Journal of Physics: Conference Series

PAPER • **OPEN ACCESS**

Energy Harvesting Flex-Coil System for Pneumatic Pistons

To cite this article: J Esch *et al* 2018 *J. Phys.: Conf. Ser.* **1052** 012079

Energy Harvesting Flex-Coil System for Pneumatic Pistons

J Esch[1,3], K Ylli[1], D. Stojakov[1], A Willmann[1], D Hoffmann[1], Y Manoli[1,2]
[1] Hahn-Schickard-Gesellschaft für angewandte Forschung e.V., Wilhelm-Schickard-Str. 10, 78052 Villingen-Schwenningen, Germany
[2] Fritz Huettinger Chair of Microelectronics, Department of Microsystems Engineering – IMTEK, University of Freiburg, Germany

E-Mail: Jonas.Esch@hahn-schickard.de

Abstract. Condition monitoring systems are being implemented in many branches of industry as they help reduce machine downtime and enable the application of predictive maintenance. For easy and maintenance-free retrofitting an autonomous power supply is necessary. This work presents results on a foil-based inductive energy harvester as part of a condition monitoring system (system-on-a-foil) which can be retrofitted to pneumatic pistons. A maximum of 180 µJ of energy was generated with a single coil of the best layout for one motion cycle (back-and-forth motion) of the piston with a speed of 1 m/s. The total setup with five coils and an additional flux guide generates 1 mJ per motion cycle. This setup allows measuring the capacitor voltage and environmental data and transmitting them via bluetooth low energy to a portable device.

1. Introduction

Condition monitoring systems are very important for modern industrial facilities. They help to reduce machine downtime and to increase productivity. Many machines use pneumatic pistons for linear motions. At the moment pneumatic pistons have only a proximity switch to detect the end position after a forward or backward motion. The proximity switch is triggered by means of a magnet, which is attached at the piston rod inside the piston case. To get more information a sensor system is being developed, which measures the position during the motion. Two different settings have been implemented. In the first setting hall sensors are placed outside at the case of the piston. In the second setting a combination of flat coils is used. Due to the moving magnet inside the piston, a voltage is induced in each of the coils. Based on the voltage characteristic the position of the piston rod can be calculated during the motion. For predictive maintenance additional sensors are necessary to measure vibrations, temperature, humidity and pressure. To generate the power for the microcontroller and the different sensors the coils are also used as an energy harvesting system.

To get a practicable condition monitoring systems for pneumatic pistons the system is designed as a system-on-a-foil. Such a label with thinned chips and flexible tracks can be easily applied to pneumatic pistons. Figure 1 shows a pneumatic piston with a schematic of the system-on-a-foil and an

[3] To whom any correspondence should be addressed.

inside view of the magnet including flux lines. The final energy harvesting setup with the maximum power generation is shown in Figure 2. This setup includes a power management, an environmental sensor and bluetooth low energy for wireless data transmission.

Figure 1. Schematic of the pneumatic piston with the system-on-a-foil including the energy harvesting coils and a small inside view to show the magnet and the flux lines [1].

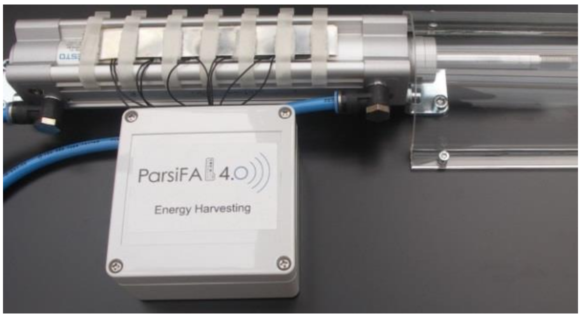

Figure 2. Photograph of the pneumatic piston including coils and flux guiding stripes connected with a power management.

2. Concept and Setup

A system-on-a-foil including an energy harvester means that the energy harvester coils also have to be implemented in the foil. In other energy harvesting systems, planar coils have been developed on PCB boards [2] or polyimide layers [3]. In this system the coils are designed on flexible circuit boards, with a copper layer height of 28 µm and various line widths and spacings (e.g. 120/80 means a copper line width of 120 µm and a spacing of 80 µm between copper lines). With the first manufacturing process a stripe (Figure 3) with two layers is generated. In a second step the stripe is folded to a multi-layer coil where 7 foldings imply a total of 14 coil layers (Figure 4). Each coil layer contains approximately 40-50 windings, depending on the line widths. Quadratic and circular layouts were designed and manufactured. The coil diameter is 18 mm and 10 coils can be placed next to each other along the test piston. The energy harvester uses the magnet from the proximity switch which moves with the piston rod. During piston motion a voltage is generated in the coils.

