Structural Health Monitoring of Fiber Reinforced Plastics

Strukturüberwachung von Faserkunststoffverbunden

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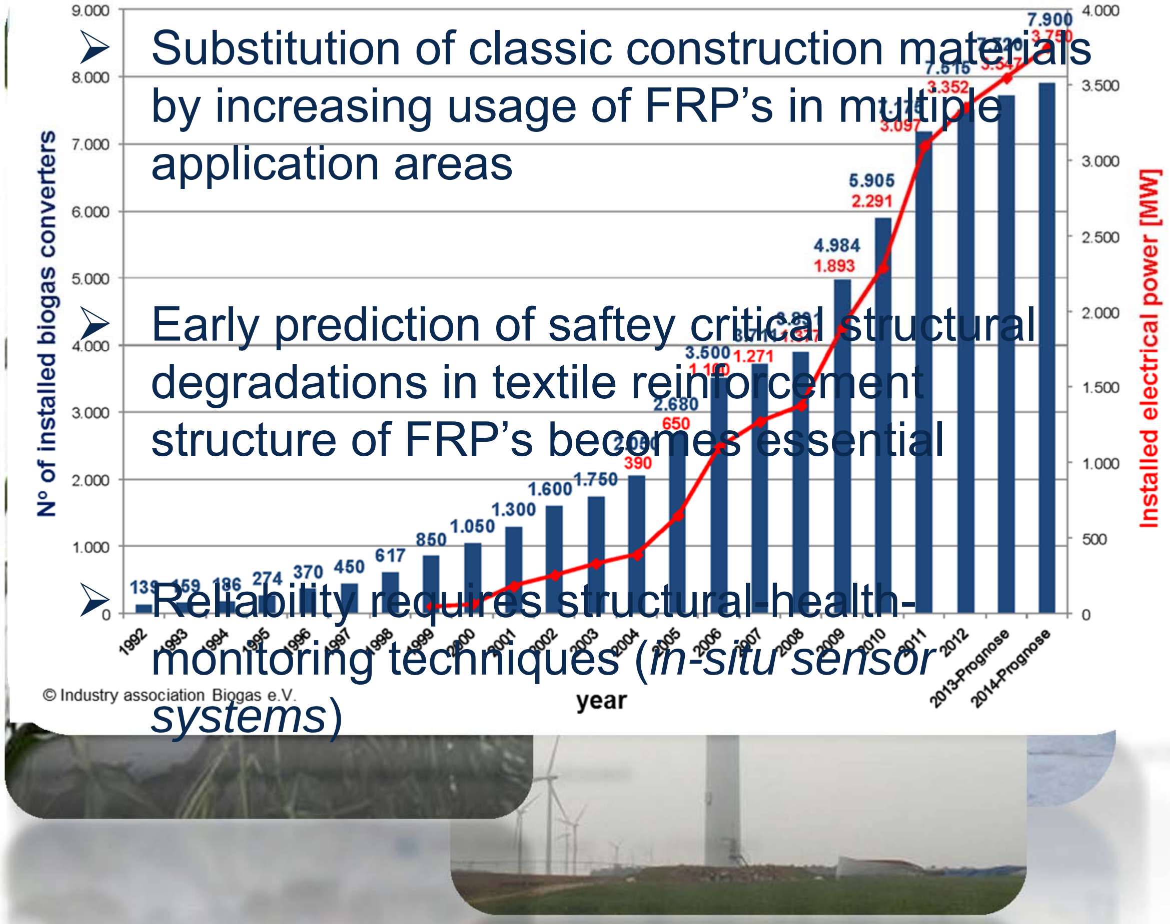
1. Initial Situation & Motivation
2. Goals & Approach
3. Results
   I. Functional model 1 - Textile membrane for biogas storage facilities
   II. Functional model 2 - FRP wind turbine blade
4. Conclusions & Outlook

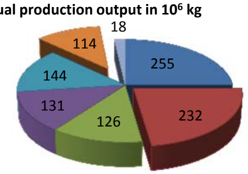
1. Initial Situation & Motivation

- Substitution of classic construction materials by increasing usage of FRP's in multiple application areas

- Early prediction of saftey critical structural degradations in textile reinforcement structure of FRP's becomes essential

- Reliability requires structural-health-monitoring techniques (*in-situ sensor systems*)





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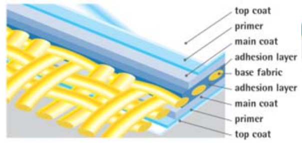

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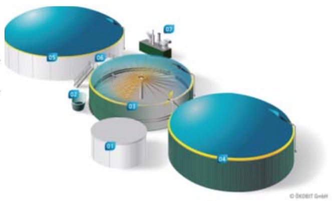

