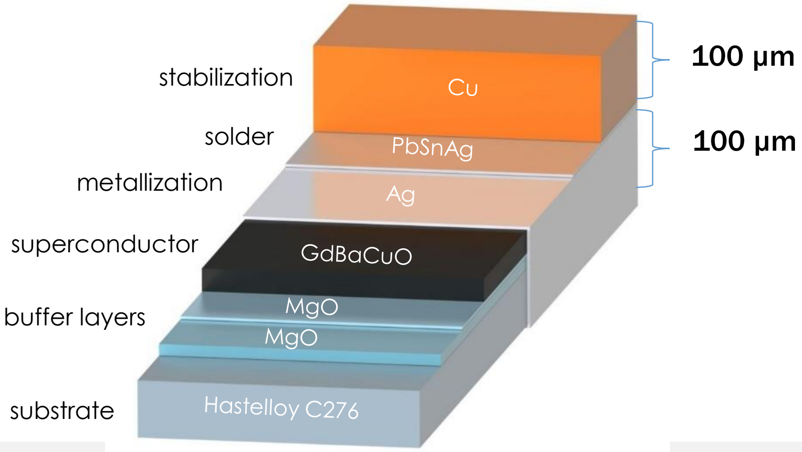
HTS tape design



Example of adiabatic quench temperature simulation

THEVA TPL2100 Pro-Line HTS tape

HTS wire with thick copper stabilization for superior electrical stability and high mechanical robustness

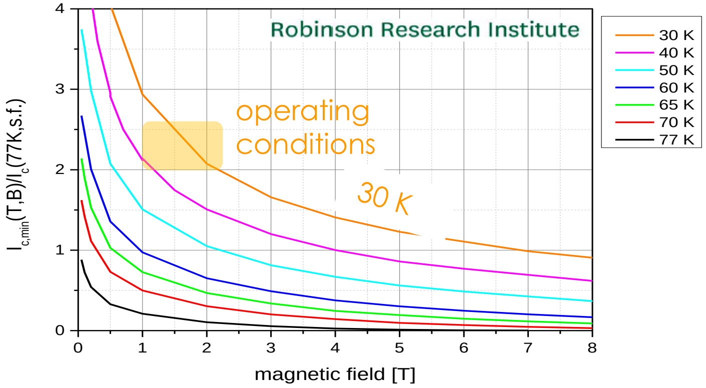


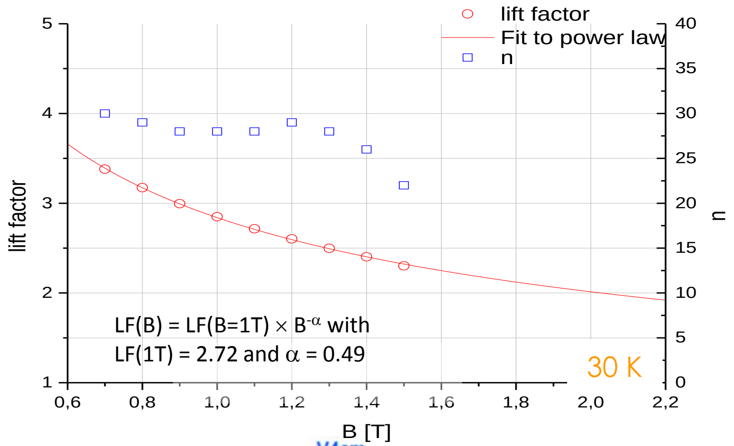
HTS tape designed according to needs!

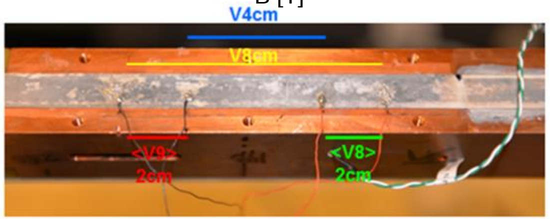
Characterization of HTS tapes

Magnetic field performance - Ic(B,T)

patterned bridges 1-2 mm wide







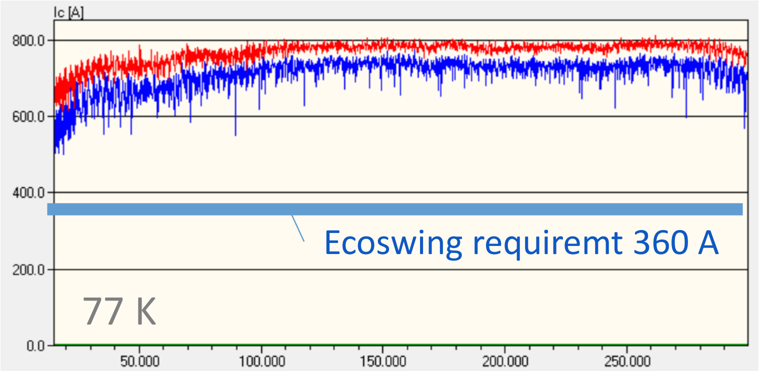
full width samples 12 mm wide, up to 80 mm long