In order to get a higher voltage and power output, the original magnet (NdFeB N35) in the pneumatic piston was replaced by a bigger magnet with a higher magnetization (NdFeB N50).

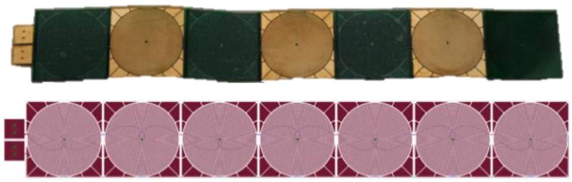

Figure 3. Photograph of the unfolded seven layer coil (top) and the layout (bottom).

Figure 4. Photograph of the folded coil.

3. Experimental Data

3.1. Experiment setup

Pneumatic Pistons are used for linear motions in many industrial machines. Depending on the task such systems can move slow and fast. In the laboratory setup the velocity is measured by a distance measuring system and controlled by pneumatic throttle. For comparison all experiments were carried out with the same moving speed of approximately 1 m/s. The schema for the coil positions is given in

Figure 5. To each coil a load resistor was connected, which is equal to the respective coil resistance. The voltage at the load resistors was measured simultaneously and is shown in Figure 6. For the modified piston (Figure 6 b) the generated voltage is 10 times higher than for the original piston (Figure 6 a). The results are shown for the circular 7 folded layer coil setup. For the circular 10 folded layer setup the voltage is 45% higher.

The induced voltage in the first and the last coil is very low because the magnet starts and stops moving under this coils and the moving speed is very slow. When comparing the data of voltage and speed measurement there is a direct correlation between the voltage peaks and the moving speed.

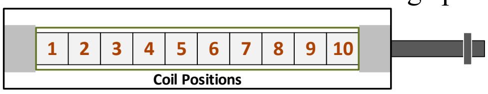

Figure 5. Schematic of the piston including the coil positions

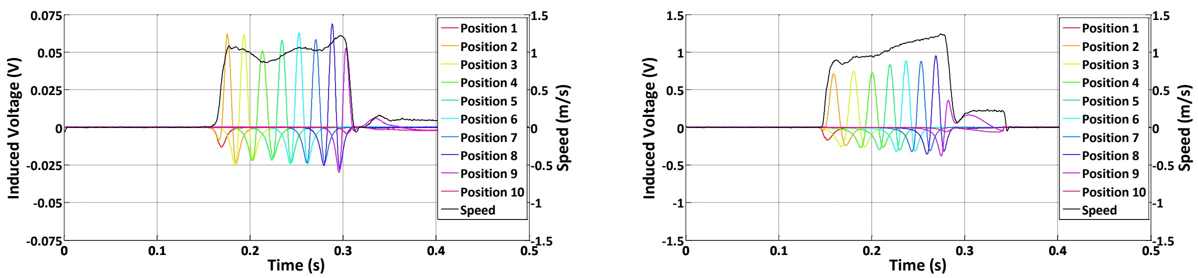

Figure 6. (a) Induced voltage for every coil for one piston motion with the original magnet including the speed measurement. (b) Induced voltage for every coil for one piston motion with the modified magnet including the speed measurement.

The generated energy for each coil and one motion cycle (one back-and-forth motion) is shown in Figure 7 and Figure 8. The energy is very low for coils at the end positions (Coils 1, 2, 9 and 10). This is because of the damping at the end which reduces the motion speed. Figure 7 shows a comparison between quadratic and circular coil designs and several line widths. The quadratic designs show extremely large resistances due to the fabrication process, where the copper line became unexpectedly narrow in the corners of each winding, thus creating a bottle-neck for the electrical current. When comparing circular coils of different line widths, experimental data indicates, that a comparatively small coil resistance leads to improved power outputs. An increased number of stacked coil layers also lead to an improved power output, although a stack of 10 folded layers loses its flexibility and is practically as rigid as a copper wire coil.

