ANALYTICAL, NUMERICAL AND EXPERIMENTAL STUDY ON TUNING OF PIEZOELECTRIC BASED VIBRATION ENERGY HARVESTER USING SHAPE MEMORY ALLOY

At the present scenario, the majority of vibration based PZT energy harvesters are working efficiently, when the excitation frequency is near natural frequency. But in reality, excitation frequency is varying or random in nature. Hence, the natural frequency (resonant frequency) of energy harvester should be tuned to excitation frequency so as to harvest the maximum power. When the fundamental natural frequency of the harvester almost coincides with the excitation frequency, the harvester power becomes maximum. The objective of this research work is to tune the natural frequency of the energy harvester with excitation frequency using shape memory alloy to maximize the harvester power.

The mathematical model of the electromechanical shape memory alloy, based tunable cantilevered piezoelectric energy harvester is without/with a tip mass. In the parametric case study, frequency response function (FRF) for voltage, current, power, and relative tip displacement of the beam are represented for a wide range of frequencies for different load resistances in both the cases. It is found that the shifting of natural frequency is around 8-10 % without tip mass and 4-6 % with a tip mass for the first three modes of vibration. It shows that if there is any variation in the excitation frequency in this range, the SMA can tune the system’s natural frequency to match the excitation frequency. It is possible to harvest maximum power even if there is a change in excitation frequency. The effect of SMA is very much realized in the first mode as the damping effect is reduced by 27 % without tip mass and 25 % with a tip mass which increases the power output.

The damping effect is reduced from 1.8 to 1.3. In the open circuit frequency condition, the amplitude of vibration is increased about 47 %, in the short circuit region, whereas in the open circuit region the amplitude is decreased about 8 %. In short circuit frequencies, the amplitude is reduced about 10 % in the short circuit region, whereas in the open circuit region around 40 % increase in the amplitude of vibration is achieved.

The electromechanical Brinson shape memory alloy based resonant frequency tunable harvester without/with a tip mass expressions are derived and are used in the parametric case study of the frequency response function. FRFs for voltage, current, and power of the beam are represented for a wide range of frequencies for different load resistances for the both cases. The analytical conclusions show that by altering the temperature and utilizing the effects of SMA, the natural frequency of energy harvester can be tuned. It is noticed that the change in natural frequency for the first three modes of vibration to match the excitation frequency is approximately 25-26 % in both the cases.

The shape memory alloy based resonant frequency tunable PZT energy harvester is numerically simulated using COMSOL Multiphysics software. The analytical frequency response functions of the harvester's voltage, current, and power are compared with numerical FRFs. The maximum difference between the numerical and analytical results are 9.77 % in FRF's and 1.85 % in resonance frequency. The analytical results show a good agreement with the results of simulated results.

Experimental testing of a tunable natural frequency of the SMA plate cantilevered vibration-based energy harvester using shape memory effect with closed and open loop control system for short and open circuit condition is carried out. It is noticed that the change in the natural frequency for the first mode of vibration to match the excitation frequency is approximately 21 %. This means that any vibration in excitation frequency within this range (28 Hz to 34 Hz), SMA plate has the capacity to change the natural frequency to match the excitation frequency. It is observed that there is a large increase in the voltage from 2 % to 539 % for the frequency range from 25 Hz to 35 Hz due to the shape memory effect.

The experimental natural frequency of the SMA base resonant frequency tunable cantilever energy harvester is validated with the natural frequency of the SMA base resonant frequency tunable cantilever beam energy harvester by a numerical method using COMSOL Multiphysics 5.3 software. The maximum difference between the experimental results and numerical results are 1.19 % of the natural frequency. A good agreement is obtained between the experimental and numerical results.

From this research, it is found that tuning of the harvester frequency with the excitation frequency of the energy harvester can be achieved by using shape memory effect.