15 samples taken out of production over about **1a**:
LF(1,5 T, 30K) = 2,2 ± 0,4

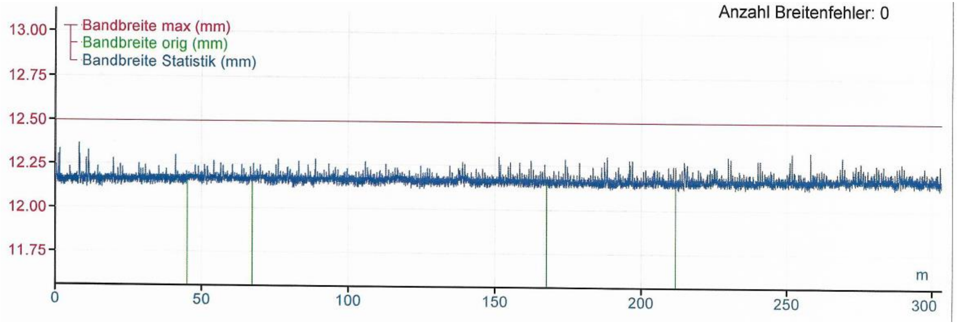
Reliable lift factor as prerequisite for stable production

Quality control of HTS tape

Critical current measurement using Tapestar hall scanning



Optical width measurement after lamination



Other parameters to be controlled: Lamination strength, bending radius, thickness

Quality control is considered crucial for successful manufacturing of the HTS coils

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Qualification of Materials and Procedures
Just a few examples…

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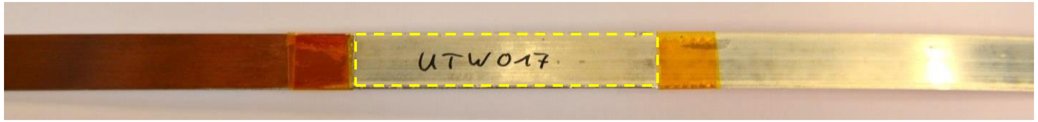
- Qualification of superconductive joints



- Validation of magnetic properties

- Validation of copper RRR

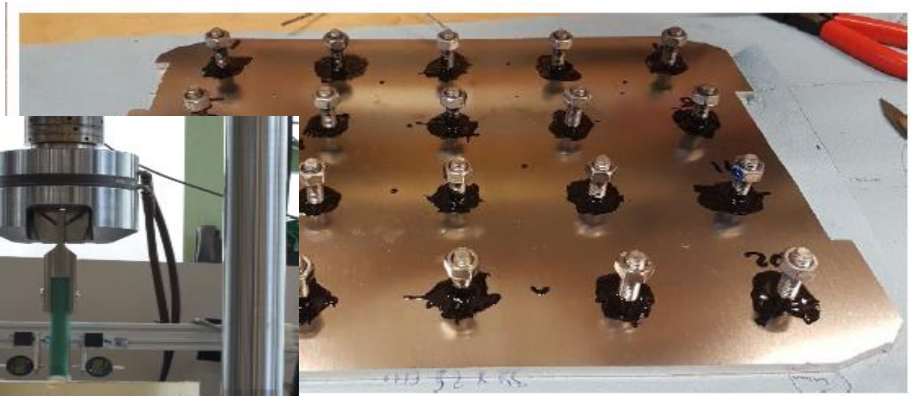
ECOSWING Copper pieces

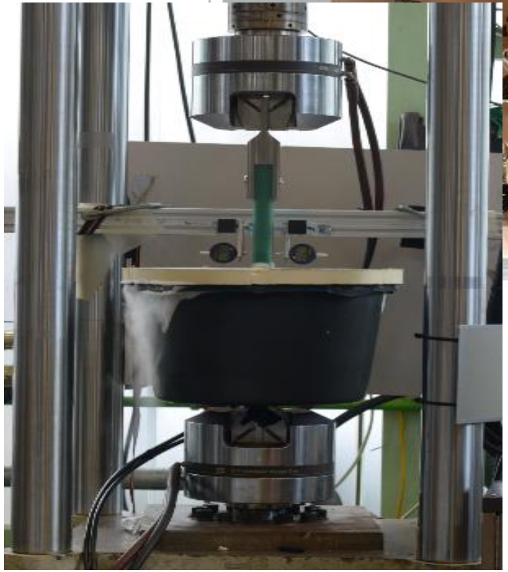
Potential measured across 2.5 cm
Measurement current: 1A at low temperatures, 0.1A at 273.15 K
Operator: Jaap Kosse
Measurement date: 14/10/15

Sample	RRR (273.15/10)	RRR (273.15/30)	R at 273.15K [Ω]	R at 10K [Ω]	R at 30K [Ω]
Piece 2, Electrical connection, #1	124.2	81.6	4.403E-04	3.545E-06	5.395E-06
Piece 2, Electrical connection #2	123.5	81.8	4.575E-04	3.705E-06	5.596E-06
Piece 3, Cooling Plate, #1	78.6	59.0	9.524E-04	1.212E-05	1.613E-05
Piece 3, Cooling Plate, #2	78.7	59.2	9.471E-04	1.203E-05	1.600E-05

Qualification of Materials and Procedures
Just a few examples…

- Qualification of lubricants and adhesives
- Qualification of structural materials (w/ TNO Delft)
- Qualification of getters, sealants, procedure for affixing MLI…





Components

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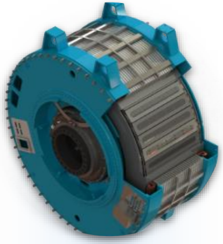
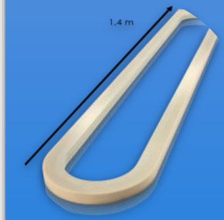
Specs



Design

Materials



Compo-
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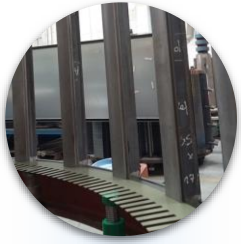

