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Comparison of electromagnetic and piezoelectric vibration energy harvesters with different interface circuits

Xu Wang [a,*], Xingyu Liang [b], Zhiyong Hao [c], Haiping Du [d], Nong Zhang [e], Ma Qian [a]

[a] School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University, Bundoora East, Vic 3083, Australia
[b] School of Mechanical Engineering, Tianjin University, Tianjin, PR China
[c] School of Energy Engineering, Zhejiang University, Hangzhou, PR China
[d] School of Electrical, Computer and Telecommunications Engineering, University of Wollongong, NSW, Australia
[e] School of Electrical, Mechanical and Mechatronic Systems, University of Technology, Sydney, NSW, Australia

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ABSTRACT

A frequency response analysis has been conducted for a single degree of freedom vibration energy harvester connected to four different interface circuits. The performance and characteristics of both electromagnetic and piezoelectric harvesters have been analysed and compared. The main research outcome is the disclosure of similarity and duality of the electromagnetic and piezoelectric harvesters with different interface circuits. The contribution of this paper is to provide a new method to identify a vibration energy harvester with the best interface circuit and the most stable performance.

1. Introduction

Harvesting power from the environment is an attractive alternative to battery-operated systems, especially for long-term, low-power consuming and self-sustaining electronic systems. The electromagnetic and piezoelectric vibration energy harvesters have been intensively studied in the literatures as shown in Table 1 where different piezoelectric vibration energy harvesters or electromagnetic vibration energy harvesters were connected to a single load resistor [1,2,4,6–9,13,17,20,21,23,25,26,28–30,34,37,40,42,44,48,50,51,53] or connected to bridge rectification and storage interface circuits [1,9,10,12,14–16,19,20,26,28,31–33,36,40,41,43,45,49,52]. The power output has been optimised [2,3,5,7–9,11–13,15–19,22–35,37–44,46–53] and has been normalised in dimensionless forms [1,12,13,19,21,26,27,31–34,37,40,41,44,48–53].

Most research papers have discussed some optimisations of harvested power of the electromagnetic or piezoelectric vibration energy harvesters while limited researches have been conducted to compare electromagnetic and the piezoelectric vibration energy harvesters for the power harvesting performance [25,29,50,51] and to normalise resonant harvested power and energy harvesting efficiency for dimensionless analyses [1,12,13,19,21,26,27,31–34,37,41,44,48–52].

* Corresponding author. Tel.: +61 3 99256028; fax: +61 3 99256108.
E-mail address: xu.wang@rmit.edu.au (X. Wang).

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Nomenclature

A	Piezoelectric material insert disk surface area
B	Magnetic field constant
l	The length of the coil in the electromagnetic generator
D	Short circuit mechanical damping of the single degree of freedom system
C_0	Blocking capacity of the piezo-electric material insert
e	2.718281828
e_{33}	Piezoelectric constant;
ε_{33}^S	the piezoelectric permittivity;
F	Excitation force;
f_n	Natural frequency;
H	Thickness of the piezoelectric material insert disk;
i	Square root of -1;
I	Current in the circuit;
K	Short circuit stiffness of the single degree of freedom (SDOF) system;
L_e	Self-inductance of the coil;
M	Oscillator mass of the single degree of freedom system;
P_h	Harvested power;
P_{in}	Input power;
$\frac{P_h}{\left(M^2 \cdot \frac{\lvert\ddot{y}\rvert^2}{D}\right)}$	Dimensionless resonant harvested power;
$\frac{P_{h\ max}}{\left(M^2 \cdot \frac{\lvert\ddot{y}\rvert^2}{D}\right)}$	Peak dimensionless resonant harvested power;
s	Laplace variable;
T	Period of the excitation force signal
V	Output voltage of the SDOF system
V_M	Output voltage amplitude of the SDOF system
y	Base excitation displacement
$\dot{y}$	Base excitation velocity
$\ddot{y}$	Base excitation acceleration
Y_M	Base excitation displacement amplitude
z	Relative displacement of the mass with respect to the base
$\dot{z}$	Relative velocity of the mass with respect to the base
$\ddot{z}$	Relative acceleration of the mass with respect to the base
Z_M	Relative displacement amplitude of the mass with respect to the base
α^2 or Θ^2	Squared force factor of the piezo-electrical material insert, or the equivalent force factor of the electromagnetic vibration energy harvester
α	The force factor of the piezo-electrical material insert, or the equivalent force factor of the electromagnetic vibration energy harvester
α_N^2ork^2	Squared dimensionless force factor for the piezo-electrical material insert, or dimensionless equivalent force factor for the electromagnetic vibration energy harvester
α_N	The dimensionless force factor for the piezo-electrical material insert, or Dimensionless equivalent force factor for the electromagnetic vibration energy harvester
k	The dimensionless force factor for the piezo-electrical material insert, or dimensionless equivalent force factor for the electromagnetic vibration energy harvester or dimensionless electromechanical or electromagnetic coupling coefficient;
R_N	Dimensionless resistance;
R_e	The resistance of the coil;
ξ	The mechanical damping ratio;
ξ_c	The inversed load coefficient;
ξ_e	The inversed resistive loss coefficient;
k_e^2	The electromagnetic mechanical coupling factor
Q_m	Mechanical damping quality factor;
η	Resonant energy harvesting efficiency
η_{max}	Maximum resonant energy harvesting efficiency
ω	Excitation frequency

Subscripts

0	Rectified or blocking capacity of the piezo-electric material insert
33	Piezo-electrical working mode having the same direction of loading and electric poles
C	Damping dissipated
eq	Equivalent
h	Harvested energy
in	Input
M	Amplitude or before the inversion process
max	Maximum value
m	After the inversion process
N	Normalised

Superscripts

S	Clamped
*	Complex conjugate
—	Time average
.	The first differential
..	Second differential

Special function

< >	Time averaged
| |	Modulus or absolute value

Abbreviations

N/A	Not available
SDOF	Single degree of freedom
SL	Single load

Figure legends

SL Freq	Simulated results of the single degree of freedom harvester connected to a single load using frequency domain analysis