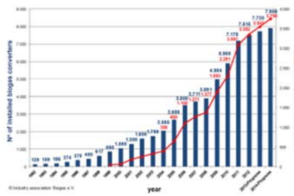

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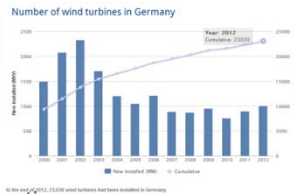
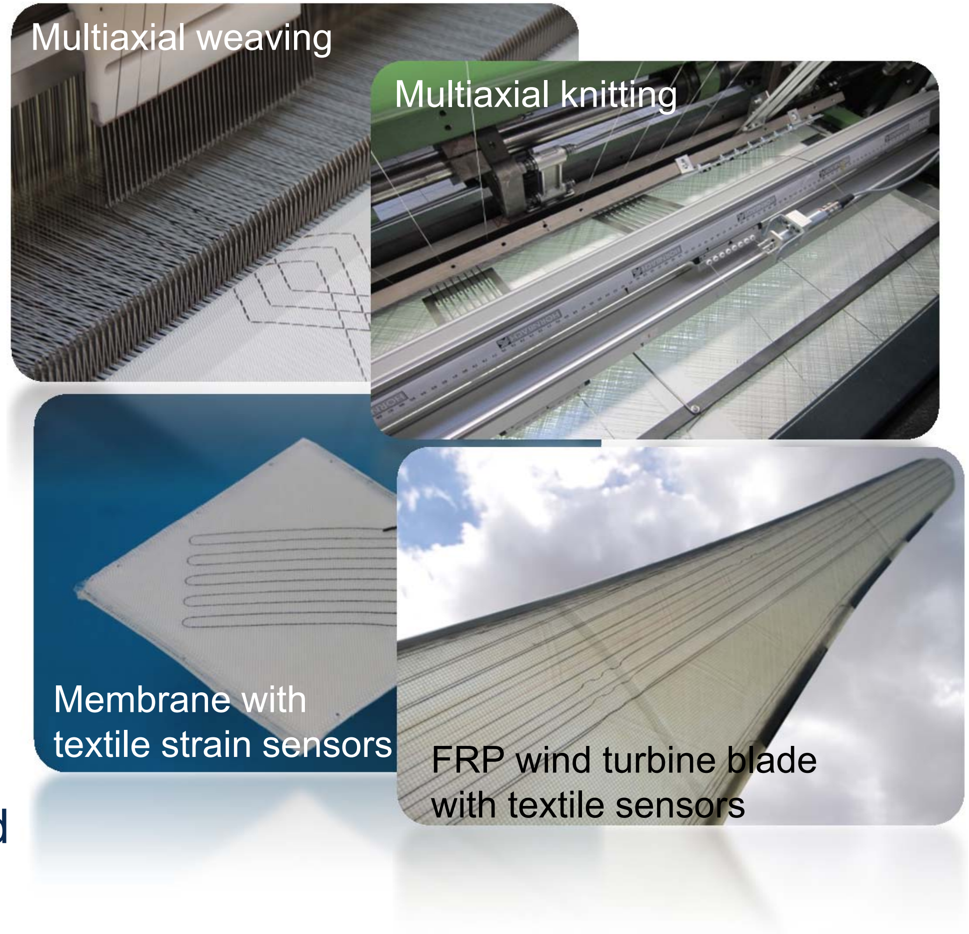


German Wind Energy Association © 2014

2. Goals & Approach

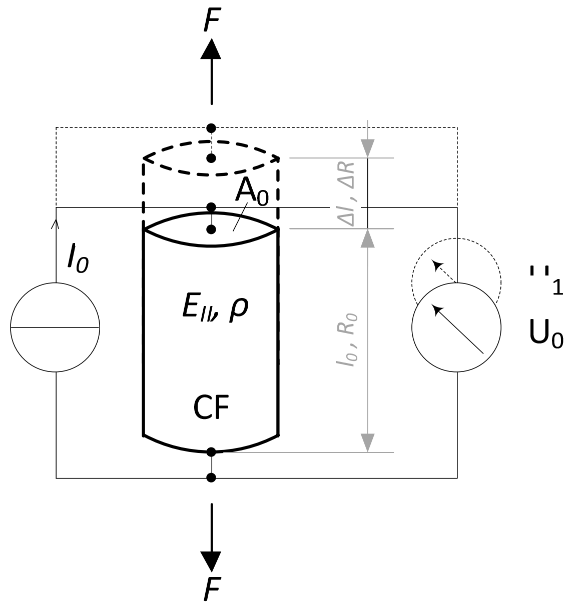
- Long-term stable structure-monitoring and damage detection for FRP‘s
- Textile-technological realization of tailored & structure-compatible sensor networks
- Cost- and time effective usage of textile-technological fabric generating techniques
- Integration of piezo-resistive materials during textile fabric’s production (multiaxial weaving and warp knitting)



2. Goals & Approach

- **Strain measurement principle**

  Piezo-resistive effect of CF by mechanical straining; geometry change causes change in resistance



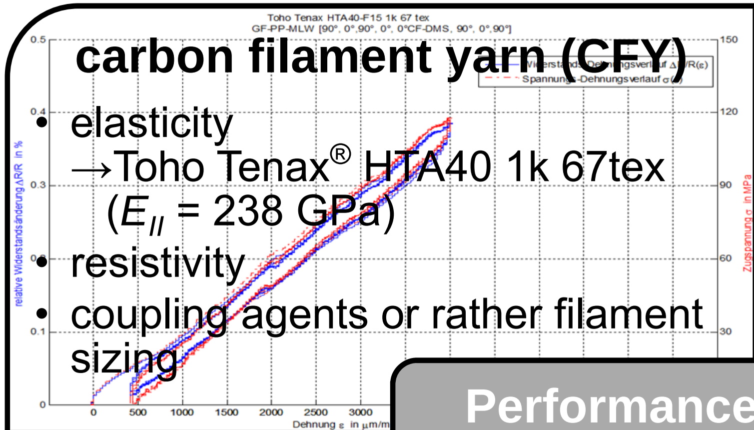
$$\frac{\Delta R}{R_0} = \frac{F}{A_0 \cdot E_{II}} \cdot k = \frac{\Delta l}{l} \cdot k$$