Assembly

Testing

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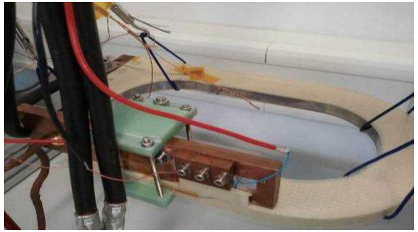
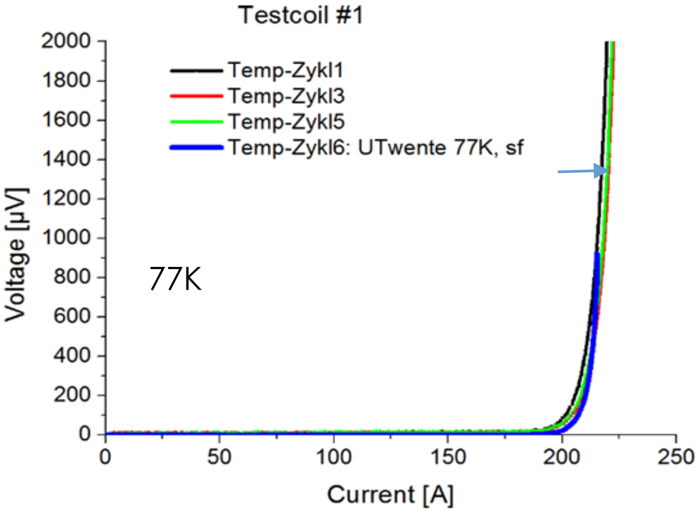
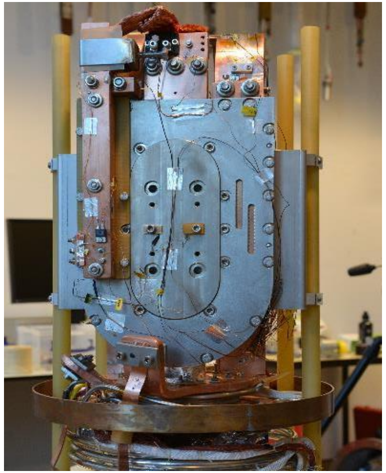
Subscale coil test

Test coil #1
- single layer
- 10 turns



LN_2 test





Pole assembly test
- magnetic pole piece
- non magnetic mechanical support
- conduction cooling

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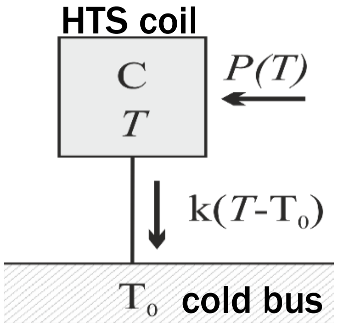
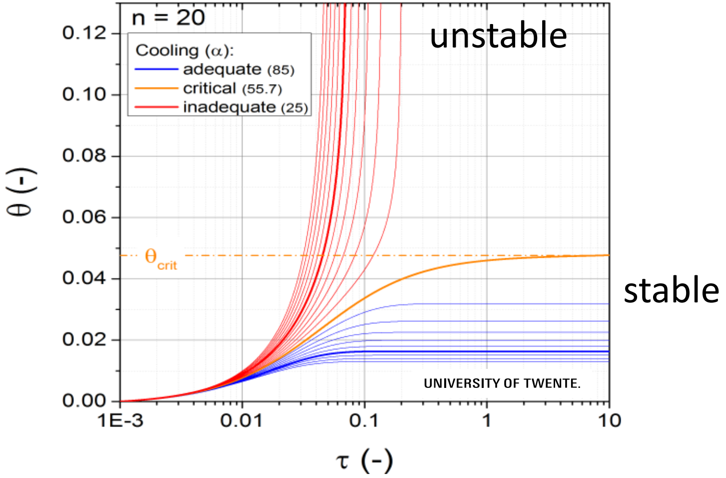
Stability & thermal drift





A very straightforward thermal model, combined with non-linear self-heating …

$$P(T) = I_0 V(T) = I_0 V_c \left[\frac{I_0}{I_c(T)} \right]^n$$

… yields a non-linear 1st order differential equation for the temperature-time response:

$$\frac{d\theta}{d\tau} = \frac{1}{(1-\theta)^n} - \alpha\theta$$

$$\tau \equiv \frac{t}{\Delta t_0} = \frac{P(T_0)}{C\Delta T_0} t \quad \text{and} \quad \alpha \equiv \frac{k\Delta T_0}{P(T_0)}$$

$$\theta \equiv \frac{T - T_0}{\Delta T_0}$$

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HTS full scale coils

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Main characteristics

- Each coil contains more than 500 m of HTS wire and has about 200 turns
- Coils are 1.4 m long, double pancake
- Potted in resin
- Used wire: Standard THEVA Pro-Line HTS conductor with Copper lamination
- Operating temperature < 30 K, conduction cooled
- Pole assembly containing only few parts for fast assembly

