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Elise Saoutieff, Pierre Gasnier, Sebastien Boisseau, Javier Ojer-Aranguren, Isabelle Rodot. Performances of a cm-scale water flow energy harvester in real environment for autonomous flowmeters. Journal of Physics: Conference Series, 2019, 1407, pp.012074. <10.1088/1742-6596/1407/1/012074>. <cea-04538236>

HAL Id: cea-04538236

<https://cea.hal.science/cea-04538236v1>

Submitted on 9 Apr 2024

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Performances of a cm-scale water flow energy harvester in real environment for autonomous flowmeters

Elise Saoutieff¹, Pierre Gasnier¹, Sébastien Boisseau¹, Javier Ojer-Aranguren² and Isabelle Rodot³

¹Université Grenoble Alpes, CEA, LETI, MINATEC, 38054 Grenoble, France

²NAITEC, 31006 Pamplona, Spain

³SERM, 34960 Montpellier, France

E-mail: elise.saoutieff@cea.fr

Abstract. This paper reports the optimization and the characterization of a 4 cm diameter water flow energy harvester inserted in pipes. In this work, a test-bench has been implemented to measure the harvester's electrical output powers, rotation frequencies and pressure losses. Furthermore, long-term tests have been carried out in a district heating and cooling system (DHCS) in order to validate its operation in a real environment. Output powers up to 490mW @ 9 m³.h⁻¹ are reported with a mean output power of 5mW in real conditions (Montpellier's DHCS in France). The pressure losses induced by the turbine and the energy extraction remains lower than 50 mbars which is among the lowest in the state of the art.

1. Introduction

District heating and cooling systems (DHCS) need to be more efficient, smarter and cheaper to increase their adoption in buildings and cities. Water flow energy harvesters aim at converting locally a part of water flowing in pipes into electricity to supply in-line sensors (temperature, turbidity, pH...). They are a great opportunity to develop autonomous Smart Water Grid systems, and to make DHCS more competitive. The monitoring of real-time water consumption and water leakages is also beneficial from an environmental point of view. Indeed, according to "AFB" (French Agency for Biodiversity) [1], drinkable water leakage losses represent around 1 billion of m³ a year, namely 20% of the drinkable water in France.

Turbines are an effective solution to convert the kinetic power of flows into electricity. The output

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 Contrary to most of water flow energy harvesters proposed in the state of art [2], we propose an axial flow turbine based on a horizontal axis propeller with distributed magnets with alternate polarities at the rotor periphery and coils outside the pipe to simplify sealing (figure 1). As soon as the water flow enters in the energy harvester, the turbine starts rotating, leading to a rotational movement of the magnets. The movement of the magnets with alternate polarities induces a variation of magnetic flux in the air coils, which is finally turned into electricity (Lenz's law).

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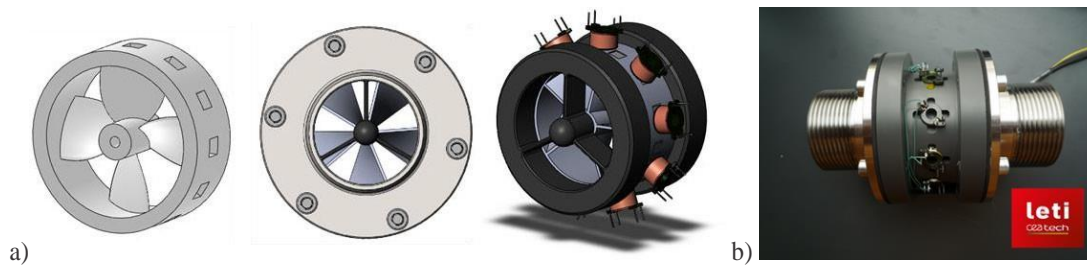


Figure 1. a) 3D CAD drawings of the propeller and electromagnetic converter of the waterflow energy harvester b) Assembled prototype (45mm wide; its external diameter is 85mm)

2. Design and optimization of water flow energy harvesters

This work follows the footsteps of [3,4] by proposing a 40mm diameter harvester for which two parameters have been optimized: (i) the propeller design and (ii) the electromagnetic converter design.

2.1. Propeller optimization

The inlet diameter has been set to 40mm to be equal to the diameter of the pipe. Then, four other parameters have to be set: (i) the shape of the blades (NACA, flat plate, cambered plate...), (ii) the number of blades N , (iii) the evolution of the chord $c(r)$, and (iv) the evolution of the blade angle $\beta(r)$. A 4-blade propeller with a tip speed ratio λ of 1, an angle of attack of 6° and a NACA2515 profile has been selected thanks to a comparative study performed in laboratory environment [5].