$$\Delta R = \frac{U_1 - U_0}{I_0}$$

exPAN CF-Roving
Toho Tenax®-J
HTA40
1k 67 tex 15S

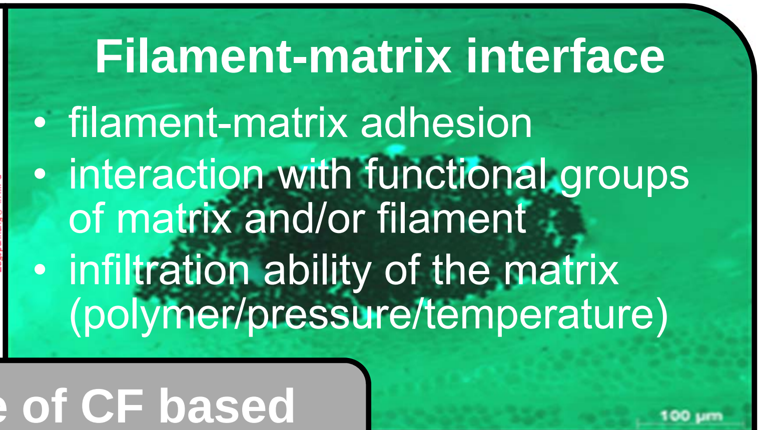
2. Goals & Approach

Factors of influence on the sensory characteristics:



carbon filament yarn (CFY)

- elasticity
  →Toho Tenax® HTA40 1k 67tex
  (E_{II} = 238 GPa)
- resistivity
- coupling agents or rather filament sizing



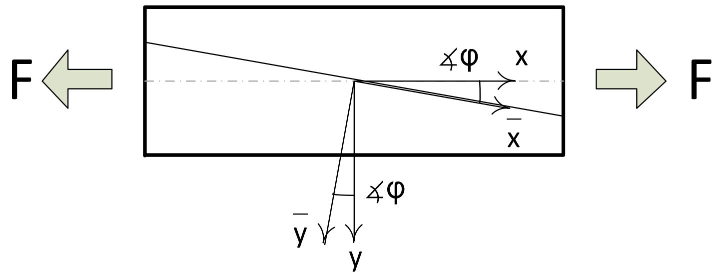
Filament-matrix interface

- filament-matrix adhesion
- interaction with functional groups of matrix and/or filament
- infiltration ability of the matrix (polymer/pressure/temperature)

Performance of CF based strain sensors in FRTP

Sensor embedding (crimp)

- textile technique related crimp in the reinforcement structure of the FRTP

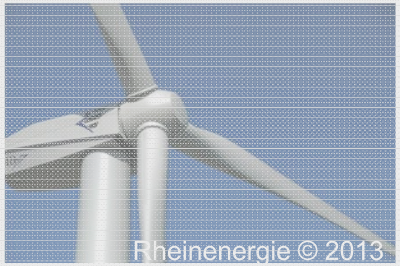


HAENTZSCHE et. al.: „Characteristics of CF-based strain sensors for SHM...“. In: Sensors and Actuators A: Physical A203(2013)1, pp. 189-203

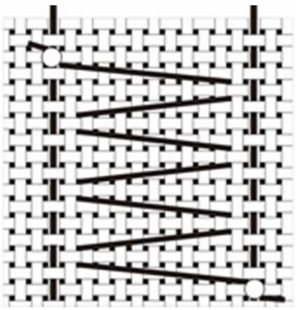
Overview Functional models

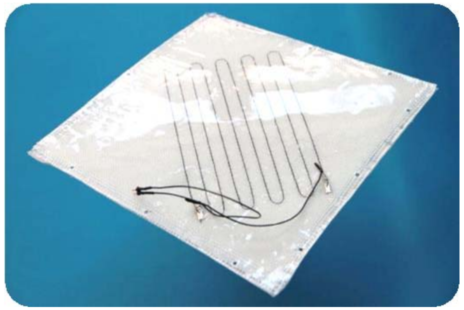
Membrane for biogas storage facilities

FRP wind turbine blade

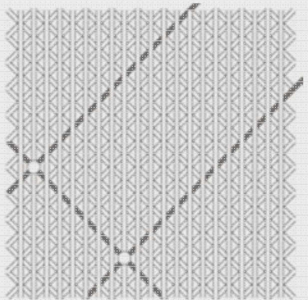


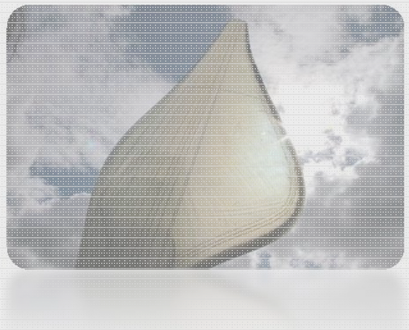
Multiaxial weaving with ORW® technology & warp yarn shogging