coil

pole assembly

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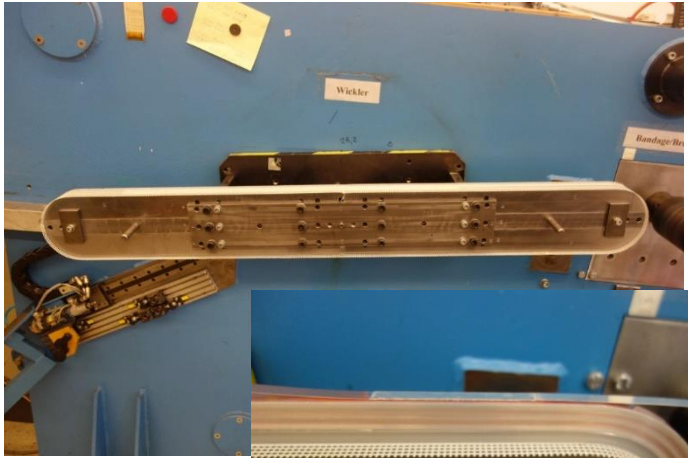
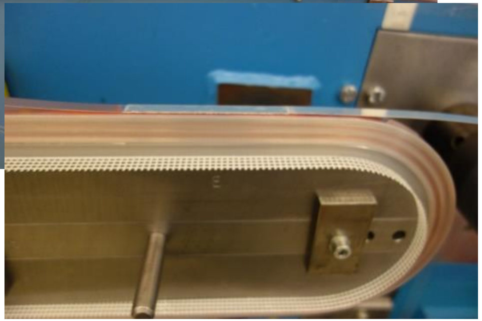
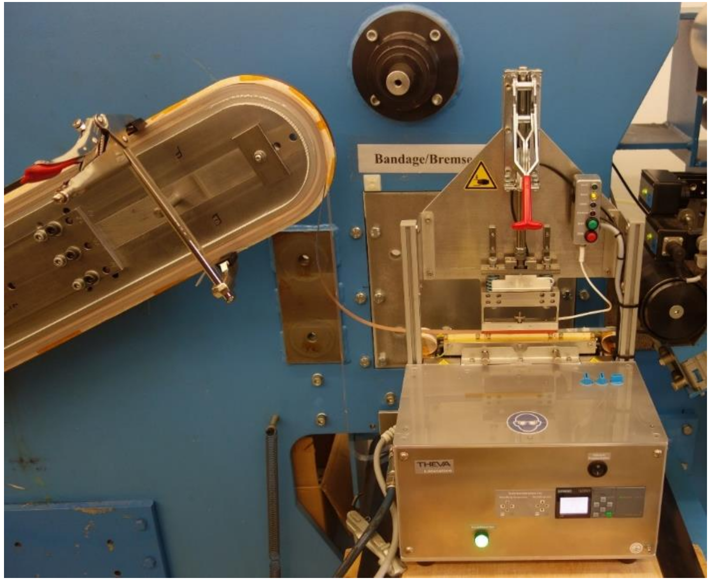
Winding of type-test coil



