Optimization Of A Bimorph Piezoelectric Energy Harvester Using Neural Network-Based Genetic Algorithm

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***Abstract*—piezoelectric bimorph cantilever beam is used to harvest the energy from an external harmonic excitation source with constant amplitude and constant excitation frequency. To maximize the charge, an attachment has been added to the cantilever beam to perfectly match one of the natural frequencies of the beam equal to the excitation frequency and to make the excitation frequency a resonance frequency. For choosing the best attachment mass, mass moment of inertia, attachment location and force location on the beam, Genetic Algorithm (GA) has been utilized while a multi-layer perceptron (MLP) neural network in the core of GA evaluation process has been utilized to obtain approximate functions for the natural frequencies based on the optimization variables. Results demonstrate the successful performance of the neural network-based genetic algorithm in choosing the best combination of the variables to maximize the charge.**

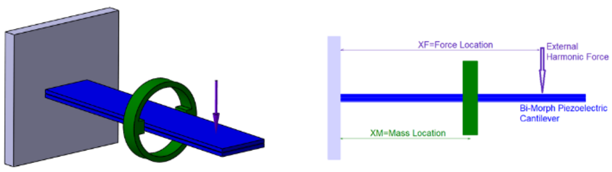

FIGURE 1. BIMORPH PIEZOELECTRIC CANTILEVER WITH ATTACHMENT

I. INTRODUCTION

Bimorph piezoelectric cantilevers are the most effective energy harvesters among other types of piezoelectric cantilever beams[1]. To modify natural frequencies of the beam and matching one of them to the excitation frequency, an attachment has been added to the beam. as can be seen in FIGURE 1, in contrast to previous researches in the literature in which the attachment is considered to be a lumped mass at the tip of the beam[2], in this paper the attachment can be placed anywhere in-span of the beam while the effect of mass moment of inertia is also considered. For any excitation frequency, different combination of attachment mass, mass moment of inertia and attachment location can be chosen to obtain equal natural frequency. In addition, the force application point on the beam is another factor which can affect the amplitude of charge. Therefore, in order to deal with this multi parameter optimization, GA has been utilized here. The variables related to physical specification of the attachment will change the structural properties of the beam including natural frequencies and mode shapes. Therefore, multi-layer perceptron neural network has been trained to obtain approximate functions for the natural frequencies based on the optimization variables. This trained network will be used in the evaluation process of the genetic algorithm to form a neural network-based genetic algorithm which can find the best combination of the optimization variables to match the natural frequency of the beam to the excitation frequency and maximize the piezoelectric charge.

II. PIEZOELECTRIC CHARGE OPTIMIZATION

A. *Piezo electric charge equation*

Piezoelectric charge equation is a function of natural frequencies, mode shapes, excitation amplitude, excitation frequency and parametric constants. Except force location, the other three optimization variables do not appear directly in the charge equation. On the other hand, the natural frequencies of the beam are functions of those optimization variables. However, there are no analytical expression for the natural frequencies as a function of the optimization variables.

B. *Multilayer perceptron neural network*

The proposed approach here is to train a multi-layer perceptron neural network to obtain natural frequencies as a continuous function of the optimization variables. Training data consist of input data and target data. Input data is a matrix with 3 rows and 8000 columns for the combination of 20 different attachment location, 20 different attachment mass and 20 different mass moment of inertia. The target data is a matrix of natural frequencies with 4 rows and 8000 columns. Each rows is related to one natural frequencies.

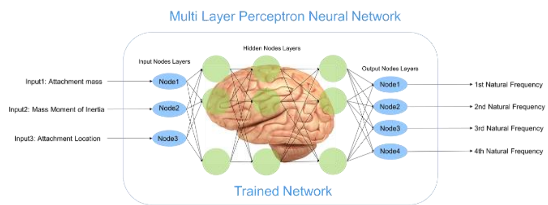

FIGURE 2. MULTI LAYER PERCEPTRON NEURAL NETWORK

The trained network has been shown in FIGURE 2 which gets the optimization variables and gives the natural frequencies. After finding the approximate functions for the natural frequencies based on the optimization variables, the mode shapes can be found with the help of boundary and continuity equations as a function of the optimizations variables.

C. Genetic algorithm optimization

Genetic algorithm has been chosen to find the best attachment location, attachment mass, attachment mass moment of inertia and force location. The fitness function for GA is the piezoelectric charge equation. To avoid being trapped in local optimums, it is necessary to define big population for the GA. For example, here population is defined with 500 individuals while the crossover rate is 0.8 and mutation rate is 0.1. On the other hand, big population means higher amount of CPU time for optimization.

