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Universität Duisburg-Essen
Feb. 20th, 2020, Duisburg, Germany

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Simulation of Quasi- Static Electric and Magnetic Signatures of Naval Vessels

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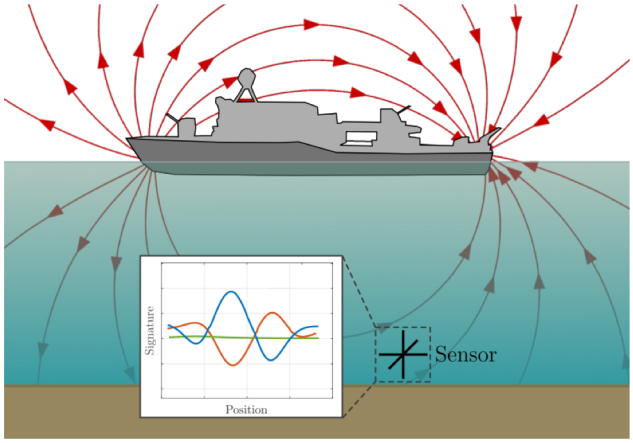
Motivation

Why simulate the signatures of naval vessels ?

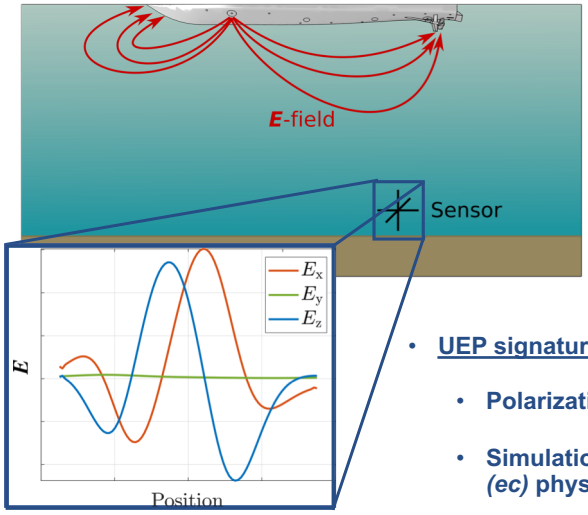


- Signatures can be subdivided in electric, magnetic, acoustic and pressure
- Signatures exploitable by underwater sensors (e.g. naval mines)
- Amplitude and shape of signatures contain information about the vessel (e.g. size, type, …)
- Signature can be used as trigger criterion for naval mines

➡ **Knowing signatures minimizes detection risk !**

Signatures of Naval Vessels

Underwater Electric Potential (UEP)



- Generated by:
  - corrosion process of the metallic materials of the vessel
  - Corrosion protection (CP) system
- UEP signature represented by an electric field *E*
- UEP signature highly nonlinear:
  - Polarization data necessary
  - Simulation possible using e.g. *Electric Currents (ec)* physics

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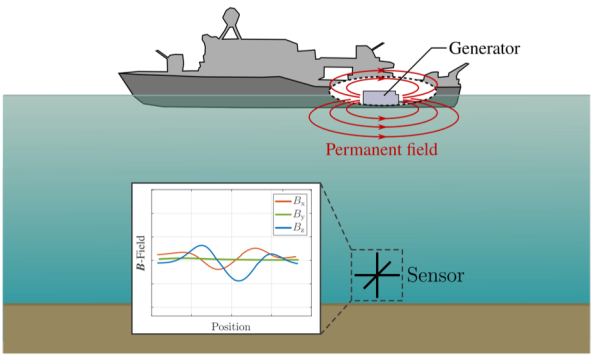
Signatures of Naval Vessels

Magnetic signatures



Generated by:

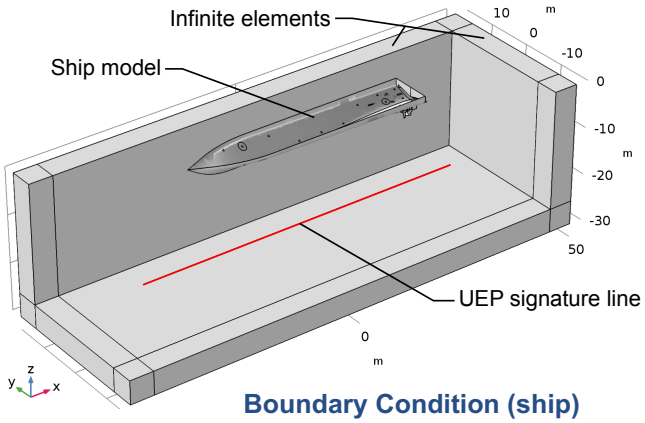
- Presence of the vessel in the earth's magnetic field (static and quasi-static)
- Onboard generators / motors
- Corrosion protection (CP) system

Magnetic signatures also time-dependent / transient

- Simulation possible using e.g. *Magnetic Fields (mf)* physics
- Using time-dependent study to account for transient effects