Start of coil winding

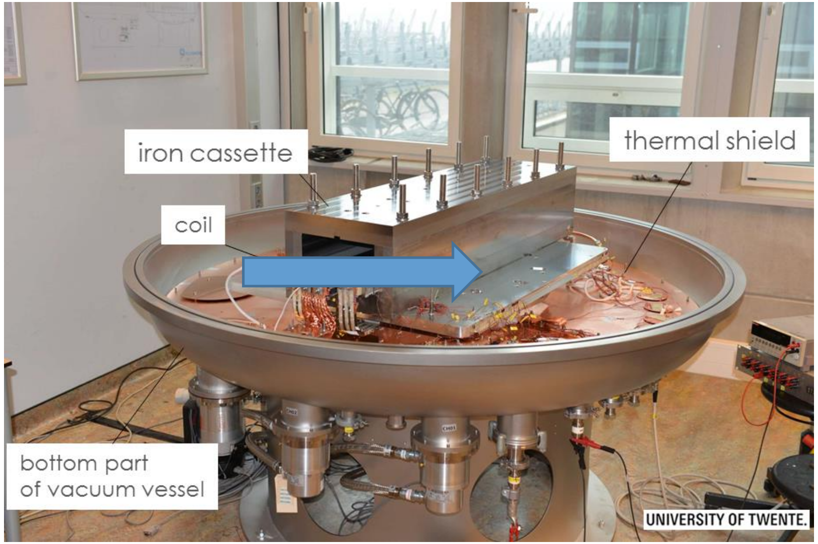


First layer nearly finished



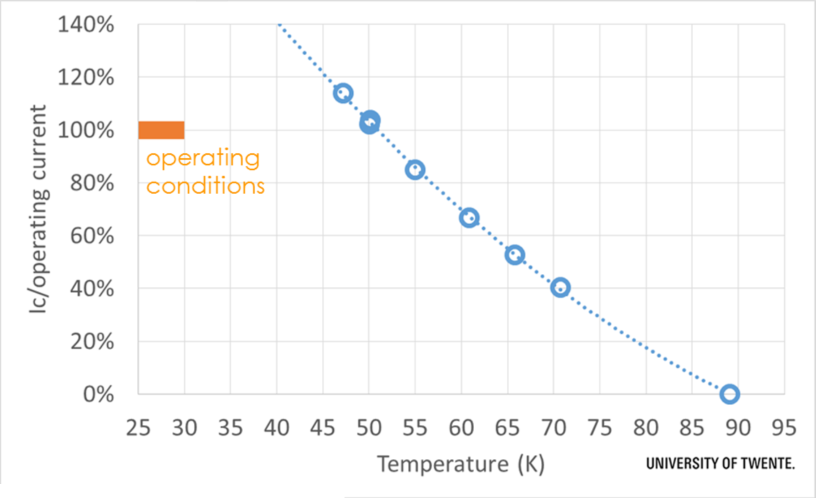
Soldering of joints

Type-testing of HTS coils



- Performance better than expected
- Nearly linear $I_c(T)$

→ **Type test passed on first attempt**



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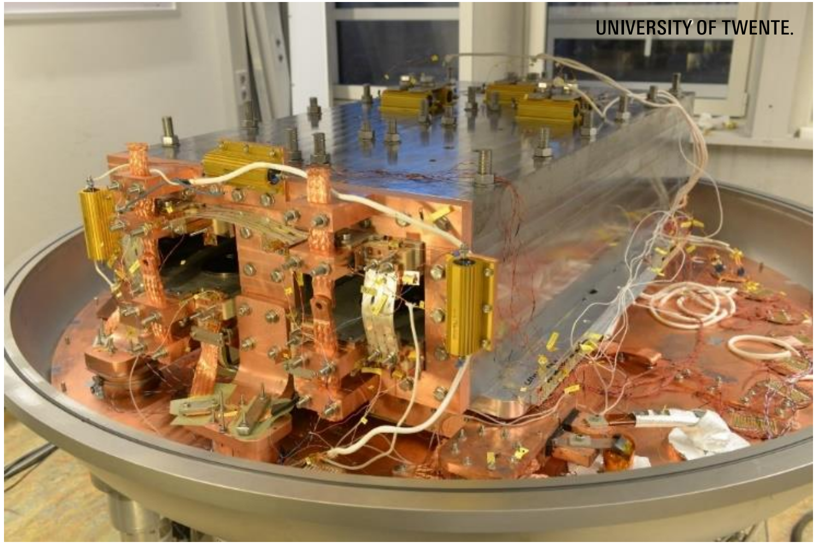
Acceptance tests at 35 K



Test rig for testing of 4 coils mounted in the coil assemblies

- Cooling via Cu coldbus identical to rotor situation
- Similar forces as in the rotor
- Overcurrent and overheat conditions to pass the test
- Focus on testing of basic functionality, only few „scientific“ measurements

Acceptance tests in LN2

LN2 test of coils

- Cooling by slow submersion in LN_2
- Test if
  - coil is superconducting,
  - resistance of joints is low and
  - I_c is as designed
- Can be done easily at different locations without special requirements

A fast and easy test suitable for economic quality control in a series production

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Cooling

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- SHI Cryogenics Group provides commercial grade cryogenic equipment
  - SRDK-500B cryocoolers
  - F-70 compressors.

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SHI
Cryogenics Group

SRDK-500B coldhead

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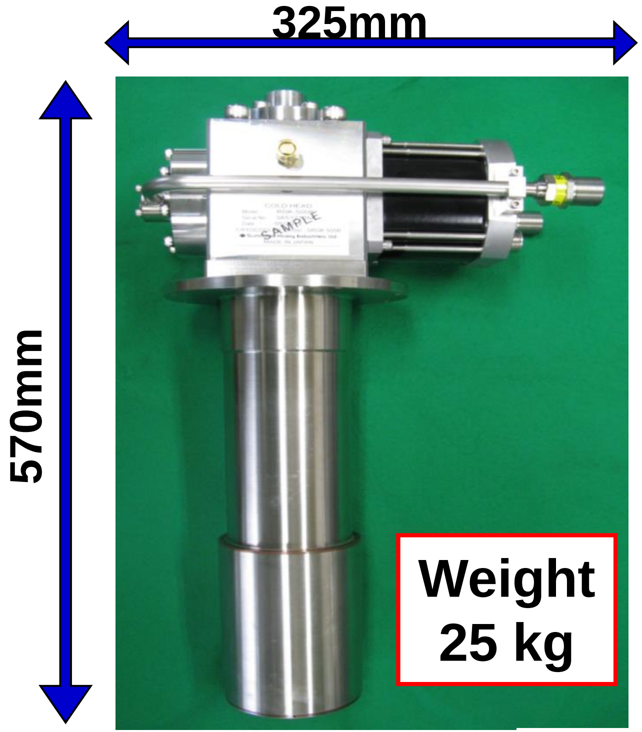

20K	40/50 W
30K	80/95 W
Compressor	F-70H
Power (50/60Hz)	7.5/9.0 kW
Maintenance	expected every 18.000 hrs
Orientational Dependence	<30%
Regulatory	UL/CE
Noise	70 dBA

