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ANALYSIS ON A MAGNETO-ACOUSTIC GENERATOR FOR HARVESTING ENERGY FROM LOW-FREQUENCY ENVIRONMENTAL NOISE

J. Bao, V. Klymko, B. L. J. Gysen, E. A. Lomonova

Eindhoven University of Technology, Department of Electrical Engineering, Electromechanics and Power Electronics, Den Dolech 2, Eindhoven, Netherlands

E-mail: j.bao@tue.nl

Abstract This paper presents a magneto-acoustic energy harvester that can harvest energy from external low-frequency noise and static magnetic field. The concept of the harvester is introduced, and the numerical simulation results of the vibration amplitude and induced voltage are presented.

Keywords: Energy Harvester, Induced Voltage, Plate Vibration

INTRODUCTION

Sensors are developing rapidly during the last decade, the miniaturization of such devices lead to significant reduction in power consumption [1]-[2]. Some sensors need to be placed in the locations where wire connections are difficult, such as in bridge pillars and rotating machines. Therefore, those sensors require autonomous power supply, and batteries are commonly used in these situations. However, batteries have to be replaced periodically, which are sometimes considerably difficult. Additionally, discarded batteries are major sources of environmental pollution. Therefore, energy harvesters which utilize environmental sources like solar, thermal, wind and vibrations are good alternatives of batteries to power up those sensors.

This paper analyzes an energy harvester that can power the embedded sensors in the machinery and plants, where the static magnetic field and the acoustic noise are present. These two sources are utilized by the harvester to generate electric voltage.

HARVESTER WORKING PRINCIPLE

Harvester system

The harvester contains a thin flexible plate of circular shape with conducting strips imprinted on its surface. The ambient noise causes the physical deformation of the plate, which is also exposed to a strong magnetic field. The conducting strips on the plate surface form loops that are intersected by the magnetic flux. The deformation of the harvester alters the magnetic flux that penetrates the loops, so that induced voltage is generated in the conducting strip. The harvesting system is shown in Figure 1. The ends of the conducting strips are connected to an AC/DC converter to charge a temporary storage, like a super capacitor. The plate dimensions are selected in such a way that the resonant frequency of the harvester is the same as the dominant frequency of the noise. To validate the harvester's working principle, a harvester is designed that works in an environment with the dominant noise frequency approximately at 100 Hz. Single copper strip printed in the center of the plate is considered for the start as shown in Figure 1.

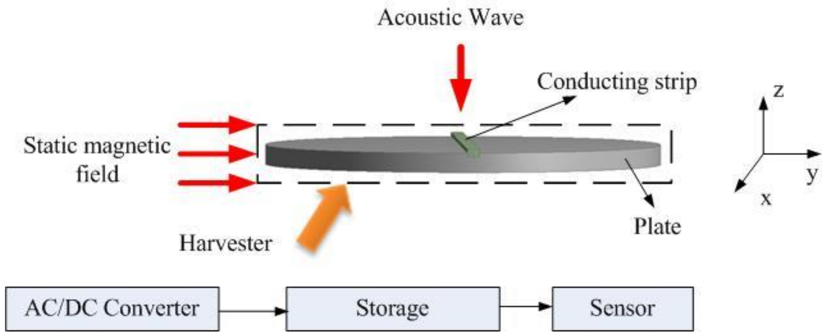


Figure 1. Harvesting system.

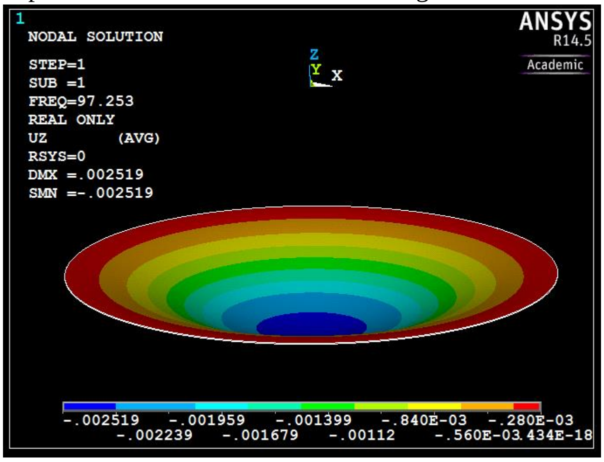
Vibration analysis

Based on the plate theory [3], the resonant frequency of a circular plate having m nodal circles and n nodal diameters with a clamped edge is,