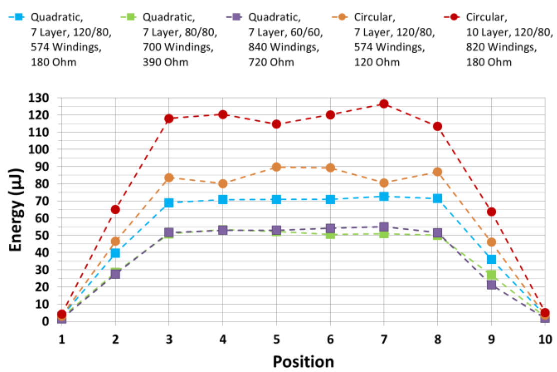

Figure 7. Energy comparison for different coil layouts and foldings.

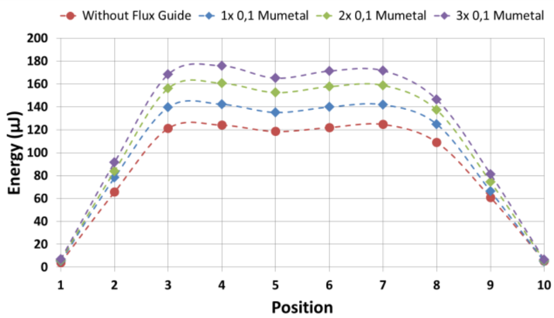

Figure 8. Energy comparison for varying number of flux guiding stripes.

The placement of thin layers of flux guiding material (mumetal) on top of the coils further improves the power output as shown in Figure 8. For the setting with the circular 10 folded layer coils adding three mumetal foils with a total height of 0.3 mm the generated power is 50% higher. The preceding simulations deviate by less than 5% from the experiments.

3.2. Demonstrator setup

To show the functionality of the energy harvester with a sensor system a new setup (Figure 2) was build. A diode rectifier was used to get a DC voltage of each coil. After the rectifier a power management with a capacitor and regulated voltage output was used to power a microcontroller with a bluetooth low energy communication interface. An environmental sensor was connected to the microcontroller in order to measure temperature, humidity and pressure. For generating usable voltage levels, two coils were used at each position and connected in series. In total, five coil pairs were positioned in the middle part of the piston and six mumetal foils were added above.

If the system starts the first time (cold-start) it needs about 80 seconds (one complete motion per second) to get enough energy in the capacitor for starting the sensor system and data transmission. Once the sensor system is started, the capacitor voltage is captured and transmitted every second whereas the environmental data is measured and transmitted every five seconds. In this configuration, the capacitor is still further charged as long as the motion of the piston continued.

4. Conclusion

In this work we presented an energy harvester for pneumatic pistons with no additional mechanical components. Only a replacement of the already existing magnet within the piston and mounting of coils were required to generate enough power for a sensor system with radio transmission. The functionality of the concept was demonstrated for an original pneumatic piston and a modified version. One motion cycle of the piston generates 1 mJ of energy. This is equivalent to a continuous output power of 1 mW when the piston does one motion cycle per second. For the final sensor system it is possible to use the first and last coil as a trigger signal to wake up the system. With such a configuration the power consumption can be reduced.

After the comparison of the simulation and experimental data an optimization algorithm was used to find the best coil layout. To get a coil layout with good manufacturability the feasible line width to space ratio is deposited as a boundary condition in the simulations. In addition to the line width to space ratio the line high was changed to 60 µm to reduce the coil resistant. Ongoing work includes a new fabrication run of the flex-coils and further experiments. An increase of 80% in power output is expected.

5. References

[1] Festo AG & Co. KG, *Forschungsprojekt ParsiFAl 4.0: Festo Unternehmen.* Available: https://www.festo.com/group/de/cms/12002.htm (2017, Sep. 21).

[2] Y. Li, W. Zhang, Y. Zhang, and J. Cao, “A batch-fabricated electromagnetic energy harvester based on flex-rigid structures,” *Sensors and Actuators A: Physical*, vol. 263, pp. 571–579, 2017.

[3] D. Hoffmann, C. Kallenbach, M. Dobmaier, B. Folkmer, and Y. Manoli, “Flexible Polyimide Film Technology for Vibration Energy Harvesting,” in *Proceedings Power MEMS*, pp. 344–347.

6. Acknowledgements

This research was supported by the German Federal Ministry of Education and Research (funding code: 16ES0435).