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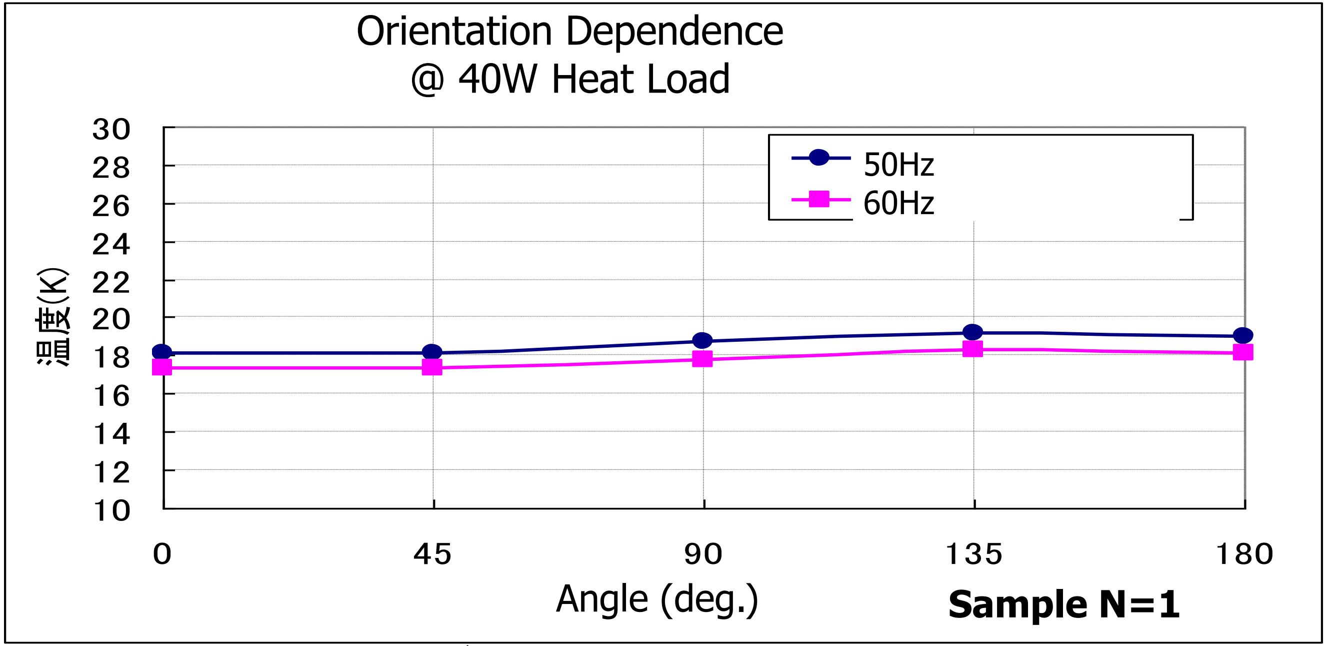
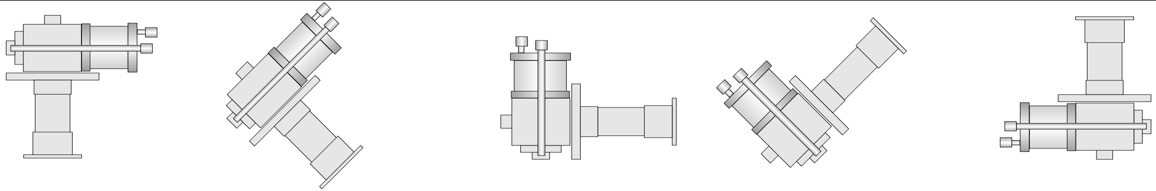
SHI Cryogenics Group

SRDK-500B
Orientation dependence





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Power conversion

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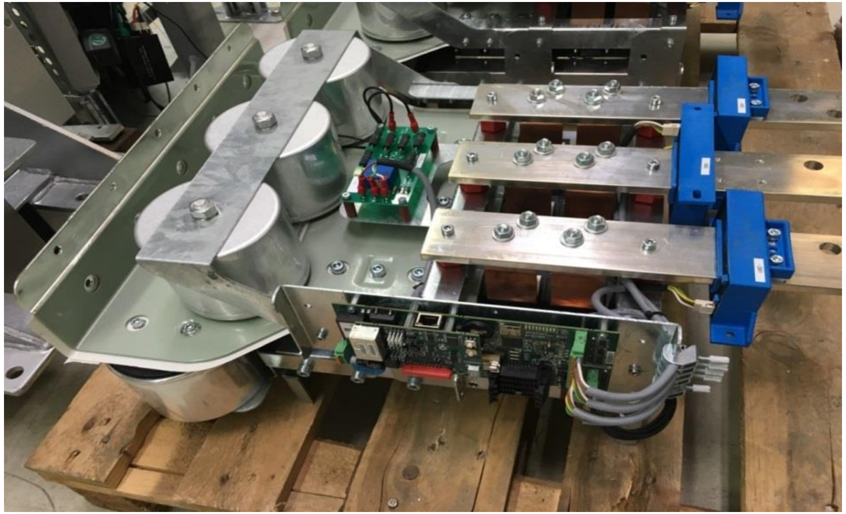

Power Stack

- DELTA provides the power converter
  - Latest IGBT technology
  - Assembled power stack shown on the left
- Power rating up to 1000 kVA
  - High power density design
  - Cost effective standard liquid cooling
- DELTA also provides
  - Quench protection / DAQ
  - Exciter.

