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A MEMS turbine prototype for respiration harvesting

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Abstract. The design, manufacturing, and performance characterization of a MEMS-scale turbine prototype is reported. The turbine is designed for integration into a respiration harvester that can convert normal human breathing into electrical power through electromagnetic induction. The device measures 10 mm in radius, and employs 12 blades located around the turbine periphery along with ball bearings around the center. Finite element simulations showed that an average torque of 3.07 µNm is induced at 12 lpm airflow rate, which lies in normal breathing levels. The turbine and a test package were manufactured using CNC milling on PMMA. Tests were performed at respiration flow rates between 5-25 lpm. The highest rotational speed was measured to be 9.84 krpm at 25 lpm, resulting in 8.96 mbar pressure drop across the device and 370 mW actuation power.

1. Introduction

Energy harvesting from humans is becoming a promising alternative for powering portable electronic devices [1-2]. A number of harvesters have been reported so far, taking advantage of various body activities and transduction mechanisms. To give examples, thermal generators located around the human skin convert temperature difference into electricity, and tend to deliver nanowatt-level power due to low temperature gradients achievable around the body under comfortable conditions [3-4]. Piezoelectric materials allowed for power generation from high mechanical stress available around the body joints and shoe insoles [5-6]. Electromagnetic generators have been reported to output as high as 5 W utilizing knee motion [7]. In addition to these body activities, normal respiration also poses great potential for energy harvesting. Detailed studies on human breathing showed that watt-level power is available in the form of fluid flow [8-10], which indicates that milliwatts can be generated with a harvester having a few percent efficiency.

In recent works, different respiration harvester designs have been reported based on linear displacement magnets [11] and vibrating structures [12]. However, these designs limited the output power to microwatts due to the inefficient use of airflow. The most efficient technique for converting fluidic flow into electricity involves the use of turbomachinery and electromagnetic induction as in

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wind turbines. Accordingly, we have dedicated our efforts to developing a MEMS respiration harvester with a turbine-based architecture that can output several milliwats for powering portable electronic devices and biosensors as well as for recharging batteries. This work focuses on the development of the first turbine prototype, and reports our findings on turbine performance.

2. Design and simulations

The general turbine structure in Figure 1 measures $r_{out} = 10$ mm in radius and 1.3 mm in thickness. Turbine blades are defined around the turbine periphery with a radial length of $r_{out} - r_{in} = 2.5$ mm. A test package is designed to tightly encapsulate and actuate the turbine with tangential airflow through rectangular openings (Figure 1b). Stainless steel ball bearings ($\emptyset = 1$ mm) are located at $r_b = 2.3$ mm, and embedded in the grooves etched on both the turbine and the package to enable turbine rotation. The area between the ball bearings and turbine blades are reserved for permanent magnet integration to facilitate electromagnetic induction on stators that are currently under development.



Figure 1. Schematic view of the turbine, (a) cut-away view showing ball bearings, shaded volume is reserved for magnet integration, (b) packaged device, (c) final turbine design with relevant dimensions

Simulations were performed using the Fluid Structure Interaction interface of the COMSOL software for a range of blade numbers to maximize the induced torque and rotational speed for a given actuation flow rate. Figure 2 shows a snapshot of the fluid velocity profile around the turbine at a normal breathing rate of 12 lpm, from which the induced torque is calculated. Based on this study and considering the manufacturing challenges, the number of blades for this first turbine prototype was determined to be 12, leading to 3.07 μ Nm torque on the turbine.



Figure 2. Simulation result showing the air velocity profile around the turbine at 12 lpm

3. Fabrication and test results

The turbine and a test package were fabricated using CNC milling with 50 µm precision on PMMA substrates. The package is made in two pieces, and encapsulates the turbine with four screws at the corners. Metal sheets are placed in between the two package pieces for adjusting the gap and eliminating the normal load on the turbine. A rubber gasket is used for sealing the package. A picture of the fabricated device is shown in Figure 3. The turbine along with other components of the harvester are currently being manufactured using microfabrication technology.



Figure 3. Picture of a fabricated turbine and package

A test setup was built to investigate the turbine performance in the range of normal breathing flow rates. In this setup, the turbine was actuated using pressurized nitrogen as the gas source. The flow rate and pressure drop across the turbine were monitored using a flow meter that can perform both measurements. A black marking was created on the turbine, and the rotational speed was measured by observing this marking during actuation using an in-house-built stroboscope. Figure 4a plots the variation of the rotational speed with respect to flow rate, exhibiting a linear correlation. The change in the slope below 10 lpm is attributed to manufacturing artifacts. Figure 4b shows the corresponding pressure drops across the device with a rather nonlinear relationship. The highest speed was measured to be 9.84 krpm obtained at the maximum actuation flow rate of 25 lpm, which resulted in 8.96 mbar pressure drop and 370 mW actuation power.



Figure 4. Rotational speed versus (a) actuation flow rate, and (b) pressure drop across the turbine

4. Conclusion

The development of a turbine prototype for respiration harvesting is reported. The turbine design is composed of 12 peripheral blades and ball bearings located around the center. Simulations on fluid velocity profile showed that 3.07μ Nm torque is induced on the turbine at 12 lpm flow rate. The device and a test package were manufactured using CNC milling on PMMA substrates. A maximum rotational speed of 9.84 krpm was achieved at 25 lpm with a resulting pressure drop and actuation power of 8.96 mbar and 370 mW, respectively. The speed performance is expected to improve after the microfabrication of the turbine as well as the complete MEMS harvester. The turbine prototype reported here will enable the development of a MEMS respiration harvester that can be integrated into portable electronic devices, and provide milliwatt-level output power. The turbine design presented in this work can also be used in flow sensing applications.

5. References

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