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A Novel Design in Harvesting Energy from Operating Machines by Converting Their Generated Waste Energies to Electricity

從運行機器中提取廢棄能量而轉化成有用的電力之嶄新設計

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Abstract

Wireless devices have been widely adopted in machine health monitoring because they can acquire data from machines that are operating and can be installed in hazardous environments. However, the major deficiency of wireless sensors is the need to replace batteries frequently. Moreover, it may be unsafe to change the batteries manually if the wireless devices are located in a hazardous environment. To overcome such deficiency, a novel alternative is to recharge the batteries by harvesting wasted energies generated from the ambient environment.

This study investigates the feasibility of implementation of an energy harvester to convert wasted energies generated from operating machines to electricity. In this research, three fundamental findings are observed. First, piezoelectric material, *QP20N*, is found to be a promising energy harvesting material to convert vibration to electricity. Second, the amount of power transfer can be optimized by matching the impedance of the piezoelectric material to that of the load. In addition, minimization of the internal impedance of the material can significantly increase its output power. Third, making the piezoelectric material vibrate at its resonance frequency will produce maximum electricity output. The most promising design of a piezoelectric-based energy harvester can be realized.

Based on the findings, a novel piezoelectric energy harvester was implemented using two designs: “frequency converter” and “inductor circuit”. In order to maximize the electricity output from the energy harvester, two criteria should be fulfilled. First, the harvester should be tuned by the “frequency converter” so that its resonance frequency could be located within the dominant vibration frequency range of the operating machine. Second, the internal impedance of the piezoelectric material could be minimized by the “inductor circuit”. Maximum power transfer occurs when the impedance of the load matches that of the piezoelectric material. Experimental results show that the inductor circuit can increase the harvested power by at most 43% at the first mode of vibration of *QP20N*. Moreover, the power generated from *QP20N* by using a frequency converter can be 83 times much more than that from QP20N alone. The harvested energy can therefore partially supply electricity to power a low-power wireless device.

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Nomenclatures

A_c = active material of the energy harvesting transducer

L_a = additional inductor

ω = angular frequency in chapter 4,
natural frequency of the piezoelectric energy harvester in chapter 5

I = area moment of inertia

I_q = area moment of inertia of *QP20N*

C = capacitance

Q = charges

A = cross sectional area

A_p = cross sectional area of piezoelectric material

[C] = damping matrix

ω_d = damped natural frequency

c1 = damping of the frequency converter

c2 = damping of the piezoelectric material

ζ = damping ratio

R_p = dc resistance due to magnetic core loss of the additional inductor

R_{dc} = dc resistance of the additional inductor

ρ = density of the frequency converter

ρ_q = density of *QP20N*

y = displacement

η = efficiency

f_e = electrical resonance

E_c = energy stored in the capacitor

F = excitation force

β = frequency ratio

L = internal inductance in Chapter 4,
length of frequency converter in Chapter 5

L_0 = inductance value of the additional inductor

Z = internal impedance

R = internal resistance

L_q = length of *QP20N*

R_L = load resistance

[M] = mass matrix

m2 = mass of the piezoelectric material

M_b = mass of frequency converter

μ = mass ratio

f_m = mechanical resonance

E = modulus of elasticity

ω_1 = natural frequency of the frequency converter

ω_2 = natural frequency of the piezoelectric material on the frequency converter

V = potential difference

X_C = reactance of capacitance

X_L = reactance of inductor

m1 = resultant mass of the frequency converter and the mass at its free end

C_0 = self-capacitance

[K] = stiffness matrix

k1 = stiffness of the frequency converter

k2 = stiffness of the piezoelectric material

T_q = thickness of *QP20N*

M = tip mass of the frequency converter

ω_n = undamped natural frequency

E_S = voltage source

W_q = width of *QP20N*

E_q = young's Modulus of *QP20N*

Abbreviations

A/D = Analog-to-Digital

DOF = Degrees of Freedom

D/A = Digital-to-Analog

DCM = Discontinuous Current Mode

FFT = Fast Fourier Transformation

FTO = Fluorine-doped Tin Oxide

ITO = Indium Tin Oxide

IDE = Inter-digitalized electrodes

IEPE = Integrated Electronic Piezo Electric

MEMS = Micro Electro-Mechanical System

MFC = Micro Fiber Composite

PV = Photovoltaic

PCB = Printed Circuit Board

QP = Quick Pack

RLC = Resistance-Inductor-Capacitor

SC = Switched-Capacitor

SSHI = Synchronized Switch Harvesting on Inductor

TCO = Transparent Conductive Oxide