(1) $$\omega_{mn} = \frac{\pi^2}{a^2}\beta_{mn}^2\sqrt{\frac{D}{\rho h}}$$

where a is the plate radius, D is the flexural rigidity, ρ is the density of the material, and h is the thickness. According to equation (1), for plates with the same radius, the resonant frequency of a certain vibration mode increases if the plate is thicker. Therefore, the plate thickness is set to be 0.1 mm, which is suitable for harvesting energy in low noise frequencies. Additionally, plate with such thickness can be easily manufactured, like the substrates of flexible printed circuit boards (PCB). The copper strip can be printed on the plate using inkjet printing technology, that is widely used in printing coppers on polyester flexible circuits. The printed copper strip thickness is significantly smaller compared to the plate itself, such that the strip's effect on the vibration is ignored.

The density of polyester is among 1200 – 1500 kg/m^3, and is set to be 1420 kg/m^3 in this paper. For a plate with 5 cm diameter, the calculated resonant frequency is at 105 Hz for the (1,0) vibration mode. This is verified by the modal analysis in ANSYS mechanical APDL that has the resonant frequency at 97.3 Hz. The vibration amplitude is simulated both in the frequency and time domains using the harmonic analysis and transient analysis in ANSYS mechanical APDL, respectively. Under 3 Pa of acoustic pressure, the amplitude in the steady state is shown in Figure 2(a) for the whole harvester, and the vibration amplitude from the start point to the steady state is shown in Figure 2(b) for the center point of the harvester. As can be seen, the harvester's center point reaches approximately 2.5 mm in both figures. After the simulation, the deformation amplitude is exported to calculate the induced voltage.



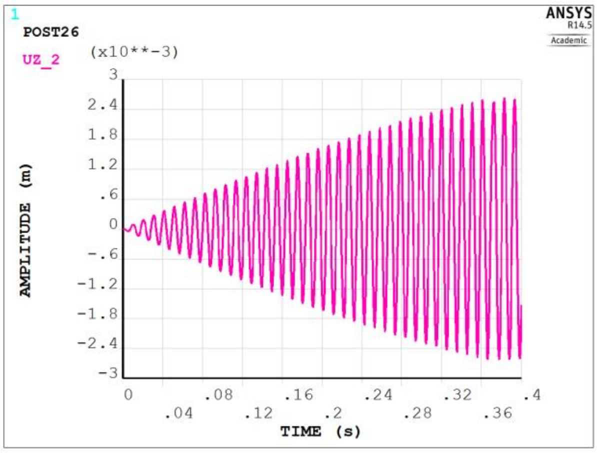


Figure 2(a) Deformation of the harvester at steady state and (b) vibration amplitude of the harvester's center point from vibration start point to steady state.

Induced voltage

The induced voltage is calculated based on the Faraday's law using MATLAB. The copper strip is divided into many small segments, the induced voltage of each segment is,

(2) $$E_i = BL_i v_i$$

where B is the flux density, L_i is the length of each segment, and v_i is the velocity of the segment. The vibration of the harvester is almost sinusoidal under a sinusoidal excitation. Therefore, the velocity can be derived using the displacement exported from ANSYS. The total voltage is the sum of the voltage across each segment. If the ambient magnetic field is 0.5 T, the harvester is able to generate 17 mV. However, this value will increase if we increase the number of copper strips while the acoustic pressure and the magnetic field remain the same.

CONCLUSIONS

An energy harvester that utilizes the motion of conducting strips on a flexible plate in a constant magnetic field to generate electrical voltage is designed and modelled. Proposed design is being tested numerically with ANSYS models. The harvester is able to generate 17 mV under 3 Pa of acoustic pressure and 0.5 T magnetic field.

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