Effects of energy harvesting from a piezoelectric element attached to a propelling flexible tail

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Abstract. Monitoring fishes migration, which can extend to distances of thousands of kilometers, via autonomous fish tags is important to assess their populations. One constraint of current fish tags is the limited power of their batteries. We propose the development of self-powered tags that generate their own power from a piezoelectric element attached to an oscillating part of the fish body such as its flapping tail. To determine the functionality and potential of this technology, we present simulations that determine the effects of attaching a piezoelectric element to a flexible substrate on performance metrics including thrust generation, propulsive efficiency, and harvested electric power.

Introduction

Fish migration involves relocation of fish groups from one area or body of water to another for duration ranging from one to 365 days. Electronic tagging is currently used for continuous monitoring and assessment of the movement patterns of these groups and fishing levels, which are important to maintain healthy fish stocks. The weight, volume and finite energy of today's batteries that power fish tags limit their operational lifetime. As such, a fish tag that does not fully rely on battery power would support the capability of monitoring fish populations over longer periods. Noting the energy associated with fish body motions, one approach for developing self-powered tags is to mount or implant a piezoelectric element in a moving part of the fish body such as its tail. Still, it is important to evaluate adverse impacts of such attachments on the fish propulsion force, its efficiency, while considering the level of harvested electric power. We address these impacts by assessing energy generated from a piezoelectric element attached to a flexible beam, representing a fish tail and capable of generating propulsion when excited at its root. The basis of our study are the results of Hussein et al. *et al* [1], which showed that there are optimal flexibility and mass ratio parameters for enhancing propulsion. In these simulations, the substrate element, representing the fish tail, is modeled as a thin unimorph cantilever beam using the Euler-Bernoulli beam theory and excited by sinusoidal pitching at its root. The tail's upper surface is covered by a PZT layer connected to an electrical load resistance. The three-dimensional unsteady vortex lattice method is used to calculate the hydrodynamic loads generated by the pitching excitation under constant forward speed. The finite element method is used to solve the coupled time-dependent equations of motion representing the fluid-structure interaction. The implicit finite different method is used to discretize the time-dependent generated voltage equation. The fluid-structure interaction is achieved by passing the hydrodynamic loads to the coupled equations of motion and solving for structural deformation of the tail at each time step where the generated voltage is updated.

Results and discussion

Figure 1 shows plots of generated power and its impact on the propulsive force and efficiency. An optimal value of about $4 \times 10^4 \Omega$ for the electric load resistance for maximum electric power generation is noted. In the low frequency excitation range (Strouhal number, $ST < 0.3$), adding the PZT layer decreases the thrust coefficient and the required power to propel the tail. At higher excitation frequencies ($ST > 0.3$), the generated thrust is increased. However, this requires additional input power as demonstrated by the lower efficiency. The level of harvested electric power is in the range of few mW, which is three orders of magnitude smaller than the level of input or propulsive power, indicating that the piezoelectric energy harvesting should not have a large impact on the power needs by the fish to generate propulsion.

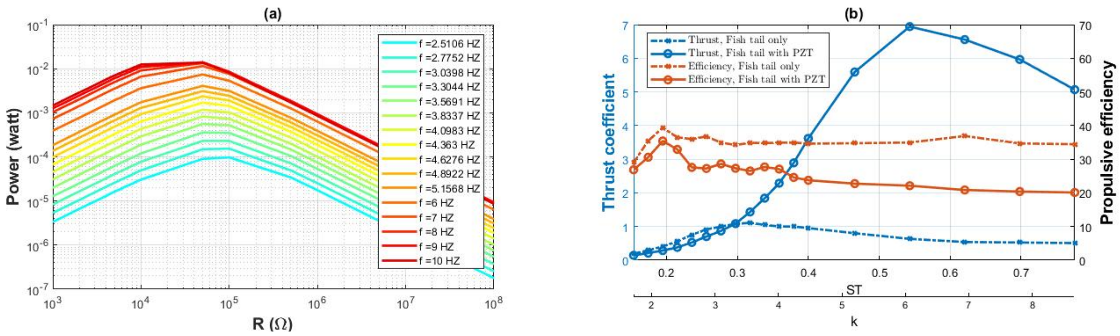

Figure 1: (a) Electric harvested power variation with load resistance at different excitation frequency values. (b) Variation of thrust coefficient and propulsive efficiency with Strouhal number, ST, and reduced frequency, K.

References

[1] Hussein, A. A., Ragab, S. A., Hajj, M. R., and Patil, M. J. (2021) Material and geometric effects on propulsion of a fish tail. *Bioinspiration & Biomimetics* **16**(6), 066008.