Multiaxial warp knitting with warp yarn shogging device



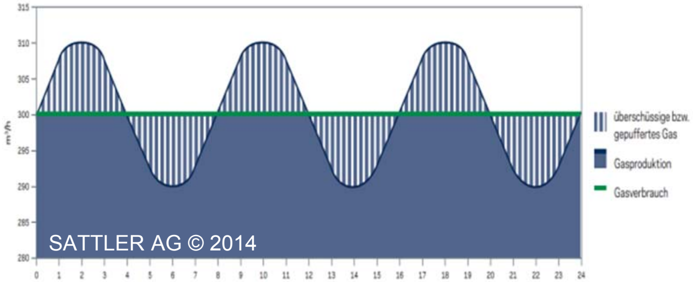


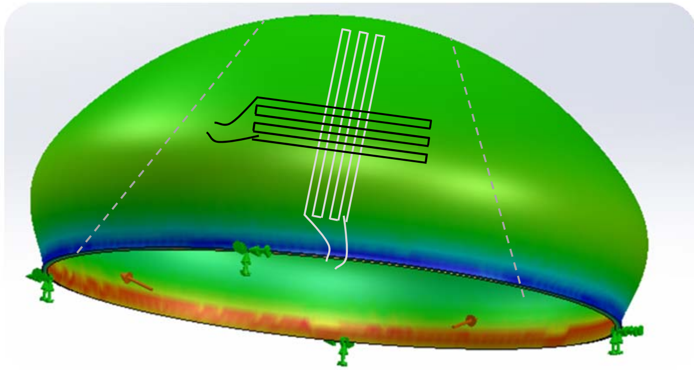
Functional model 1 (FUM1)

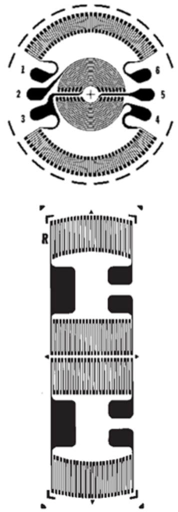
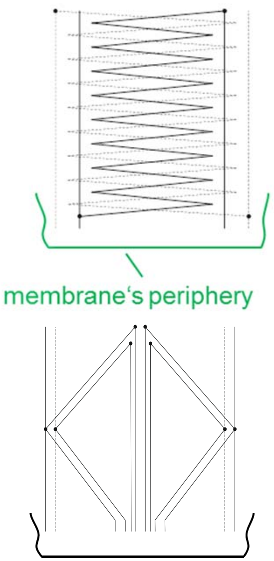
Functional model 2 (FUM2)

3. Results (FUM1)

3.1 Specification of textile reinforced membranes for biogas storage facilites





Conventional sensor layouts	Woven sensor layouts
	

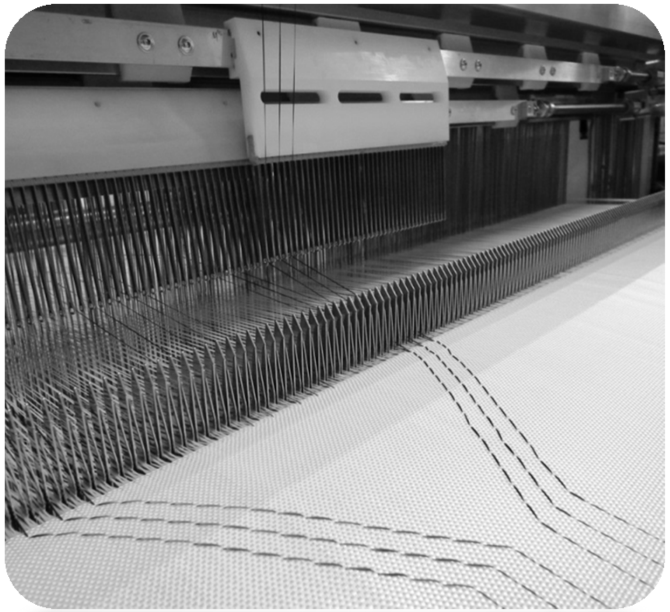
VISHAY Precision Group, Inc. © 2011

- Basic structure: single-layer woven fabric
- Dimensioning of sensor structure: 2D layouts with reachable basic resistances $R_0 = (100\ldots1000)\ \Omega$
- Usage of CF as warp & weft yarns and for additional warp yarn shogging
- CF trassing in 0° direction to serial interface on membrane‘s geometrical periphery

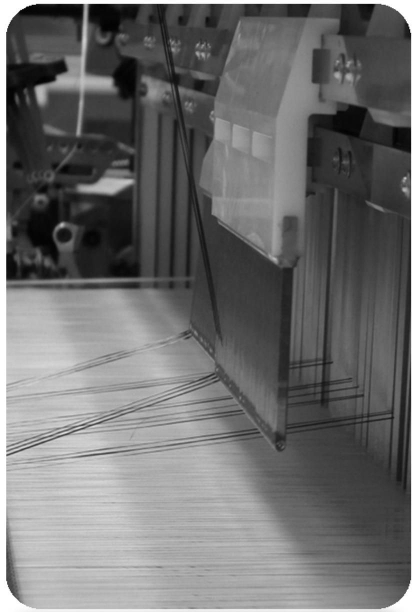
3. Results (FUM1)

3.2 Sensor integration by weaving with ORW® technology

- Multiple warp yarn shogging device
- Lateral move = ± 150 mm
  working width = 1,035 mm
- Basic fabric: 1.400 x PES 1.100 dtex, plain weave
  warp/weft density: 10/9 cm^{-1}
- Sensor material:
  CF 1k; 67 tex



Detail A: linear drive unit with needle bar and Open Reed Weave (ORW®)

