Enercon E-Ship 1
A Wind-Hybrid Commercial Cargo Ship

4th Conference on Ship Efficiency
E-Ship 1

Agenda

- About Enercon
- Motivation und Objectives
- Features and Innovations
- Evaluation, Experience und Results
- Way forward
Enercon - basic facts

ENERCON high vertical integration

- Rotor blade production, 11 factories worldwide
- Generator production, 4 factories worldwide
- Electrical components, 3 factories worldwide
- Tower production, 11 factories worldwide
- Machine house assembly, 4 factories worldwide
- Foundry, 1 factory worldwide

Total production area 820,500 m²
ENERCON concept

When it comes to performance, ENERCON's **gearless** generator concept is superior to conventional generators.

Advantages:

- Less wear due to slower rotation
- Very little machine stress due to high level of speed variability
- Yield optimized control system
- High grid compatibility

![Diagram of ENERCON annular generator with labels:
1. Main carrier
2. Yaw drive
3. Annular generator
4. Blade adapter
5. Rotor hub
6. Rotor blade](image)
Enercon market share

Market share Germany 2012

- Vestas: 24.2%
- Repower Systems: 11.0%
- Nordex: 3.7%
- e.n.o.: 1.5%
- Others: 2.8%

Source: Deutsche WindGuard 2013

Market share worldwide 2011

- ENERCON: 7.9%
- Vestas: 12.9%
- Goldwind: 9.4%
- GE Wind: 9.4%
- Mingyang: 2.9%
- Siemens: 6.3%
- United Power: 7.1%
- Suzlon Group: 7.7%
- Gamesa: 8.2%
- Others: 21.5%

Source: BTM 2012
Motivation for E Ship 1

- Increase demand and special requirements for transport of wind turbines and parts
- Conventional cargo vessels not optimal capable for ENERCON freight
- Demand for sustainable shipping / Green shipping

CO2 Emission of shipping yet highly underestimated

CO2-Emissionen der Schifffahrt bisher stark unterschätzt

13.02.2008, veröffentlicht von Greenpeace Redaktion

Die Treibhausgas-Emissionen der Schifffahrt sind dreimal höher als bisher angenommen. Das geht aus einem neuen UN-Bericht hervor, der der englischen Zeitschrift The Guardian vorliegt.

Während das Blatt in seiner Online-Ausgabe am Dienstag berichtet, beträgt der jährliche CO2-Ausstoß der weltweiten Handelschifffahrt 1,12 Milliarden Tonnen. Das entspricht einem Anteil von 4,5 Prozent der globalen Treibhausgas-Emissionen. Allein das weltgrößte Containerschiff, die Emma Maersk, pustet auf den Fahrten zwischen China und Europa 300.000 Tonnen CO2 pro Jahr in die Luft - etwa so viel wie ein mittelgroßes Kohle-Kraftwerk.

Source: www.greenpeace.de
Objectives for E-Ship 1

1. Cargo vessel - optimized for Enercon freight. Multipurpose features for maximal flexibility (second party freight)

2. Transportation of Enercon freight with a minimum impact on the environment, ecological responsibility as technological leader for renewable energy


4. Second-Source Shipping Capability
E-Ship 1

Features

**Wind Assisted Propulsion**
- Flettner Rotor-Sail system

**Optimized hull and superstructure**

**Optimized propeller and rudder design**

**Diesel-Electric Propulsion System**
- Diesel-Electric Power Generation (only with MGO Fuel)
- Enercon Propulsion Motor
- Intelligent PMS (incl. Integration of Rotor Sail System)
- Waste Heat recovery (Turbo Generator, Absorption chiller)

**Green Shipping Waste Reduction Systems**
- Biological clarification plant
- Waste Management System
- Ballast Water Treatment Systems
- Fuel / Oil tanks behind double hull
- SCR Catalytic converter for Harbor- and Emergency Power Systems

