River flow energy harvesting by employing piezoelectric eels

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Abstract

Measuring of pollutants in rivers is often required. Underwater sensor networks are commonly used for this purpose. The sensors and the respective electronics must have enough power for undisturbed constant work. The possibility of using three energy harvesting principles for powering the sensors is described in this work. The focus is on piezoelectric eels. Alternatively, miniature underwater turbines and a hybrid solution based on "plucking" of piezoelectric beams, are also considered.

1 Introduction

Accurate measurement of pollutant levels in rivers can be achieved by employing underwater wireless sensor networks which constantly monitor, process and transmit pollution data. The sensors usually have high power requirements, while batteries have limited lifetimes. Energy harvesting devices appear thus to be an attractive solution [1]. The possibility of using three energy harvesting principles is proposed in this work: piezoelectric eels, miniaturized underwater turbines and a hybrid solution where a cam driven by the turbine is used to "pluck" a piezoelectric beam (Fig. 1). Estimated values of generated powers, based on typical river flow speeds of 1-4 m/s and on possible harvesters' dimensions, are calculated and discussed.

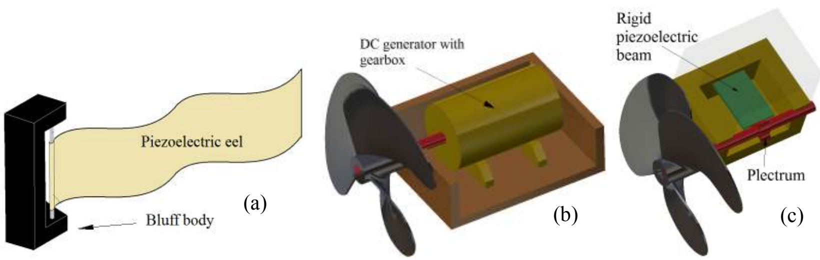

Figure 1: Considered energy harvesting solutions: piezoelectric eel (a), microturbine (b) and "plucked" piezoelectric beam (c)

2 Energy harvesting concepts

A summary of the design concepts as well as power generation estimates for the proposed energy harvesting solutions is outlined in this section.

2.1 Piezoelectric eels

Piezoelectric eel energy harvesters are composite devices made of piezoelectric polymers deposited on structural supports [2]. The eels are generally placed in river flows behind a bluff body used to generate vortexes (Fig. 1a). Fluid-solid interaction induces AC voltage generation in the eel. An analytical model of a bent section of the laminated eel (Fig. 2) has been proposed [3]. Based on the material characteristics and piezoelectric layers' dimensions, for different levels of eels' strain S_p and strain variation frequencies *f*, the model, implemented as a Matlab® routine, allows the output electric power *P*, which will be dissipated onto a matched resistive load, to be calculated (Fig. 3). Different piezoelectric materials can be used, but the two that show the highest electromechanical coupling potential are polyvinylidene difluoride (PVDF) and polyurethane (PU). PU is more compliant than PVDF, so that thicker PU layers can be used. Given the fact that PU has cca. 12 times higher electromechanical coupling (d_{31}) and a dielectric constant ε_r only half smaller than PVDF, PU proves to be a more efficient piezoelectric harvesters' material (Table 1), albeit commercially not easily accessible.

