EMR AND INVERSION-BASED CONTROL OF A SERIES HYBRID ELECTRIC EXCURSION SHIP

Dr. Walter LHOMME¹, Prof. João P. TROVÃO²

¹ L2EP, University of Lille 1, France
² University of Sherbrooke, Canada
Shipping CO2 emissions: 870 million tons in 2007

Increase predicted: 200-300% by 2050 in the absence of regulations

Needs of efficient ships on green oceans

Work started at International Maritime Organization (IMO) in 1980’s

✓ United Nations specialized agency (170 member states) with responsibility for the safety and security of shipping and the prevention of marine pollution by ships

✓ In July 2010, an “Energy Efficiency plan” was defined to reduce significantly the emissions
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- IMO & Energy Efficient Plan -

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Mandatory for new ships
Mandatory for all ships
2020: 10 - 17%
2030: 18 - 26%
2050: 35 - 41%

Target for emission reduction

Design (new ships):
- concept, speed & capability: 2 to 50%
- power & propulsion systems: 5 to 15%

Operation (all ships):
- fleet management, logistics & incentives: 5 to 50%
- energy management: 1 to 10%

(energyefficientshipping.wordpress.com/)
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- Examples of Green Ships -

**Nemo H2 Amsterdam**
(www.binnenvaart.eu/)

- 2009
- Amsterdam, NL
- First boat using fuel cell PEMFC of 70kW
- Lead-acid battery of 50kW

**ASD Tug 2810 Hybrid**
(products.damen.com/)

- 2011
- Port of Rotterdam, NL
- First European hybrid tug
- Series/parallel hybrid architecture

A tugboat pushes vessels that should not move by themselves

**The Ar Vag Tredan**
(www.stxfrance.com/)

- 2013
- Lorient, FR
- First boat using only supercap. (140 kW)
- Zero emissions
- Cruise at 10 knots for 2 x 7min (return)
- SC are charged in 4 min
1. Studied Diesel-electric Ship
2. Enhancement with a Series Hybrid Architecture
3. Conclusion & Future Work
1. Studied Diesel-Electric Ship
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- Studied Diesel-electric Excursion Ship -

Excursion Ship in Alster Lake, Hamburg, Germany

Outer Alster Lake
Max. length: 2.8 km / Max. width: 1 km

(en.wikipedia.org/)
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- Electric Power Demand of the Studied Excursion Ship -

Casting off:
take the boat of its quasi-immobility to its cruising speed

Cruising speed:
nearly constant power at constant speed

Docking:
fastest dynamics with several variations

Standby:
pick up and drop passengers

Portion of a classic tour in Outer Alster Lake
\[ J_s \frac{d\Omega_{SM}(t)}{dt} + f_s \Omega_{SM}(t) = T_{ICE}(t) - T_{SM}(t) \]

\[ C_{DC} \frac{dv_{DC}(t)}{dt} = i_{SM}(t) - i_{DC}(t) \]

\[ i_{SM}(t) = \frac{T_{SM}(t)\Omega_{SM}(t)}{v_{DC}(t)\eta_{SM}(t)} \]

\[ i_{DC}(t) = \frac{P_{dem}(t)}{v_{DC}(t)} \]
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- Results of the Studied Excursion Ship -

Engine of 200 Hp

BSFC = \frac{FC}{T_{ICE} \Omega_{ICE}} \Rightarrow \eta (\%) = \frac{100}{BSFC E_d 1000}

FC for Fuel Consumption in g/s

→ BSFC in g/kWh

E_d for Energy density of fuel in kWh/kg

Diesel = 11.7 kWh/kg
Gasoline = 11.9 kWh/kg
2. Enhancement with a Series Hybrid Architecture
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- Design of the Series Hybrid Electric Excursion Ship -

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\[ P_{SCs}(t) = P_{dem}(t) - \frac{1}{T} \int_0^T P_{dem}(t) \, dt \]

\[ P_{ge}(t) = 40.8 \text{ kW} \]

14 modules of 54V / 130F (540 Wh)
2 branches of 7 modules in series
\[ v_{DC}(t) \]
\[ i_t(t) = i_{ch\_SCs}(t) + i_{SM}(t) \]
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- Results of the Series Hybrid Excursion Ship -

Engine of 200 Hp

Downsizing

Engine of 90 Hp

Operating point $P_{ge}(t) = 40.8$ kW
Comparison and Results Analysis

- Diesel-electric Hybrid (200 Hp) Consumption: 2.919 liters
- Hybrid (200 Hp) Consumption: 2.917 liters (no reduction)
- Hybrid (90 Hp) Consumption: 2.64 liters

There is a 10% reduction in fuel consumption.
“Conclusion and Future Work”
- Conclusion -

- Possible enhancement of a diesel-electric excursion ship using EMR

- Series hybrid configuration using SCs without regenerative braking energy

- Reduction of the fuel consumption by 10% with a downsized ICE (90 Hp vs. 200 Hp) and 14 modules of SCs (223 liters / 217 kg)

**Design (new ships): power & propulsion systems: 5 to 15%**

**Perspectives**

- Major gains could be obtained with an optimal sizing

- Ecologically sensitive area: Zero-Emission Casting-off and Docking maneuvers
“Biographies and References”
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- Authors -

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Dr. Walter LHOMME
University Lille 1, L2EP, MEGEVH, France
PhD in Electrical Engineering at University of Lille1 (2007)
Research topics: EMR, HIL simulation, EVs and HEVs, Energy Storage Subsystem, Traction subsystems,

Prof. João P. Trovão
Université de Sherbrooke, e-TESC Lab., Qc, Canada
PhD in Electrical Engineering at University of Coimbra (2012)
Research topics: Electric Vehicles, Multiple Energy Storage, Energy Management