2.2. Converter optimization

A customized permanent magnet converter with ferromagnetic elements (screws) has been modelled, optimized with finite elements simulations (Altair® Flux) and fabricated. Twelve 5mmx10mmx10mm NdFeB magnets have been used and distributed at the rotor periphery with alternate polarities; 9 coils placed outside the pipe collect the variation of flux induced by the motion of magnets. The harvester's casing was machined in a nonmagnetic material (Polyoxymethylene) and the propeller was fabricated by using a 3D-printing process in polyamide powder filled with glass particles (90°C tolerant material).

3. Performances of the energy harvester

3.1. Tests in laboratory conditions

The performances and the efficiency of the water flow energy harvester have first been studied in laboratory conditions. The electromagnetic converter optimization has enabled to increase the electrical power (figure 2) by 2.7 @ $1.5\text{m}^3\cdot\text{h}^{-1}$ (3,2 mW) and up to 15.3 @ $9\text{m}^3\cdot\text{h}^{-1}$ (490 mW) compared to simple magnet-air coil converters [3,4].

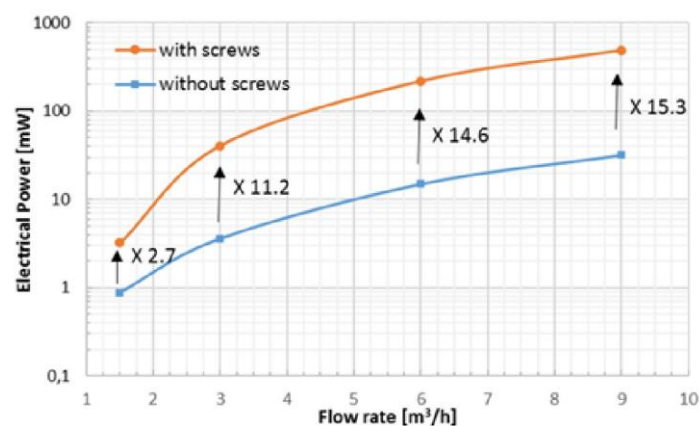


Figure 2. Electrical power with and without magnetic cores for various flow rates

3.2. Tests in real environment

The performances of the harvester have been evaluated in a real environment, i.e in a substation of the “Odysseum” district (Montpellier, France) during winter period.

3.2.1. *Overnight test* The harvester was firstly characterized (figure 3) during a whole night with typical flow rates between 1 and 4 $\text{m}^3\cdot\text{h}^{-1}$ (following demand) and a temperature around 50°C .

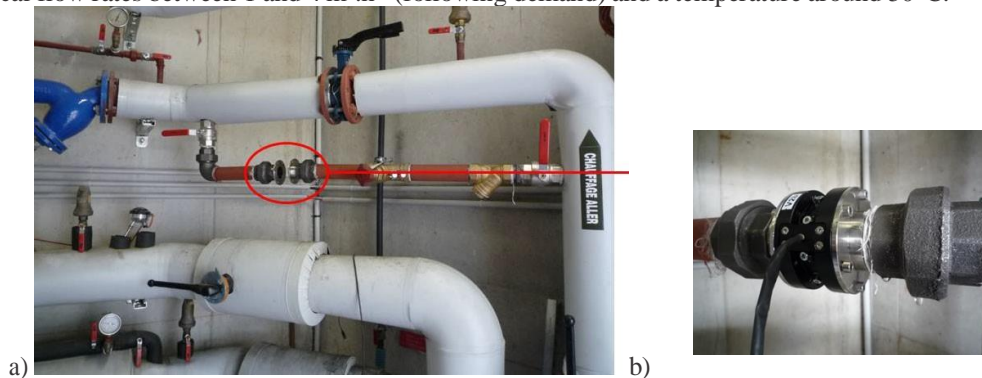


Figure 3. a) Holiday Inn substation in Montpellier, France b) integration of the water flow energy harvester in a bypass

As depicted in figure 4, the energy harvester is able to generate a mean power of 5mW (resistive load) while maintaining very low pressures losses (<0.05 bars) in the pipe, with a few interruptions due to a too low flow rate ($<1,5 \text{ m}^3\cdot\text{h}^{-1}$). One can also notice the good agreement between flow rate measurements and instantaneous powers which implies that the harvester could generate electricity while measuring the flow rate and, thus, could replace a conventional flowmeter.