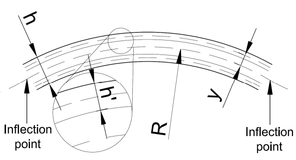

Figure 2. Bent section of the piezoelectric eel

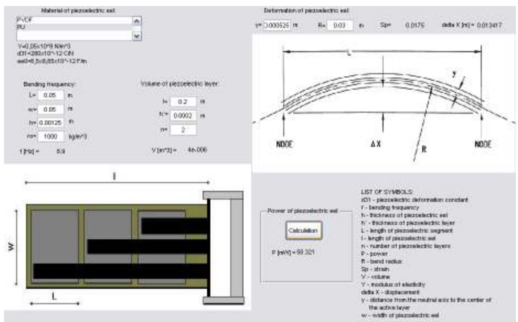

Figure 3. Matlab model of the piezoelectric eel

2.2 Underwater turbine and hybrid solution

To calculate the power generated by the water turbine (Fig. 1b), a principle analogous to a wind turbine power calculation can be employed [4]. Implementing the model as a Matlab algorithm, and supposing that the power coefficient $C_p \approx 30\%$, while generator's efficiency $\eta \approx 80\%$, a first approximation of the size of turbines' blades for varying river flow speeds can be obtained (Fig 4). It can be clearly seen that, as expected, as the river flow speed increases, the blade area exponentially decreases.

In the case of the proposed hybrid concept (Fig. 1c), the main components of the system are the turbine, used to convert rotational movement of the propeller axel into a plucking motion of an array of plectrums, and the piezoelectric bimorph used for the respective vibration energy harvesting. In fact, the cantilever, being periodically 'plucked' (hit and released) by the plectrums, oscillates freely at its first fundamental bending mode, producing electrical charge via the piezoelectric effect [5].

Table 1. Estimated power generated by a PVDF and a PU eel

	PVDF	PU
E [N/m^2]	2.7×10^9	0.05×10^9
d_{31} [C/N]	22×10^{-12}	280×10^{-12}
$\varepsilon_r\ \varepsilon_0$ [F/m]	$11\times8.85\text{x}10^{-12}$	$6.5\times8.85\text{x}10^{-12}$
S_p [m/m]	$3.67\text{x}10^{-3}$	$17.5\text{x}10^{-3}$
V_{piezo} [m^3]	$2.2\text{x}10^{-6}$	$4\text{x}10^{-6}$
P [mW]	19	74
P [mW/cm$^3_{piezo}$]	8.63	18.5

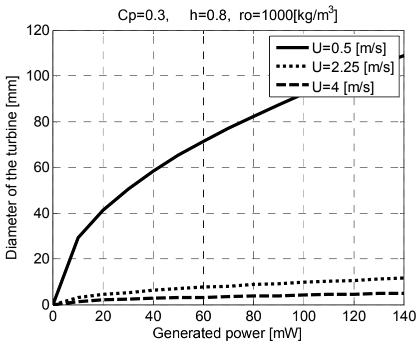

Figure 4. Power generated on a miniaturised turbine vs. river flow speed

3 Energy management

The piezoelectric eel and the hybrid concept generate random voltage amplitudes. On the other hand, by using the turbine, DC voltage, with an amplitude dependent on river flow velocity, is generated. The obtained energy must thus be properly managed to achieve DC voltage levels compatible with the used sensors and respective electronics. There are few commercially available energy harvesting chips which can make up the core of the conditioning electronics. If random voltage is present at its input, it first has to be rectified by a full wave bridge and then stored to a capacitor. When stored energy is sufficient to power the load, a buck converter delivers the voltage to the output. An input voltage to the chip can vary, depending on the used chip type, from few mV to several tens of V. In turn, additional passive elements (resistors, capacitors and inductors) have to be optimized in order to efficiently use the harvested energy, as well as to be able to power the connected loads. The energy management electronics must also be matched to the sleep/measure/wake/transmit cycles so as to achieve maximum efficiency of the whole measurement system.

4 Conclusions and outlook

In this work an outlook of possible river flow energy harvesting solutions for powering low power pollution measuring sensor nodes is given. Simulations of the behaviour of piezoelectric eels are performed for two types of piezoelectric polymers proving that PU harvesters are more efficient than PVDF ones. In view of this conclusion, future research will be focused on developing a PU eel harvester and testing it experimentally in real river flow conditions. Power levels obtainable by using the other two considered harvesting solutions will also be experimentally assessed as will also be the optimization of the power management electronics.

Acknowledgements

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