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 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
Enercon market share

**Market share Germany 2012**

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

Source: Deutsche WindGuard 2013

**Market share worldwide 2011**

- ENERCON: 56.8%
- Vestas: 12.9%
- Mingyang: 2.9%
- Siemens: 6.3%
- United Power: 7.1%
- Sinovel: 7.3%
- Suzlon Group: 7.7%
- Gamesa: 8.2%
- Goldwind: 9.4%
- GE Wind: 9.4%
- 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.

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

**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)

Optimized propeller and rudder design

**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

4th Conference on Ship Efficiency
Green-Shipping Innovation: Rotor-Sail System
Green-Shipping Innovation: Rotor-Sail System / Flettner Rotor

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

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
Magnus-Effect

$v_- < v < v_+$

$p_- < p_+$

$\vec{F}$

$\vec{v}$

$\vec{v}_+$

$\vec{v}_-$

$\vec{p}_-$

$\vec{p}_+$

Drag force

Propelling force

Lift force

Apparent wind

Fair wind

True wind
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 Commercial operation of E-Ship 1

2010
MV „E-Ship 1“
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
E-Ship 1 – Evaluation, Operating Experience and Results

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

\[
\begin{align*}
V_{\text{with Rotors}} &= 16.7 \text{ kn} \\
P_{\text{Shaft}} &= 2769 \text{ kW} \\
P_{\text{Shaft theor.}} &= 4747 \text{ kW} \\
V_{\text{without Rotors}} &= 14.3 \text{ kn} \\
P_{\text{Shaft}} &= 2769 \text{ kW} \\
\Delta P_{\text{Shaft}} &= 1978 \text{ kW} \\
- \text{ Rotor } P_{\text{rots}} &= 280 \text{ kW} \\
\text{netto } P_{\text{red.}} &= 1698 \text{ kW}
\end{align*}
\]
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
E-Ship 1 – Evaluation, Operating Experience and Results

Voyage Analysis: Emden-Portugal / Oct 2012

Average Motor only +25.0% Fuel
Average Total Voyage +6,8% Fuel
Average Sail-Rotor Operation -5,1% / net +2,1% Fuel 1

Average
Motor only
Total Voyage
Sail Rotor Operation

<table>
<thead>
<tr>
<th>SPEED [kn]</th>
<th>Motor only</th>
<th>Total Voyage</th>
<th>Sail Rotor</th>
</tr>
</thead>
<tbody>
<tr>
<td>12,47</td>
<td>13,69</td>
<td>14,59</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>P-Shaft [kW] Trial Cond.</th>
<th>Motor only</th>
<th>Total Voyage</th>
<th>Sail Rotor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td>2432</td>
<td>2816</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Counts [min]</th>
<th>Motor only</th>
<th>Total Voyage</th>
<th>Sail Rotor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1519</td>
<td>3569</td>
<td>2050</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time Ratio %</th>
<th>Motor only</th>
<th>Total Voyage</th>
<th>Sail Rotor</th>
</tr>
</thead>
<tbody>
<tr>
<td>43</td>
<td>100</td>
<td>57</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>P-Shaft actual [kW]</th>
<th>Motor only</th>
<th>Total Voyage</th>
<th>Sail Rotor</th>
</tr>
</thead>
<tbody>
<tr>
<td>2497</td>
<td>2598</td>
<td>2673</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>dP Ref Trial Cond. [kW]</th>
<th>Motor only</th>
<th>Total Voyage</th>
<th>Sail Rotor</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>167</td>
<td>-143</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>P el Rotor [kW]</th>
<th>Motor only</th>
<th>Total Voyage</th>
<th>Sail Rotor</th>
</tr>
</thead>
<tbody>
<tr>
<td>203</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>dP Ref Trial Cond. net [kW]</th>
<th>Motor only</th>
<th>Total Voyage</th>
<th>Sail Rotor</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>dP brutto %</th>
<th>Motor only</th>
<th>Total Voyage</th>
<th>Sail Rotor</th>
</tr>
</thead>
<tbody>
<tr>
<td>-5,1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>dP netto %</th>
<th>Motor only</th>
<th>Total Voyage</th>
<th>Sail Rotor</th>
</tr>
</thead>
<tbody>
<tr>
<td>25,0</td>
<td></td>
<td>6,8</td>
<td>2,1</td>
</tr>
</tbody>
</table>

Reference Line:
Trial Condition
(- optimal conditions)

0 10 20 30 40 50 60 70 80

Power Shaft [kW]

10 11 12 13 14 15 16 17 18 19 20

Speed over Ground [kn]
Sailing along Brazilian coast, July 2011

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

\[ V_{\text{with Rotors}} = 12.0 \text{ kn} \]
\[ P_{\text{Shaft}} = 297 \text{ kW} \]
\[ P_{\text{Shaft theor.}} = 1937 \text{ kW} \]
\[ \text{delta } P_{\text{Shaft}} = 1640 \text{ kW} \]
\[ - \text{ Rotor } P_{\text{rotors}} = 390 \text{ kW} \]
\[ \text{netto } P_{\text{red.}} = 1250 \text{ kW} \]
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!

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

Copyright:
© ENERCON GmbH. Any reproduction, distribution and utilisation of this document as well as the communication of its contents to third parties without express authorisation is prohibited. Violators will be held liable for monetary damages. All rights reserved in the event of the grant of a patent, utility model or design.

Content subject to change:
ENERCON GmbH reserves the right to change, improve and expand this document and the subject matter described herein at any time without prior notice.