Thermoelectric energy harvester for a smart bearing concept

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Abstract

To meet new market demands, the reliability and robustness of the new designs has to undergo constant improvement. The diagnostics or machine condition monitoring (MCM) force new constructions to be equipped with wide variety of sensors. This means also cables, interfaces and control electronics which may cause the system to be rather bulky. The paper presents a concept of a bearing housing that by using of the thermoelectric phenomena supplies the energy for a set of sensors and wireless communication module, converting a bearing set into a self-powered wireless sensor node (as the bearings are often source of diagnostics signals). The presented conception is still under development. Due to multidisciplinary nature of the device being designed the effort was taken to create a reliable, parametric model of the whole device enabling further development and optimization.

Keywords: heat transfer, monitoring, smart materials, sensor network

1. Introduction

New constructions tend to meet more and more strict demands of reliability and robustness, therefore there is a growing number of sensors and supplementary electronics integrated in machines designed nowadays. The bearing system in any machine is under special consideration when it comes to the system health assessment [4] and it's also an important transfer path between vibration source to the protected areas. All the concepts of smart bearing systems base on the extensive use of sensors and actuators, to which a power supply has to be delivered. In many cases the energy needed is at the level that could be covered by a fraction of local power loss in a machine – if it could be recovered. The potential application of the presented concept is a power supply system for the wireless sensor in a network of energetically self-sufficient sensors. Moreover, the energy harvested from the thermal power loss in a bearing node may be used as well to power the semi-passive vibration reduction devices. Many existing monitoring systems are cable or battery operated, however, there is a lot of effort taken for creating energy harvesting devices. The main area of interest is vibrational energy and piezoelectric transducers or waste heat recovery with thermoelectric materials. There are successful designs that are able to produce substantial amount of energy e.g. thermoelectric generators applied on mufflers or exhaust manifolds of combustion engines [7]. There is still lack of highly integrated low power energy harvesters, that can sustain the right energy level for continuous stable operation of MCM systems. Considering the bearing system as the energy source, there are only few harvesters designed till now, however, they introduce a lot of limitations to the bearing type and operating conditions (like rpm, bearing type etc.) and are not machine integrated designs.

The article presents the concept of an energy harvester based on thermoelectric generators and analysis of recovered power level together with the morphological analysis of the bearing housing shape. As the thermoelectric materials achieve relatively low efficiency rates at the temperatures in a vicinity of 320K a special care was taken to determine the design giving satisfactory energy density ratio.

2. Principle of operation

The thermoelectric phenomenon is a collective term, it refers to the phenomena of transforming electric potential into temperature difference ΔT (and reverse) and of absorbing/emitting heat with the current flowing through the thermoelectric element (effect depends on directivity of the electric current). The thermo generators consist of thermocouples connected electrically in series and thermally in parallel.

The cause of the power loss in a bearing is a frictional moment generated as a result of viscous drag, rolling friction, microslip etc. In general, the total frictional moment in a bearing depends on its dimensions and type, the load and its type (radial, axial), rotational speed and type of lubricant used. Equations introduced by Palmgren [6] and commonly referenced in literature enable to calculate the power loss in a bearing depending on its size, load, rpm and lubrication.

3. Modeling

To be able to develop an efficient harvesting system it is necessary to have reliable method for thermoelectric generators modeling. One can choose analytical method [2], electric analogy [5], FEM (e.g ANSYS) [1], differential equation based modeling [3](e.g. COMSOL) or heat transfer modeling with appropriate boundary conditions set (accounting for TEG presence). All the above methods were used and compared by the authors. It can be shown that the behavior of the TEG can be modeled in a sufficiently precise way (relative errors less than 15% for the matched impedance case) with most of these methods (Fig. 1). However analytical approach proved to have a limited use.

4. Experimental setup

The experimental bench presented in Fig. 2 consists of a DC motor (1), shaft (3) connected with the power unit by

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flexible clutch (2) and three bearings set (3x1206 self-aligning type). The radial load is induced by one of the bearing seat that can be shifted in a radial direction giving load to the bearings.

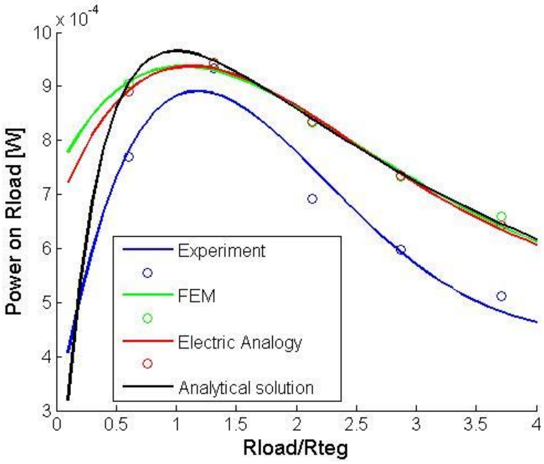

Figure 1: Power harvested by the TEG of a small size (7x7 [mm]) for 3 [K] of temperature difference at the element's junctions. X-axis presents a ratio of load resistance to generator internal resistance

Another experiment with the resistive regulated heater placed instead of a bearing was conducted to check the model accuracy for the wide range of power dissipated in a bearing. The data would be difficult to obtain in the laboratory due to long cooling/warming cycles of the test rig. The results of the experiment and numerical analysis are summarized by the table given below.

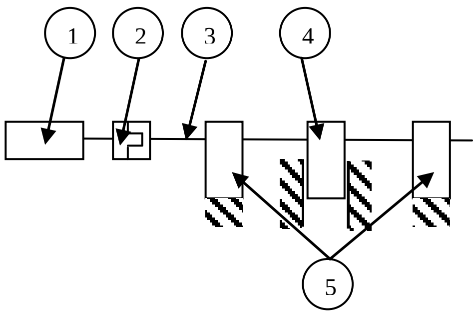

Figure 2: Schematic overview of the experimental bench

5. Conclusion

The results clearly show that energy harvester taking advantage of a single (medium size) bearing can power low-power measurement node. The constant power level of around 10-100 [mW] (depending on the harvester construction and operational conditions) and voltage output at the level of 0.5-1.2 [V] (series connection of all TEGs) are above the minimum requirements of low power electronics like DC-DC converters (threshold of around 20 [mV]), power management units. The peak power consumption of the measurement node and wireless module can be satisfied when standard measurement/stand-by time intervals are used. However, the volume energy density of presented harvesting device and its efficiency is low (due to TEG's performance). The system is bulky and moreover requires some free space around to not disrupt natural convection process. The presented solution is a concept in an early phase of design hence it is not operating at the optimum performance yet.

The numerical simulations show that the single components as well as the system as a whole can be simulated with acceptable errors. Special attention is needed when modeling convection cooling phenomenon as well as all thermal bridges and contact resistances in the system. The further work will focus on the model accuracy enhancement. The shape design of the device will be improved to make it less bulky and not to exceed standard bearing housing outline dimensions. The possibility of the self-powered combined harvesting and vibration reduction system will be investigated during future works.

Table 1: Experimental and numerical results summary

Dissipated power [W]	Harvested power / experiment [mW]	Harvested power / simulation [mW]
3.4	0.9	0.78
7	2.1	2.3
12	4.9	6
20	15.8	15.4
30	27.23	32

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