Simulation Setup

Computational domain for UEP signature



Boundary Condition (ship)

- Inward current density $J_{\mathrm{n,inward}} = -\boldsymbol{n} \cdot \boldsymbol{J}$
- $J_{\mathrm{n,\,inward}} = f(\varphi)$

Stationary Equations (ec)

- $\nabla \cdot \boldsymbol{J} = Q_j$
- $\boldsymbol{J} = \sigma \boldsymbol{E} + \boldsymbol{J}_{\mathrm{e}}$
- $\boldsymbol{E} = -\nabla V$

Solver and DoF

- Stationary evaluation
- Direct solver (PARDISO)
- DoF approx. 450000

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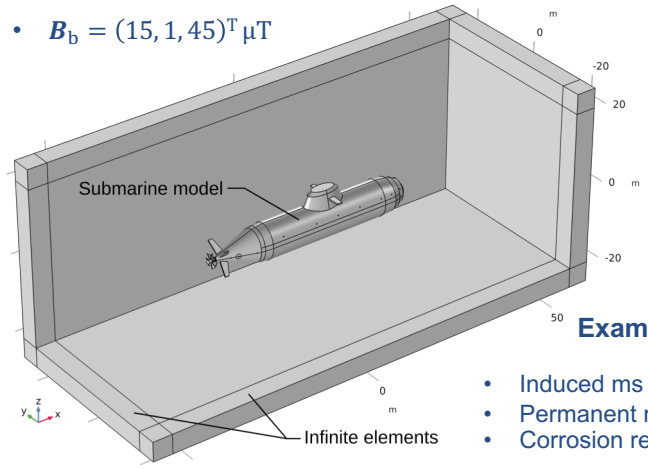
Simulation Setup

Computational domain for magnetic signatures

Background field

- $\boldsymbol{B}_{\mathrm{b}} = (15, 1, 45)^{\mathrm{T}}\,\mu\mathrm{T}$



Stationary equations (mf)

- $\nabla \times \boldsymbol{H} = \boldsymbol{J}$
- $\boldsymbol{B} = \nabla \times (\boldsymbol{A}_{\mathrm{b}} + \boldsymbol{A}_{\mathrm{r}})$
- $\boldsymbol{J} = \sigma \boldsymbol{E} + \boldsymbol{J}_{\mathrm{e}}$

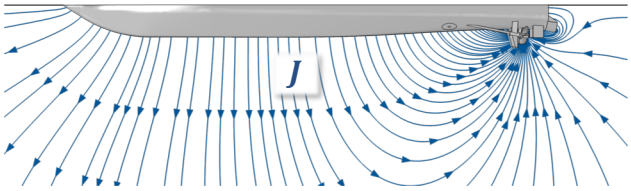
and time dependent (mf)

- $\boldsymbol{E} = -\frac{\partial}{\partial t}(\boldsymbol{A}_{\mathrm{b}} + \boldsymbol{A}_{\mathrm{r}})$

Example magnetic signatures (ms)

- Induced ms
- Permanent ms
- Corrosion related ms
- Eddy current ms
- Disturbance ms
- …

Simulation Results – UEP



- UEP related current density J pointing from hull (distributed anode) to propellers (cathodes)
- Different material combinations can be examined

- Electric potential distribution ”on hull” can be visualized (hull protected or unprotected)
- Necessary electric currents for cathodic protection (CP) analyzable

Helpful in both estimating the UEP signature and designing the CP system

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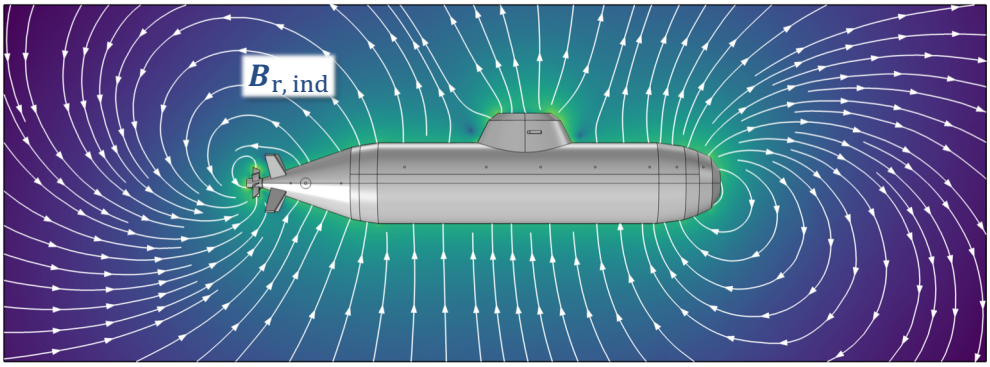
Simulation Results – Magnetic signatures