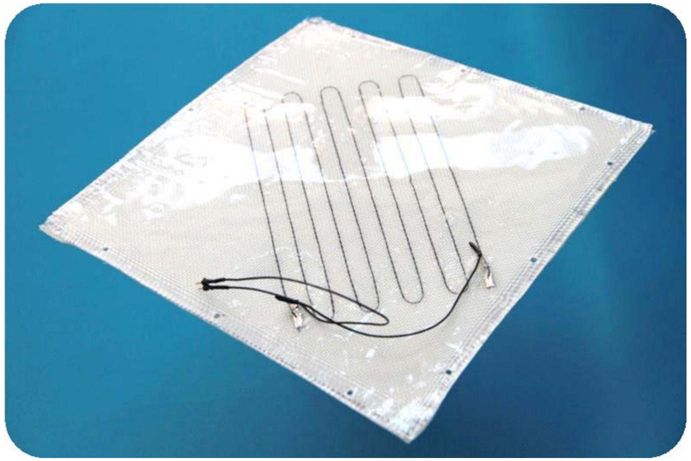


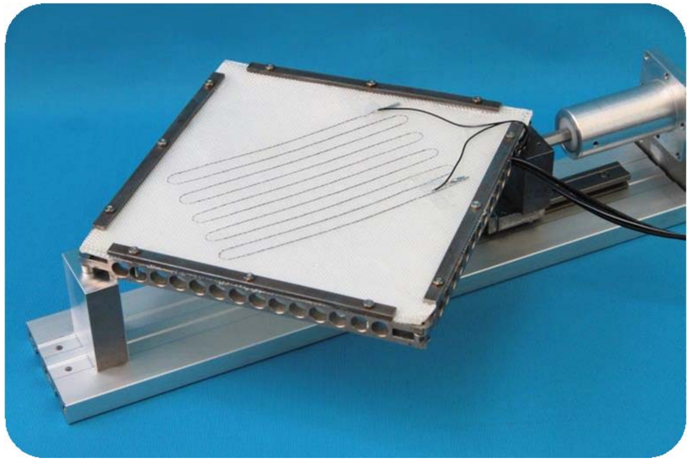
Detail B: needle bar with CFY in open shed position

3. Results (FUM1)

3.3 Manufacturing of membranes with integrated CF sensors

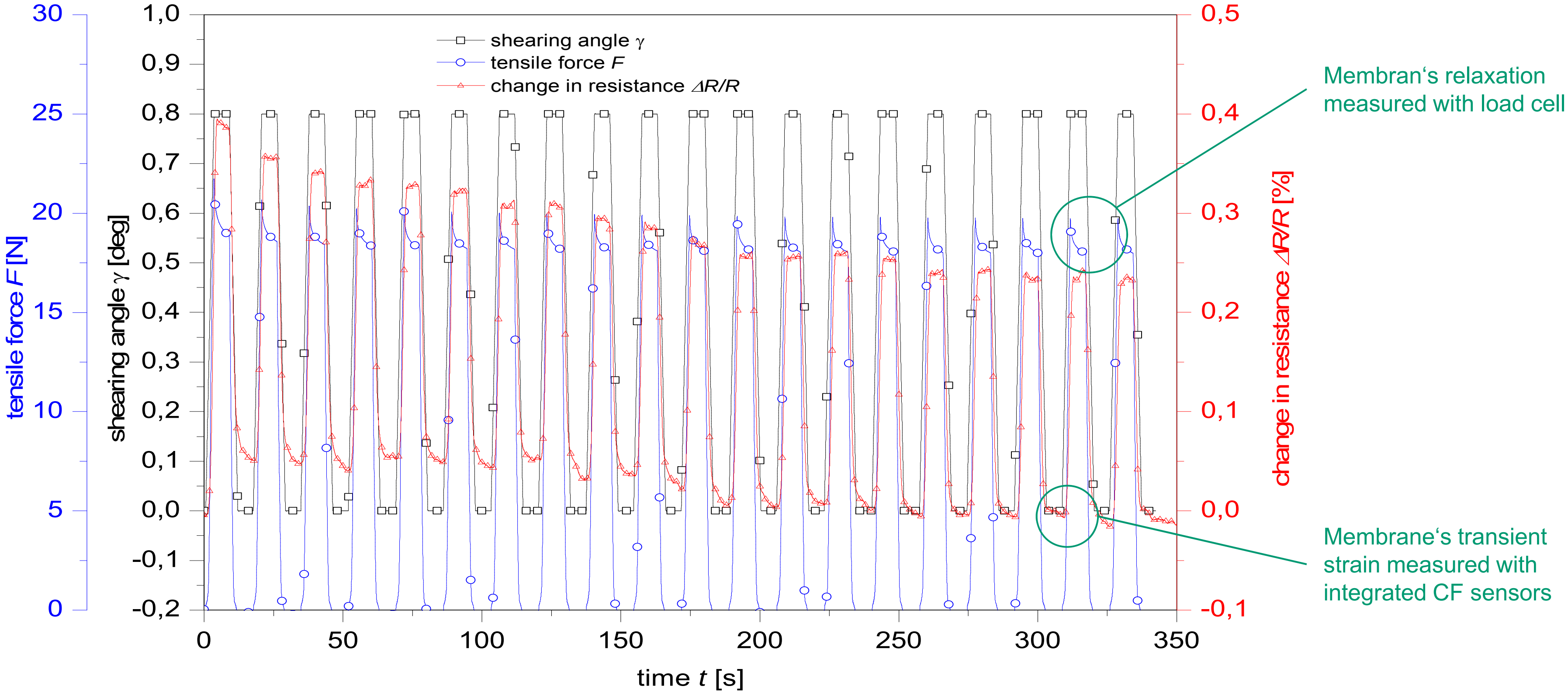
- Woven fabric 200x200 mm²,
- Meandering CF sensors with $R_0 \approx 700\ \Omega$
- Hand lamination with 2C silicone rubber
- 2-layer laminat $[-90°_{CF}, 0°, 90°]_2$ with 2 meanders in 0°/90° direction