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Green-Shipping Innovation: Rotor-Sail System
1924 “Buckau” (LOA approx. 54m)
First Trails by Anton Flettner
2 Flettner Rotors 18m/2,8m

1927 “Barbara” (LOA approx. 90m)
Second Trails by Anton Flettner
3 Flettner-Rotors 17m/4m

2000: First ideas for a wind-assisted propulsion cargo vessel based on ideas of Anton Flettner
Magnus-Effect

\[ \dot{v}_- < \dot{v} < \dot{v}_+ \]

\[ p_- < p_+ \]

true wind

fair wind

apparent wind

drag force

propelling force

lift force

Ship 1 - Technology and Innovation

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E-Ship 1 - Technology and Innovation

Green-Shipping Innovation: Rotor-Sail System / Flettner Rotor

1924 “Buckau”  
First Trails Anton Flettner

2000: First ideas for a wind-assisted propulsion cargo vessel  
2000: Start of research and first case studies  
2002: 1st Enercon Test Rig for Evaluation of Flettner-Rotor Technology  
2004: Concepts for E-Ship 1 starts to get shape  
2007: 2nd Enercon Test Rig for Evaluation and Optimization of Flettner-Rotors, “Full-Scale Test”  
2007: Keel laying, Lindenau Werft Kiel  
2008: Launching and christening  
2010: First Commerical operation of E-Ship 1
Design and Optimization of Sail Rotor System

Calculation of fundamental structure and operation parameters:

- Static and dynamic structure behavior
- Determination of fundamental operation parameters, e.g. lift (thrust), revolution speed
- Determination of required drive power
- Integration into overall ship structure
Detailed Design of Sail-Rotors

Design
- Static and dynamic loads
- Fluid mechanic
- Drives and control technology

Set-up of Rotors Sails
- Supporting column
- Rotor
- Rotor hub / support
- Drive
- Rotor heating (cover plate)

Operation
- Operation manuals
- Inspection and maintenance manuals
Full scale test and evaluation of Rotors-Sails

Validation and Optimization of Rotors-Sails

- Measuring of static and dynamic behavior
- Measuring of performance
- Validation of drive-power assumptions
- Validation of thermal behavior
- Optimization of machine elements, e.g. support
- Optimization of control technology
- Development of solutions for noise reduction
- Balancing of rotors
- Development of Control Technology to enable fully automated operation
- Integration into Power Management System
- Development of sea-worthiness components (GL approved)
Manufacturing and Integration
Shipping routes

Miles travelled: 150,000 nm
Operating Experience

Behavoir at sea conditions

E-Ship 1 has a very good sea condition characteristic. The Rotor-Sail System contribute to absorption of sea disturbance. (aerodynamic damping, gyroscopic absorption). Safe to operate.

Crew requirements

Control system enables fully automated operation of Rotor-Sail System. Direction and speed of rotation are set depending on wind conditions.

Rotor-Sail Systems requires low maintenance

- No special crew know-how / training required
- No additional crew required.
Continuous recording of performance data:
- Vessel speed
- Rotor-RPM
  - $dv = f(\text{Rotor-RPM})$

Power on drive shaft = constant!

Wind: Bft 6 (12.2 m/s)
Stb abaft (ca. 135°)

Determination of Power Saving Potential

Wind: Bft 6 (12.2 m/s)
Stb abaft (ca. 135°)
Determination of Power Saving Potential

Calculation of saved power (as result of speed difference) under consideration of trail conditions

\[ V_{\text{with Rotors}} = 16.7 \text{ kn} \]
\[ P_{\text{Shaft}} = 2769 \text{ kW} \]
\[ P_{\text{Shaft theor.}} = 4747 \text{ kW} \]
\[ V_{\text{without Rotors}} = 14.3 \text{ kn} \]
\[ P_{\text{Shaft}} = 2769 \text{ kW} \]

\[ \Delta P_{\text{Shaft}} = 1978 \text{ kW} \]
\[ - \text{ Rotor } P_{\text{rotors}} = 280 \text{ kW} \]
\[ \text{netto } P_{\text{red.}} = 1698 \text{ kW} \]
Determination of Power Saving Potential