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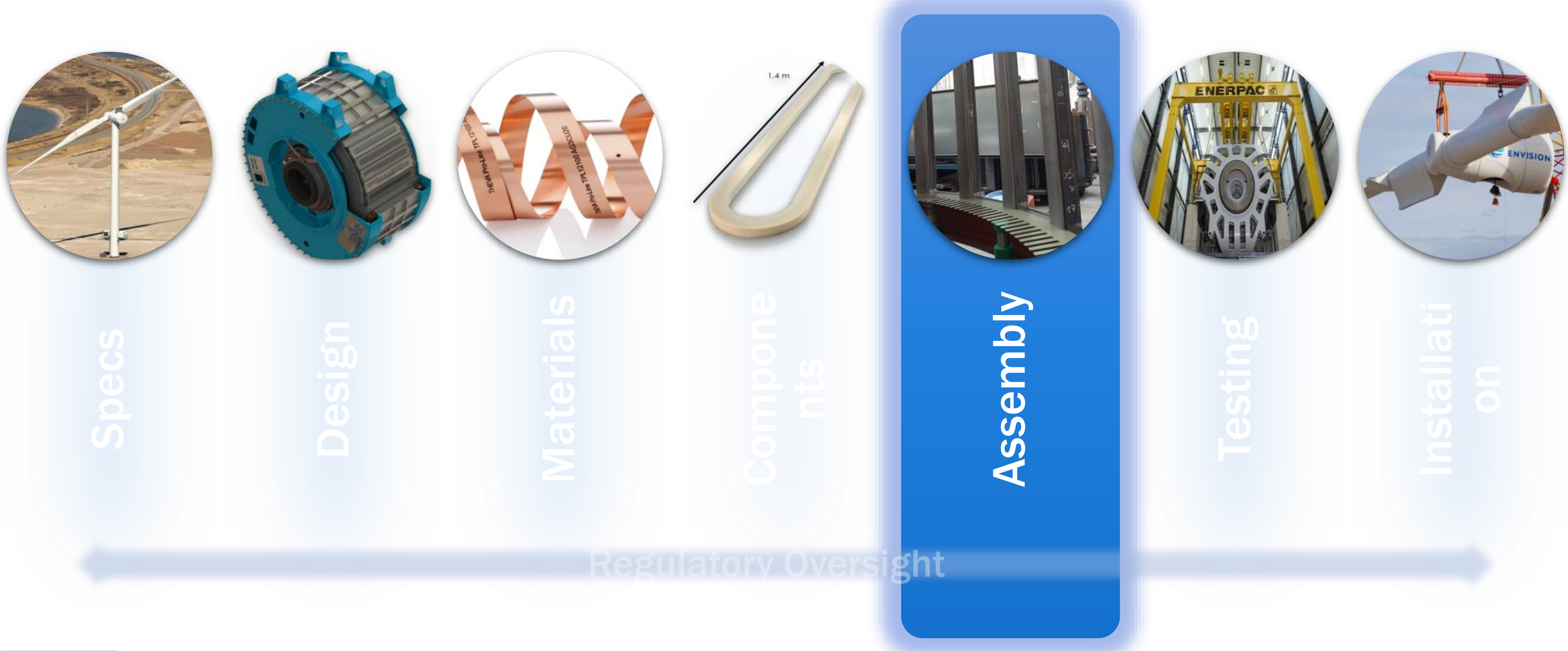
DELTA ENERGY SYSTEMS

Assembly



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Main shaft
Raw cast at foundry

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Rotor yoke
With coils ready for mounting

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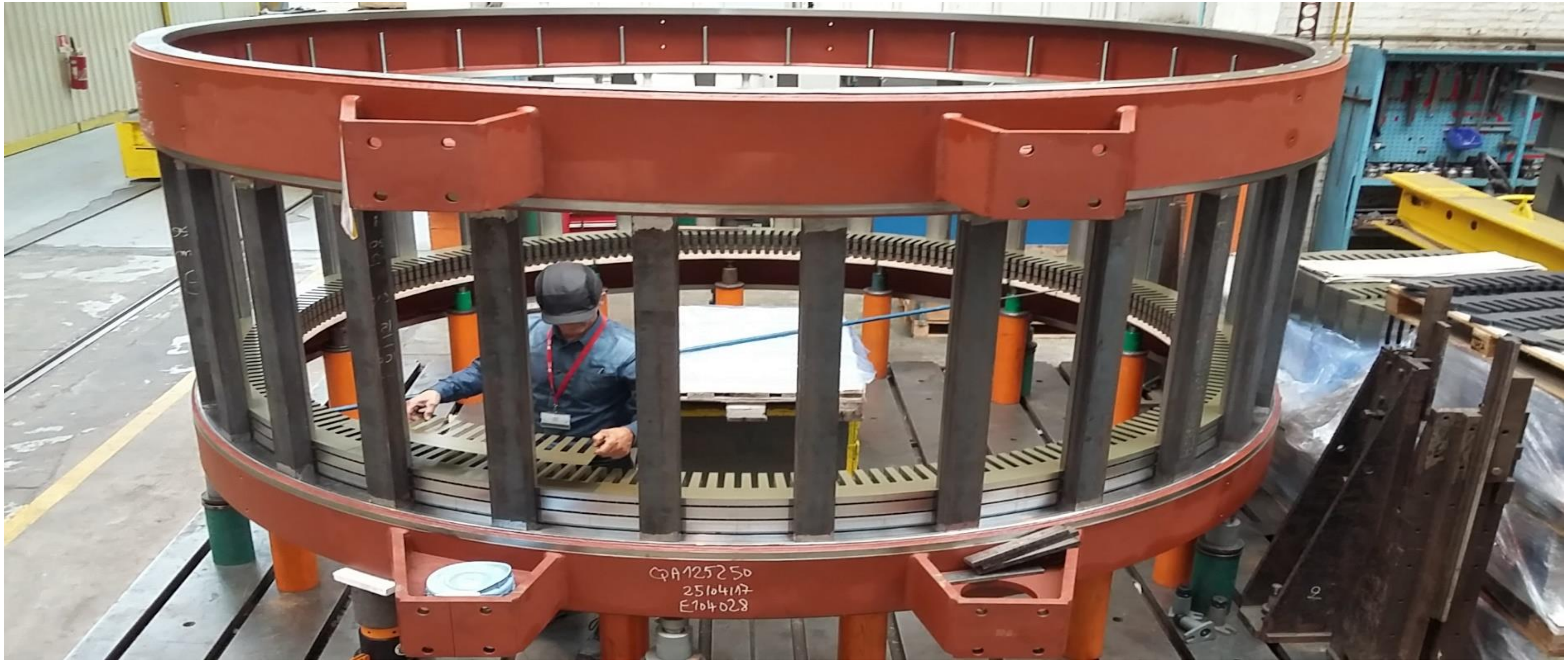
Stator assembly

Conventional with iron core sheets



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Electric

Stator coils

Form wound copper, mica insulation, VPI, class F

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- 2

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Stator flanges
Drive end side and non-drive end side