3. Results (FUM1)

3.4 Sensor behaviour during cyclical in-plane shear stressing



- Stress-depending sensor signal of CF strain sensor (WHEATSTONE bridge) integrated in GF reinforced VMQ membrane

Overview Functional models

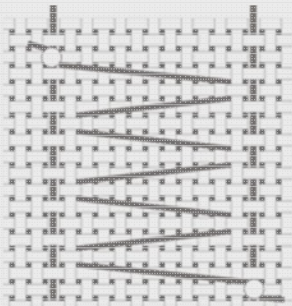
Membrane for biogas storage facilities

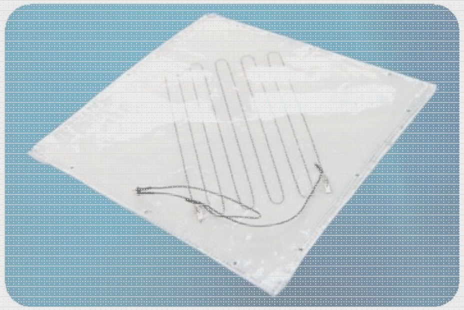

Zorg Biogas © 2014

FRP wind turbine blade

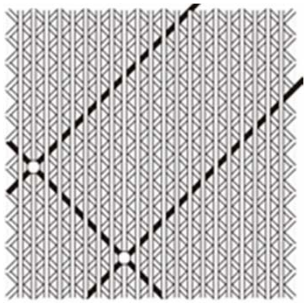

Rheinenergie © 2013

Multiaxial weaving with ORW® technology & warp yarn shogging





Multiaxial warp knitting with warp yarn shogging device



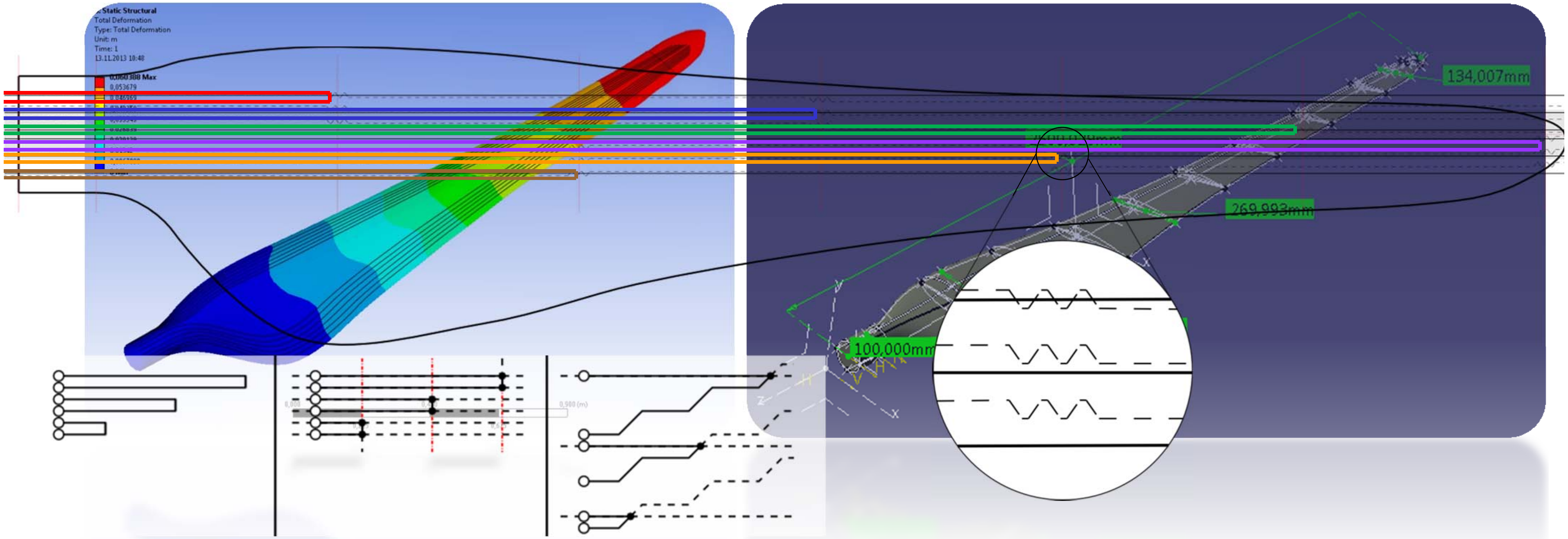
Functional model 1 (FUM1)

Functional model 2 (FUM2)