Rotor Sail CFD Performance Modell:

Calculation with CFD and Validation with measurement data

Power saved in [%] vs. Wind (true) = 24kn/6 BFT
estimated
Ship Speed = 16,0kn

Power saved [%] estimated at 16kn Ship Speed
**Average Motor only** +25.0% Fuel

**Average Total Voyage** +6.8% Fuel

**Average Sail-Rotor Operation** -5.1% / net +2.1% Fuel

### Voyage Analysis: Emden-Portugal / Oct 2012

<table>
<thead>
<tr>
<th>Speed over Ground [kn]</th>
<th>Power Shaft [kW]</th>
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<tbody>
<tr>
<td>10</td>
<td>1000</td>
</tr>
<tr>
<td>11</td>
<td>2000</td>
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<tr>
<td>12</td>
<td>3000</td>
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<td>13</td>
<td>4000</td>
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<td>14</td>
<td>5000</td>
</tr>
<tr>
<td>15</td>
<td>6000</td>
</tr>
<tr>
<td>16</td>
<td>7000</td>
</tr>
<tr>
<td>17</td>
<td>8000</td>
</tr>
</tbody>
</table>

#### Average

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Motor only</th>
<th>Total Voyage</th>
<th>Sail Rotor</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPEED [kn]</td>
<td>12.47</td>
<td>13.69</td>
<td>14.59</td>
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<tr>
<td>P-Shaft [kW] Trial Cond.</td>
<td>1997</td>
<td>2432</td>
<td>2816</td>
</tr>
<tr>
<td>Counts [min]</td>
<td>1519</td>
<td>3569</td>
<td>2050</td>
</tr>
<tr>
<td>Time Ratio %</td>
<td>43</td>
<td>100</td>
<td>57</td>
</tr>
<tr>
<td>P-Shaft actual [kW]</td>
<td>2497</td>
<td>2598</td>
<td>2673</td>
</tr>
<tr>
<td>dP Ref Trial Cond. [kW]</td>
<td>500</td>
<td>167</td>
<td>-143</td>
</tr>
<tr>
<td>P el Rotor [kW]</td>
<td>203</td>
<td>-5.1</td>
<td>2.1</td>
</tr>
<tr>
<td>dP Ref Trial Cond. net [kW]</td>
<td>60</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>dP brutto %</td>
<td>-5.1</td>
<td>2.1</td>
<td>-</td>
</tr>
<tr>
<td>dP netto %</td>
<td>25.0</td>
<td>6.8</td>
<td>2.1</td>
</tr>
</tbody>
</table>

1) net: incl. electric Power Consumption of Sail Rotors

Reference Line:
- Trial Condition (~ optimal conditions)
Sailing along Brazilian coast, July 2011

Wind: Bft 6-7 (13.5 m/s)  
Portside abeam (ca. -90°)

$V_{\text{with Rotors}} = 12.0 \text{ kn}$

$P_{\text{Shaft}} = 297 \text{ kW}$

$P_{\text{Shaft theor.}} = 1937 \text{ kW}$

$\Delta P_{\text{Shaft}} - \text{Rotor } P_{\text{rotors}} = 1640 \text{ kW}$

$\text{netto } P_{\text{red.}} = 1250 \text{ kW}$
E-Ship 1

Way Forward Enercon E-Ship 1

- Further Evaluation and improvement of vessel operation
- Optimization and development of innovations for maritime applications:
  - Rotor-Sail Systems
  - Control technology
  - Systems for operation support
Thank you for attention!

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ENERCON GmbH • Dreekamp 5 • 26605 Aurich • Germany
Phone: +49 4941-927-0 • Fax: +49 4941-927-109

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