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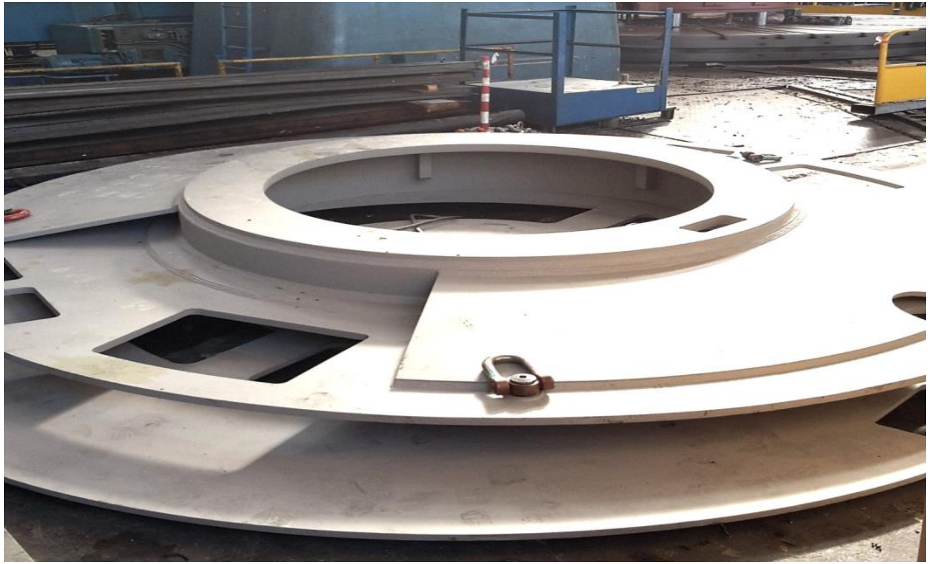

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Stator air ducts

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Acknowledgements to the Team

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EcoSwing Mission

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“EcoSwing aims at nothing less than world's first superconducting low-cost, lightweight drive-train demonstrated on a large-scale modern wind turbine”

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THANK YOU!

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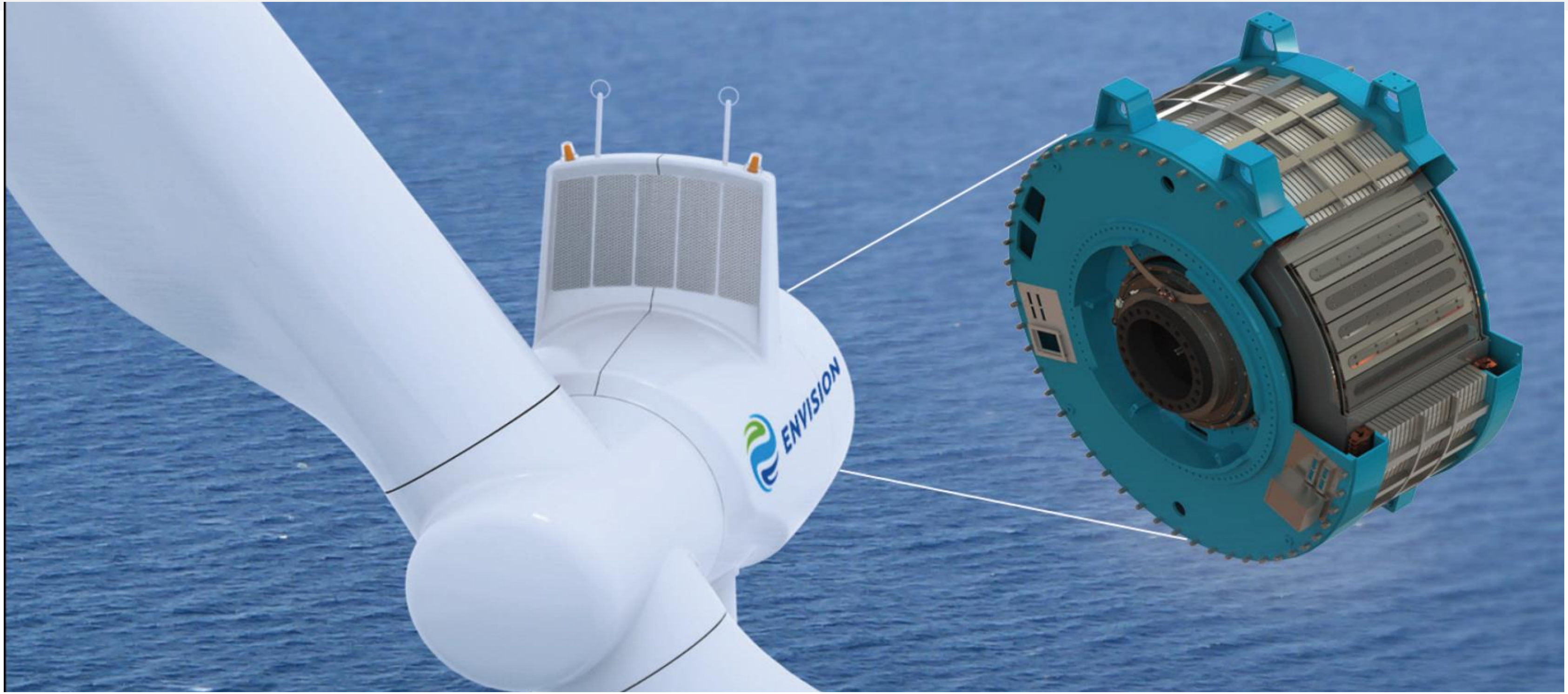

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