D. Neural network-based genetic algorithm

The evaluation process of neural network-based genetic algorithm has been shown in FIGURE 3. The trained network gives the natural frequencies of the selected individuals immediately. This is extremely less time consuming in comparison to numerical procedure for solving the frequency equation. Mode shapes, natural frequencies and force location will be used to find the fitness value of that individual. Therefore, GA can find the best optimization variables in reasonable CPU time.

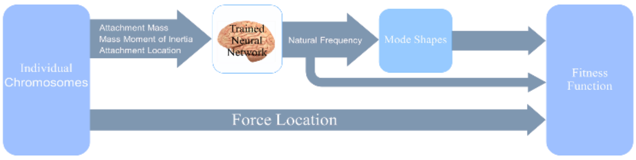

FIGURE 3. GENETIC ALGORITHM EVALUATION PROCESS

III. RESULTS

A. Survey: effect of attachement location on piezoelectric charge

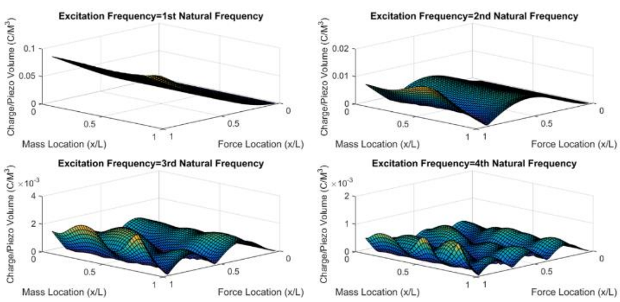

FIGURE 4. CHARGES FOR ATTACHMENT LOCATION VS. FORCE LOCATION FOR 4 RESONANCE EXCITATION FREQUENCY

The effects of attachment vs. force location on the piezoelectric charge are demonstrated in FIGURE 4. Lots of local optimums can be seen due to changing the attachment location and force location. The similar results can be achieved for changing the attachment mass and mass moment of inertia. Therefore, decision making for choosing the best optimization variables to maximize the charge amplitude is not possible analytically.

B. MLP neural network fitting function

In FIGURE 5, the attachment mass moment of inertia considered to be constant. It can be seen that how the approximate function of the trained MLP network is fitted to the discrete training data.

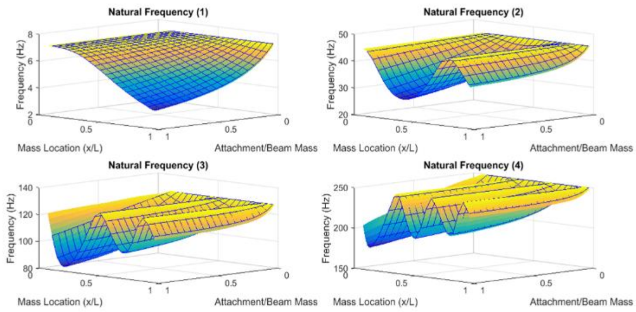

FIGURE 5. TRAINED NETWORK AND DISCRETE TRAINING DATA

Now, by having the approximate functions of natural frequencies based on the optimization variables, the neural network-based genetic algorithm can be used to find the best possible combination of optimization variables to maximize the charge amplitude. For this case Excitation frequency is the average of bare beam first and second natural frequency. Optimization start with 500 individuals. The optimization reaches the best value in the reasonable CPU time. as has been shown in FIGURE 6, Slight changes in GA suggested variables decrease the amplitude of charge. Second natural frequency of the bimorph and selected attachment is equal to the excitation frequency.

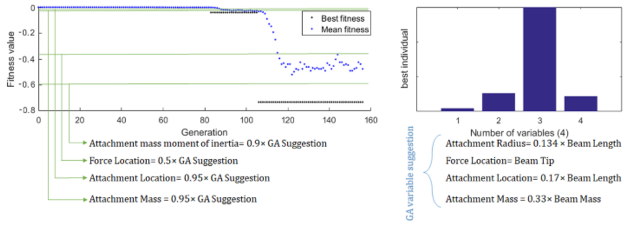

FIGURE 6. GENETIC ALGORITHM OPTIMIZATION PROCEDUER

IV. CONCLUSION

It has been shown that there are lots of local optimums in charge amplitude for different values of optimization variables. However, the neural network-based genetic algorithm have the ability to choose the best possible combination of the optimization variables and maximize the charge in a reasonable CPU time.

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