3. Results (FUM2)

3.5 Specification of textile reinforced small wind turbine blade

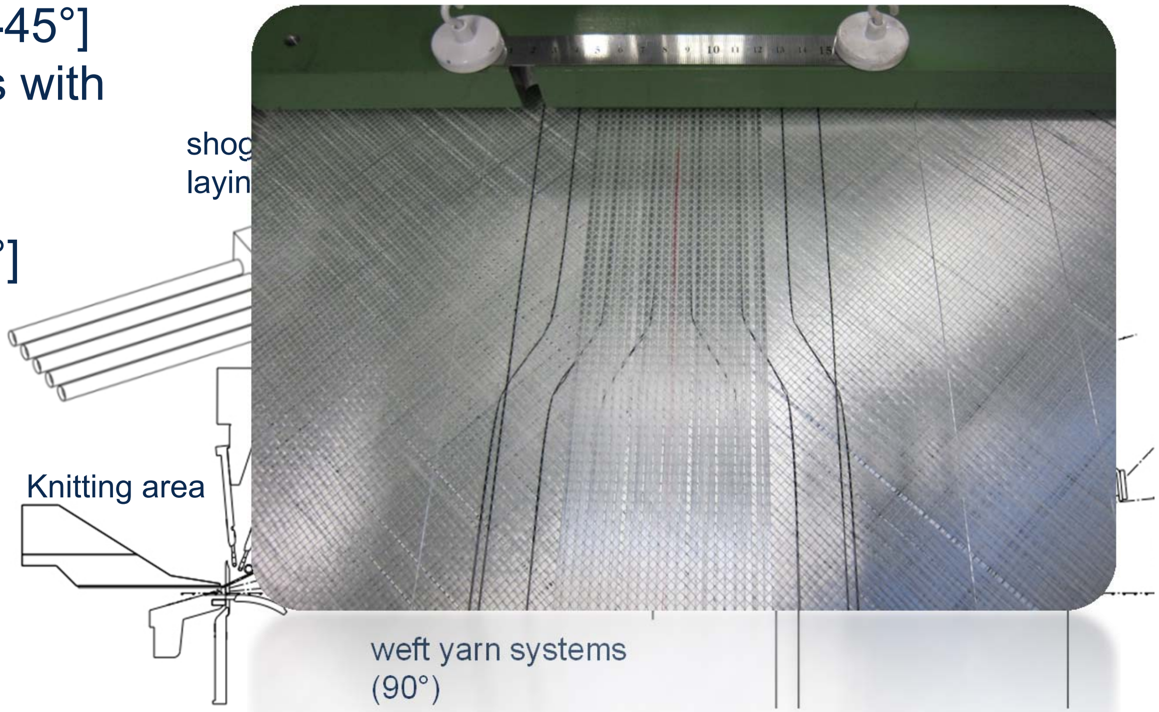
- Design and composite construction of small wind turbine blade
- Half shell segments with tension and compression flanges (no main beam)
- Accumulated strain measurement along integrated CF sensor‘s length



3. Results (FUM2)

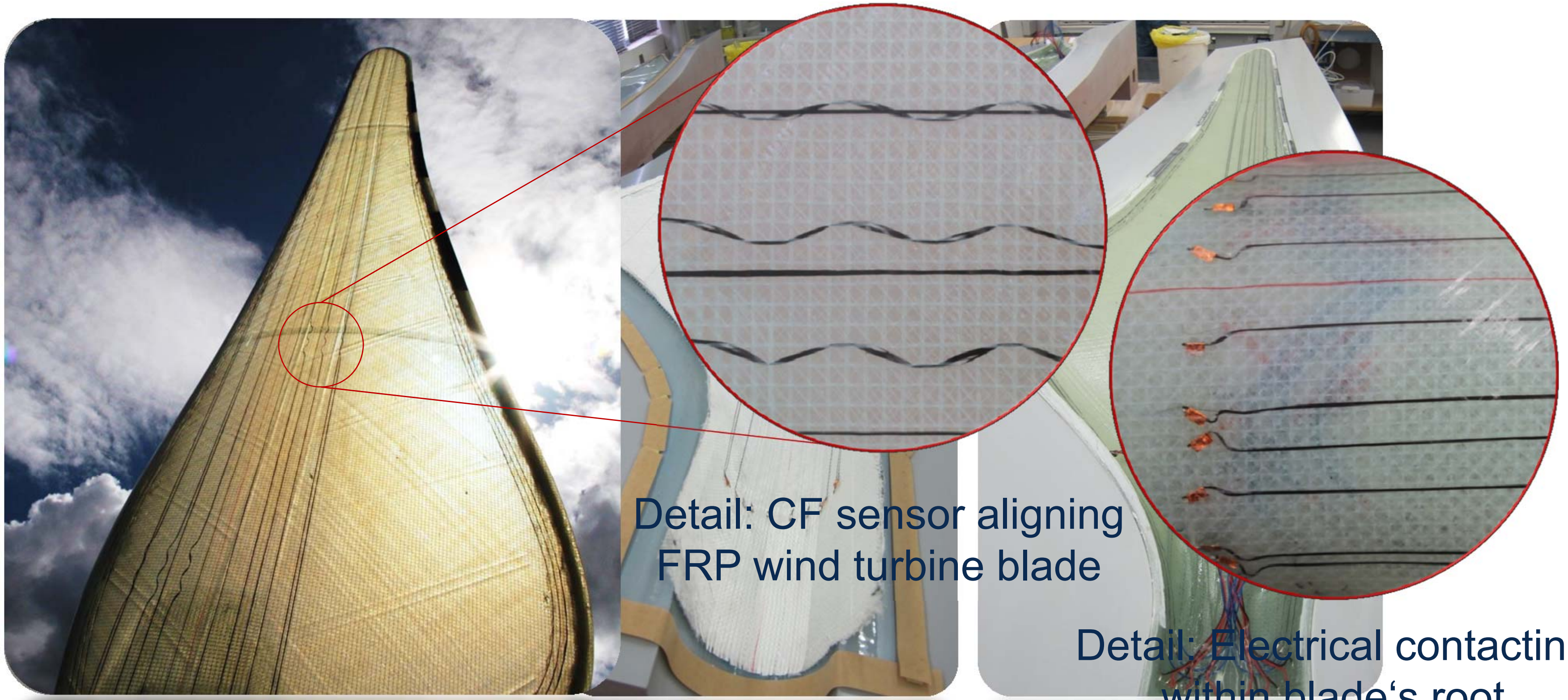
3.6 Adaption multiaxial warp knitting technique for 2D sensor integration

