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A multi-degree of freedom piezoelectric vibration energy harvester with piezoelectric elements inserted between two nearby oscillators

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ABSTRACT

A novel piezoelectric vibration energy harvesting system is proposed whose harvesting performance could be significantly enhanced by introducing one or multiple additional piezoelectric elements placed between every two nearby oscillators. The proposed two degree-of-freedom piezoelectric vibration harvester system is expected to extract 9.78 times more electrical energy than a conventional two degrees of freedom harvester system with only one piezoelectric element inserted close to the base. A parameter study of a multiple degree-of-freedom piezoelectric vibration energy harvester system has been conducted to provide a guideline for tuning its harvesting bandwidth and optimizing its design. Based on the analysis method of the two degrees of freedom piezoelectric vibration harvester system, a generalised MDOF piezoelectric vibration energy harvester with multiple pieces of piezoelectric elements inserted between every two nearby oscillators is studied. The harvested power values of the piezoelectric vibration energy harvesters of 1 to 5 degree-of-freedom have been compared while the total mass and the mass ratio of the oscillators are kept as constants. It is found that the greater numbers of degree-of-freedom of a PVEH with the more additional piezoelectric elements inserted between every two nearby oscillators would enable that system to harvest more energy. The first mode resonant frequency will be shifted to a low-frequency range when the numbers of degree-of-freedom increase.

1. Introduction

In the past few years, the technology of energy harvesting from ambient natural environment has received a wealth of interests and been well studied. The biggest motivation behind the energy harvesting is to provide the promising energy for self-powered wireless sensors or devices and to overcome the limitations imposed by the traditional power sources such as batteries and the electrical grid. The most common configuration of piezoelectric vibration energy harvester is the cantilever beam structure simplified as a one degree-of-freedom spring–mass–dashpot oscillator in the literature [1,2]. It is feasible and efficient in converting vibration energy into electrical energy in some scenarios, such as industry motors, or machines with known sufficient vibration levels and repeatable and consistent vibration frequency ranges. Thus, the harvested power

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Nomenclature

u_0	the base excitation displacement
u_1	the relative displacement of the 1st oscillator mass (m_1) with respect to the base
u_2	the relative displacement of the 2nd oscillator mass (m_2) with respect to the base
u_n	the relative displacement of the nth oscillator mass (m_n) with respect to the base
m_1	the 1st oscillator mass
m_2	the 2nd oscillator mass
m_n	the nth oscillator mass
k_1	the short circuit stiffness between the base and the oscillator (m_1)
k_2	the short circuit stiffness between the m_1 and the m_2
k_n	the short circuit stiffness between the m_{n-1} and the m_n
c_1	the short circuit mechanical damping between the base and the oscillator (m_1)
c_2	the short circuit mechanical damping between the m_1 and the m_2
c_n	the short circuit mechanical damping between the m_{n-1} and the m_n
C_{p1}	the blocking capacity of the 1st piezoelectric patch element
C_{p2}	the blocking capacity of the 2nd piezoelectric patch element
C_{pn}	the blocking capacity of the nth piezoelectric patch element
R_1	the external resistance connected with 1st piezoelectric patch element
R_2	the external resistance connected with 2nd piezoelectric patch element
R_n	the external resistance connected with nth piezoelectric patch element
α_1	the force factor of the 1st piezoelectric patch element
α_2	the force factor of the 2nd piezoelectric patch element
α_n	the force factor of the nth piezoelectric patch element
V_1	the output voltage of the 1st piezoelectric patch element
V_2	the output voltage of the 2nd piezoelectric patch element
V_n	the output voltage of the nth piezoelectric patch element
P_1	the harvested resonant power of the 1st piezoelectric patch element
P_2	the harvested resonant power of the 2nd piezoelectric patch element
P_{input}	the input power
s	the Laplace variable
i	the square root of -1
η_1	the resonant energy harvesting efficiency of 1st piezoelectric patch element
η_2	the resonant energy harvesting efficiency of 2nd piezoelectric patch element

Superscripts

$\cdot$	the first differential
$\cdot\cdot$	the second differential

Abbreviations

DOF	degree-of-freedom
PVEH	piezoelectric vibration energy harvester
MDOF	multiple degree-of-freedom

falls significantly when ambient excitation frequency is different from the resonant frequency because the vibration energy harvester is only efficient in a particular resonant frequency. Unfortunately, potential ambient vibration energy sources exist in a wide-range of frequencies and in a random form, which is a major challenge for the energy harvesting technology. As a result, a number of approaches have been pursued to overcome this limitation. The approaches include multi-frequency

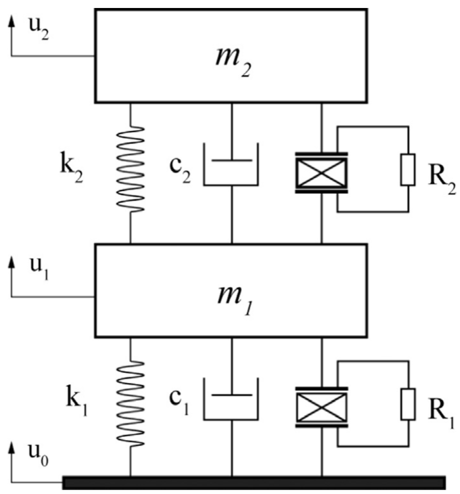

Fig. 1. A 2DOF piezoelectric vibration energy harvester inserted with two piezoelectric patch elements.