DOI 10.5162/EUROSENSORS2025/TP32

Study of the possibility to add piezoelectric sensors on boat hulls and investigation of shear stress caused by drag

Guillaume Cayla[1], Peter D. Folkow[1],
Vincent Udén[2], Henrik Staaf[2], Cristina Rusu[2], Alex A. Shiri[3] and Michael.Leer-Andersen[3]
[1] Chalmers University of Technology, Hörsalsvägen 7, 412 58 Göteborg, Sweden,
[2] Research institute of Sweden, Lindholmsallén 10, 417 55 Göteborg, Sweden
[3] SSPA Sweden AB, Chalmers Tvärgata 10, 400 22 Göteborg, Sweden
henrik.staaf@ri.se

Summary:
Reducing flow resistance of underwater vehicles is of great importance to reduce energy consumption in maritime transportation. In this paper, we present numerical simulations and experimental methods for structural health monitoring of boat hulls, using self-powered piezoelectric sensors to assess shear/drag forces. The studies are based on drag tests on an immersed plate using piezoelectric sensors placed in different locations. Simulations are done using COMSOL Multiphysics. The numerical results show good agreement with experimental sensors' voltage output measured at various speeds.

Keywords: Piezoelectricity, Structural health monitoring (SHM), Fluid-Structure interaction (FSI), Strain, MEMS

Introduction

Marine structures sustain various mechanical loads from solid-fluid interactions of different types, which usually have negative impact on the structural performance. For a ship hull, loads like drag force induce vibrations that may lead to fatigue or even structural failure of the hull. Monitoring stress and strain, especially in vulnerable zones, remains essential for durability and safety for maritime applications. In addition, there is an increasing demand for research and solutions for the reduction of emissions from the shipping sector. In 2023 the International Maritime Organization introduced mandatory reductions levels in carbon emissions for new and existing ships, by stating energy efficiency indicators [1]. One effective means is the implementation of drag reduction methodologies, e.g. by introduction of air lubrification [2]. Therefore, understanding and minimizing the drag forces are key factors for lower emissions. Such studies are part of the goals of the current EU project REFEST for fishing fleets [3].

Strain gauges and piezoresistive sensors are commonly used for measuring strain/stress. However, strain gauges require an external power source, whereas piezoelectric sensors are self-powered, i.e. generate voltage when exposed to mechanical deformations. Piezoelectric transducers are typically used in boat's hull monitoring as ultrasonic sensing to create surface acoustic waves [4]. In this study, we use flexible piezoelectric sensors to measure dynamically the strain/ stress induced by water friction / resistance.

Piezoelectric sensors

For this study, we use commercial sensors, Micro Fiber Composite™ (MFC) that consists of rectangular piezoceramic rods, sandwiched between layers of adhesive, electrodes, and polyamide film [5]. The dimensions are 28mm x 14mm x 0.3mm with polarization in d31 mode and placed at different positions on the metal plate structure of 7m x 1m x 0.05m (Figure 1).

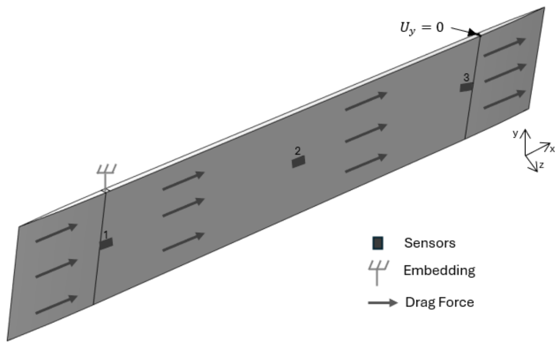

Fig. 1. Mounting of piezoelectric sensors on the plate that is tested under water (1:Front, 2:Middle, 3:Rear).

The sensors are mounted with thin adhesive and waterproof insulation. The plate was driven underwater at speeds from 1m/s to 5m/s. Special control and reading electronics were developed for real-time data acquisition (not shown here as well as the experimental part).

Simulation

The plate is supported by a rigid connector at the front and a chain at the back. This plate was simulated using *COMSOL Multiphysics 6.2*. Due to complexities when modelling the fluid-structure interaction (FSI), simplifications were made such as applying harmonic loading along the plate, corresponding to drag forces from turbulent flow. In this way, we can model the vibrations induced by fluid–structure interaction. In terms of boundary conditions, as seen in Figure 1, all the displacements are prescribed in the front of the plate and only displacements along the Y axis are prescribed at the back end of the plate, corresponding to the plate, being hold by the loose chain, if we assume small displacement hypothesis. These simplifications in the simulation allow to focus on electro-mechanical coupling of piezoelectric sensors and the strain from water resistance. Piezoelectric sensors are simulated with solid elements, with the same dimensions as sensors used during experiments. We coupled sensors with the plate, assuming a perfect interface with a flexible attachment to allow strain transmission.

Results

The voltage output from the piezoelectric sensors was analysed through both simulation and experimental measurements at flow velocities ranging from 1 to 5 m/s.

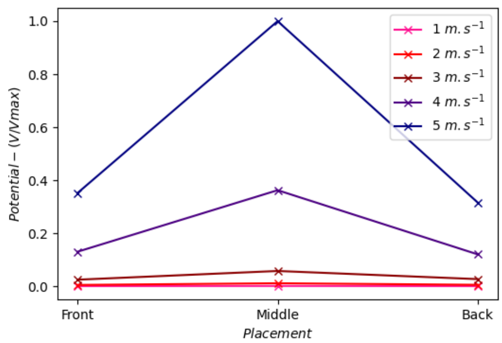

Fig. 2. Numerical output voltage for Smart Material-P2 along the plate [5].

As shown in Figure 2, the simulated results (normalized to the maximum value) indicate a distinct increase in voltage with higher fluid velocity, with the middle position consistently showing the highest output.

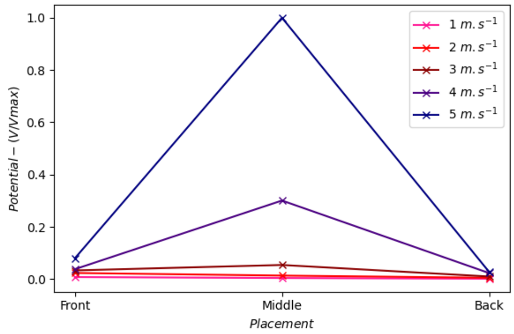

Fig. 3. Experimental output voltage for Smart Material-P2 sensors along the plate [5].

The measured data, presented in Figure 3, shows the same trend: The voltage output increases with velocity and peaks in the middle sensor placement. While absolute value differs due to normalization in the simulation and "real-world" effects in the measurement, the overall trend shows strong agreement.

Conclusion

This study demonstrates the potential of flexible piezoelectric sensors for monitoring strain caused by drag on submerged structures. The comparison between simulation and experimental data demonstrates that the developed model captures the key behaviour of strain distribution induced by hydrodynamic drag. They both shows that the middle region of the plate experiences the highest voltage output, indicating a stress concentration in this area. This correlation is validated by the numerical model. Future work will aim to refine the model to incorporate more realistic flow behaviour and test sensor response under more dynamic and realistic marine conditions.

References

[1] IMO, 2023. IMO strategy on reduction of GHG emissions from ships. MEPC 377 (80), 2023.
[2] https://www.scribd.com/document/486376944/SSPA-Hull-air-lubrication-future-and-challenges
[3] https://www.refest-project.eu/
[4] Lu Zhang et al 2019 IOP Conf. Ser.: Mater. Sci. Eng. 531 012090.
[5] https://www.smart-material.com/MFC-product-main