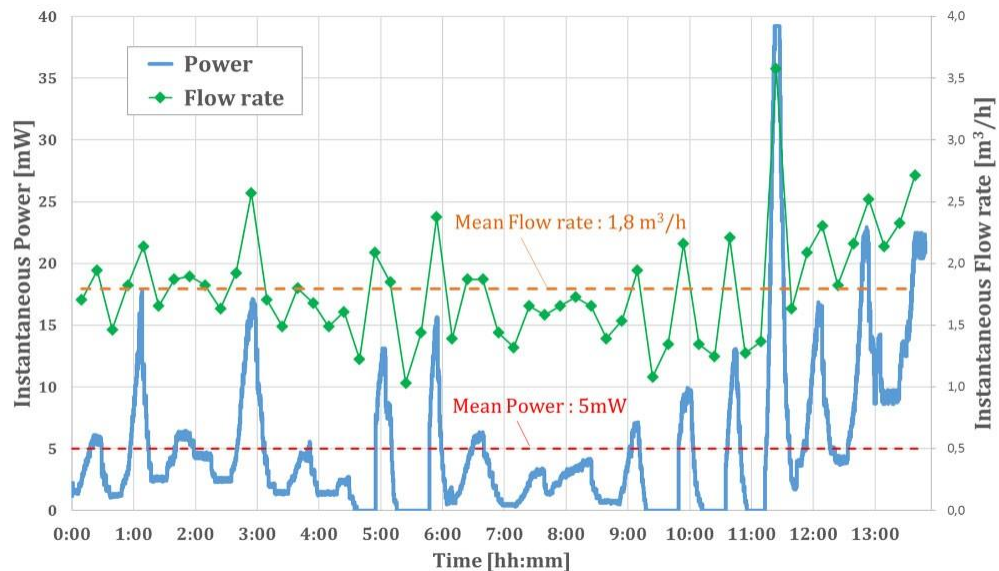


Figure 4. Measurement results in a real environment: instantaneous power (in blue) and flow rate (in green) as a function of time

3.2.2. Long-term operation The energy harvester was then tested continuously during 4 months with temperatures up to 90°C. We validated that the propeller was still rotating and supplying power to the resistive loads after these 4 months. However, we noticed the presence of fouling and dirtying on the rotor. Photographs of the propeller after the long term test are shown in figure 5. This fouling is undoubtedly due to the harsh environment of the water in DHCS pipes, which contains rust particles and in particular metallic particles. One can note that, this issue occurs also for standard flowmeters with propellers.

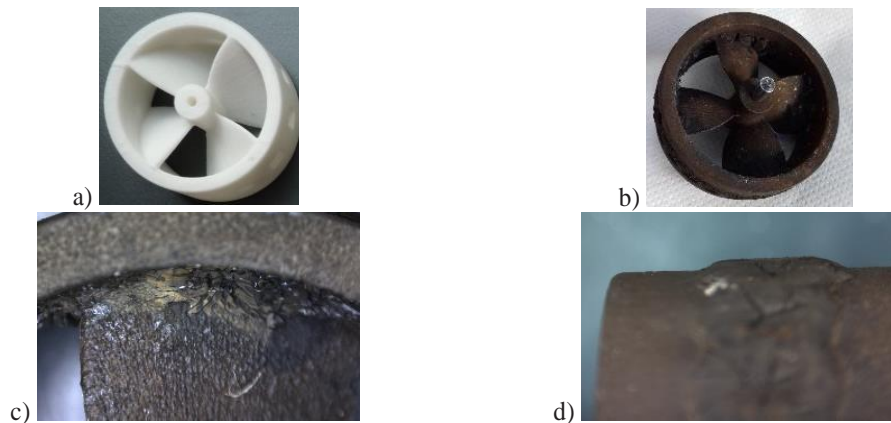


Figure 5. Photographs of a propeller a) before and b) after long-term tests and zoom on the c) blade tip and d) the magnet ring of a the propeller after 4 months of operation in DHCS pipes

4. Conclusions

This work is the first to propose the optimization of a centimeter-scale water flow harvester as well as its long-term characterization in a real application case.

Thanks to the optimization of both the propeller and the generator, the water flow energy harvester shows high output powers at high flow rates ($490\text{mW}@9\text{m}^3\cdot\text{h}^{-1}$) in both cold and hot water with very low pressure losses ($<50\text{ mbars}$). The proportionality between the rotation speed of the turbine and the flow can be used to turn this energy harvester into an autonomous flowmeter. The proposed harvester has been tested in a substation of a heating system during 4 months. The presence of fouling and dirtying on the propeller did not degrade its good operation. The next steps will be focused on the development of new propellers with coatings to reduce fouling and to increase their lifetime in harsh environments.

Acknowledgements

This work was carried out in the framework of the European Union's Horizon 2020 research and innovation program under grant agreement n° 696174 – InDeal project – (<http://www.indeal-project.eu/>).

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