- Patended warp yarn shogging device for multiaxial warp knitting machines
- GF Triax NCF [0°, +45°, -45°] for blade‘s tensile flanges with integrated CF sensors
- GF Biax NCF [+45°, -45°] for blade‘s half shells
- Sensor material: CF course-oriented linkage of sensor & NCF



3. Results (FUM2)

3.7 Final assembly of small wind turbine blade



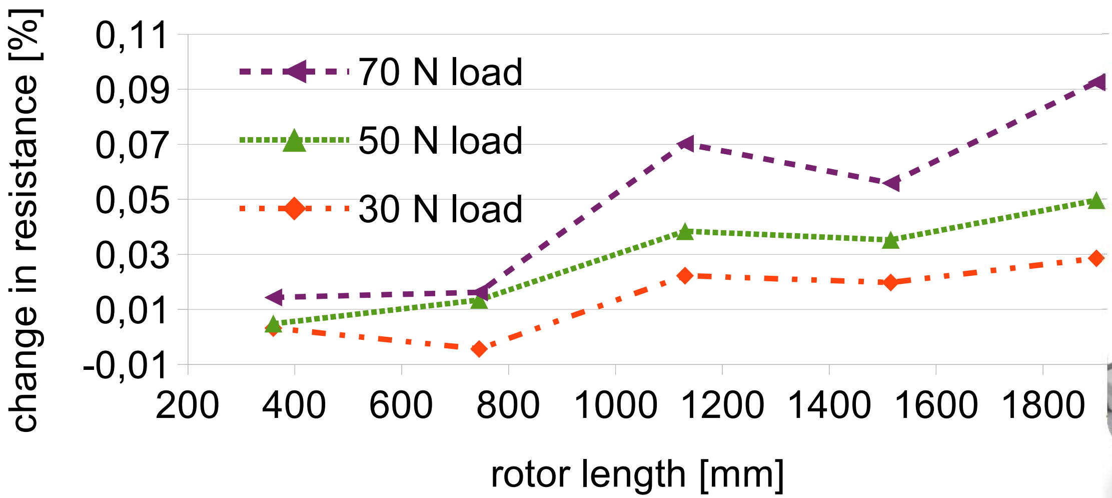
Blade with integrated
Electrical contacting (I)
CF sensor system for spatially resolved strain measurement

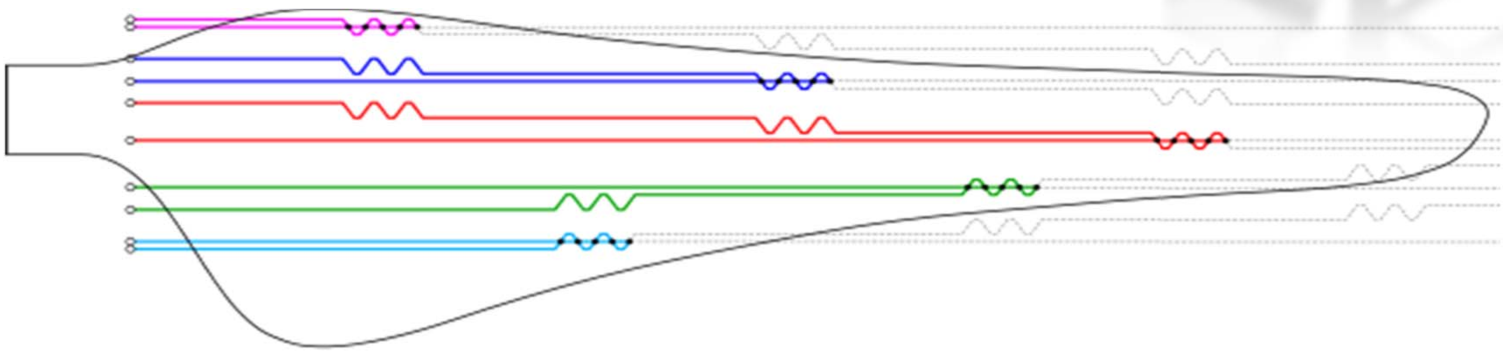
Pre-cut & Drapery (II)

VAP Infiltration & Curing (III)

3. Results (FUM2)

3.8 Rotor resistance change under constant loading





4. Conclusion & Outlook

- Realization of 2 functional FRP models: wind turbine blade and membrane with integrated CF sensors for SHM
- Good correlation between mechanical stress and measured change in resistance
- Outlook: Measurements under biaxial and dynamic loading scenarios

5. Appropriation of funds

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MULTIFUNCTIONAL FIBER-REINFORCED PLASTICS WITH INTEGRATED TEXTILE-BASED SENSOR AND ACTUATOR NETWORKS

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Thank you very much for your attention