Design and electromagnetic optimization of a respiration harvester

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Abstract

This work reports the design and electromagnetic optimization of a MEMS-scale turbo generator for harvesting fluidic energy in human exhalation. The device is composed of a turbine with dual-layer integrated permanent magnets, ball bearings, and stators with micro coils. For an efficient energy conversion, number of magnetic poles should be optimized to obtain maximum flux density in a given device geometry, where magnetic reluctance and leakage act as two competing effects. This optimization has been performed for different commercially available magnet thicknesses with fixed inner and outer radii of 2 mm and 8 mm, respectively. It has been shown that the optimum number of poles for 0.5 mm-thick magnets is 28, while pole numbers as high as 32 lead to higher flux densities for thinner magnets. The results presented here shed light on the efficient design of magnetic micromachines in similar scales.

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1. Introduction

Energy harvesting is a developing technology alternative to electrochemical batteries for low-power portable electronic devices. Among various environmental energy sources, harvesting human power to generate electricity is attracting significant attention [1-2]. Milliwatt- to watt-level power has been previously achieved using devices with piezoelectric and electromagnetic transduction mechanisms integrated on human body [3-5]. These results are particularly important to develop wearable power generators for personal electronic devices that will not depend on traditional batteries.

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Detailed experiments and analysis on human respiration showed that up to 1 W of fluidic power is available in normal exhalation, making it a promising power source for portable electronic devices [6-8]. One of the first demonstrations of a respiration harvester was presented by Sun in [9]. Composed of piezoelectric PVDF microbelts, the device generated microwatt-level output power and stored 20 μJ to a capacitor in 12 minutes. Currently, we are developing a MEMS-scale turbo generator capable of generating milliwatts of power using normal exhalation. This work reports our findings on the design and electromagnetic optimization of the device.

2. Design

The turbo generator consists of three main components: (i) a turbine rotor with multi-polar, dual-layer, and axial-flux NdFeB permanent magnets (Figure 1a), (ii) ball bearings (Figure 1b), and (iii) two stators with planar micro coils located 50 μm above and below the dual-layer magnets. The turbine and stator substrate material is silicon, while coils will be made of electroplated copper for low coil resistance. Commercially available stainless steel balls will be used with diameters ranging from 0.5 mm to 1 mm. The NdFeB magnets will also be off-the-shelf components that can provide a remanent flux density of as high as 1.4 T. Due to turbomechanical design constraints and microfabrication limitations as well as to maximize magnet area and output power, inner and outer radii of the magnets are selected to be 2 mm and 8 mm, respectively.

Tangential pneumatic actuation leads to the rotation of the turbine together with the permanent magnets, which induces voltage on both stators in accordance with electromagnetic induction principle. In such a multi-pole axial-flux magnet configuration, number of poles should be optimized to result in maximum magnetic flux density passing through stator coils. While low pole numbers lead to a long azimuthal flux path and a large magnetic reluctance, higher number of poles leads to leakage fluxes between adjacent poles that do not penetrate through the stator. Both effects reduce the effective average flux density acting on the stator. For pole number optimization as well as to observe these effects, the AC/DC module of the COMSOL finite element analysis software was used to perform magnetic flux density simulations.

Fig. 1. Turbine rotor design, (a) exploded view showing turbine, axial-flux NdFeB magnets, and stainless steel balls, (b) cut-away view showing ball bearings, (c) assembled turbine rotor. Figure is not drawn to scale.
3. Results and Discussions

Permanent magnets should be as thin as possible to allow for their integration into a silicon turbine frame. Considering this limitation along with current commercial availability, magnet thickness was set to be 0.25 mm and 0.5 mm in the simulation model. The thickness of the silicon in between dual magnet layers is selected to be identical to magnet thickness. In addition, commercial availability also limits the maximum number of poles to 32. Figure 2 shows the simulation model and the flux density distribution over a stator for 10 poles as an example. Although maximum flux density value can be as high as 0.498 T, the average value effective on stator coils decreases down to 0.377 T.

Simulations were performed for two different thicknesses and for pole numbers between 2-32. The variation of the average magnetic flux density with respect to number of poles is shown in Figure 3. Magnetic reluctance and leakage as two competing effects are clearly seen for 0.5 mm-thick magnets in Figure 3a. The simulations revealed that optimum number of poles for 0.5 mm-thick magnets is 28, while the effect of large reluctance remained dominant up to 32 poles for 0.25 mm-thick magnets. This shows that higher numbers of poles are favorable as the magnet thickness is decreased for the given magnet area.

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**Fig. 2.** (a) COMSOL simulation model drawing, (b) flux density distribution over the stator for 10 poles.

**Fig. 3.** (a) Magnetic flux density vs number of poles for 0.5 mm-thick magnets showing the ranges where large reluctance and flux leakages are dominant, (b) magnetic flux density vs number of poles for 0.25 mm-thick magnets.
4. Conclusion

The design and electromagnetic optimization of a MEMS turbo generator is presented. Composed of a turbine with dual-layer axial-flux permanent magnets, ball bearings, and a stator, the device generates voltage in response to pneumatic actuation. Number of magnetic poles is optimized for two smallest commercially available magnet thicknesses under the competing effects of high magnetic reluctance and leakage. It has been shown that 28 poles and 32 poles lead to maximum magnetic flux density for 0.5 mm- and 0.25 mm-thick magnets, respectively, within the given geometry. The results and methodology reported in this work will be instrumental in the optimum design of similar-scale magnetic micromachines.

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References