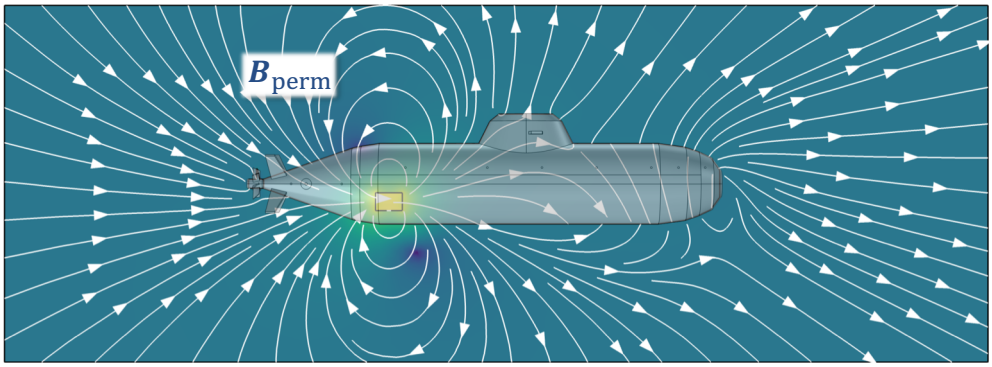
Induced magnetic fields



- Influence of magnetized hull can be evaluated for various material combinations
- Crucial for magnetic silencing (degaussing)

Simulation Results – Magnetic signatures

Permanent magnetic fields



- Impact of onboard sources can be examined which additionally generate disturbances in the earth's magnetic field
- Crucial for magnetic silencing (degaussing)

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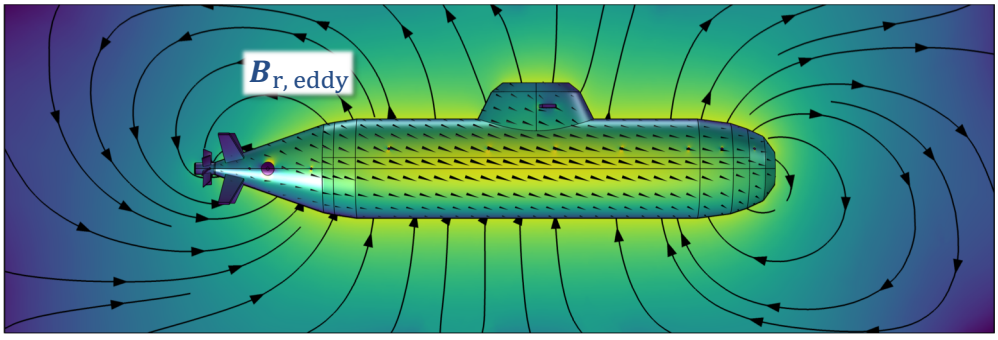
Simulation Results – Magnetic signatures

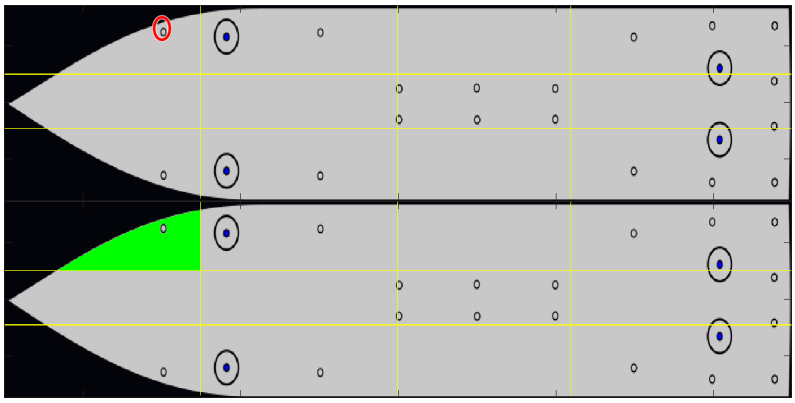
Eddy current magnetic fields



- Eddy current magnetic field is one of the most important magnetic signatures
- Still on-going research regarding real-time control for eddy current field compensation

Additional research

Cathodic protection and artificial neural networks (ANN)



- Using Comsol and LiveLink for Matlab to predict sector of coating damage with approx. 90 % accuracy

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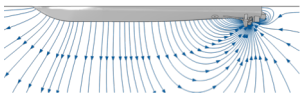
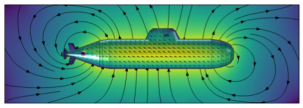
Conclusion & Outlook

- Electrochemical behavior for corrosion of hull and UEP signature can be simulated

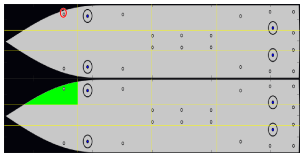


- Estimation of cathodic protection design

- Evaluation of magnetic signatures possible in both stationary and time-dependent manner



- Combination with LiveLink for Matlab allows for new concepts (e.g. coating damage evaluation)



Thank you for your attention!

Questions?