MAGNETIC POTENTIAL WELL TUNING OF RESONANT CANTILEVER ENERGY HARVESTER

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Abstract: Cantilever energy harvesters have presently been tuned by manipulating beam dimensions or by placement of a tip mass. While these techniques lend themselves well to designing a highly tuned resonance, the design is fixed and each system is unique to a specific frequency. Here we report investigations of magnetic potential well tuning to vary the spring constant, which shifts the resonance. The significance of this work is the design of a harvesting system with variable resonance, adjusted by changing the effective spring constant by means of shaped pole-pieces on a pair of magnets. Wider tuning range with reduced tuning force is thus achieved.

Keywords: frequency tuning, magnetic potential well, energy harvester.

INTRODUCTION

The existence of low level vibrations in many different environment types, as documented by researchers such as Roundy et al. [1], has lead to the widespread attraction of design engineers to harvest, or scavenge, this kinetic energy into a usable electrical form. Vibrating cantilever devices using piezo-electric transduction have been particularly explored for this purpose, as they combine relative simplicity of structure with reasonable output voltages even at low excitation frequencies. An important consideration when using such piezoelectric cantilevers as energy harvesters is to match the resonant frequency of the device with that of the ambient frequency, so as to extract the largest electrical power output. Correspondingly, a major limitation of these devices is that they only respond at or near this design frequency, and if the mechanical Q of the device is high in order to get a strong peak response, the operational bandwidth is low.

For ambient vibration which contains a strong component at a particular frequency, a low Q, wide bandwidth device is not ideal. However, a tunable high Q device can combine high output power with the ability to adjust the operational frequency for a source frequency that is varying, or is not known a priori.

Setting of the operational frequency is usually done during the construction of the device and involves modifications to the length, width, thickness, and/or mass [2]. However, this only allows a single trimming of the response, and is difficult to do in the operational environment. Furthermore, it cannot deal with dynamic changes in the source frequency. These shortcomings have led to many efforts to increase the effective frequency range of piezoelectric vibration energy harvesters by making them adjustable in service [3-6], or by broadening their bandwidth [7]. However, compact, robust, low power tuning techniques are still desirable.

It has been demonstrated that changing the distance between a magnet mounted on the cantilever tip and an additional tuning magnet can change the effective spring constant and thus modify the resonant frequency [8]. In that approach the longitudinal force on the cantilever imposed by the magnets changes its stiffness, and thus its frequency. However this technique requires significant power to reposition the magnets, and therefore tuning can only be performed infrequently. We report a novel tuning system for an energy harvester with a larger tuning range using the concept of a magnetic potential well [9] to shape the tuning magnetic field. A tuning magnet with a shaped pole-piece attached is placed adjacent to the tip magnet, and the tuning magnet position is controlled dynamically using an actuator. The tip magnet thus moves in the magnetic field provided by the tuning magnet. The shaped pole-pieces on the magnets provide a spatially varying field which applies a greater attractive force when the cantilever tip is in the centre of its oscillation path. This adds a restoring force to that provided by the deflection of the cantilever, thus changing the effective spring constant and the resonant frequency of the cantilever. The resonant frequency is tuned by changing the distance between the two pole-pieces.

MODELING

Fig 1 shows the resonance frequency tuning concept of the cantilever harvester by the magnetic potential well technique. A simulation model for the cantilever with shaped pole pieces was set up in the FEMM 2D magnetic simulation software [10]. The variation of the energy of the magnetic field was calculated as a function of cantilever tip deflection angle. Thus the potential well caused by the deflection of the tip was mapped for pole pieces of various shapes. An example of the magnetic field lines for wedge shaped pole pieces is shown in Fig 2.

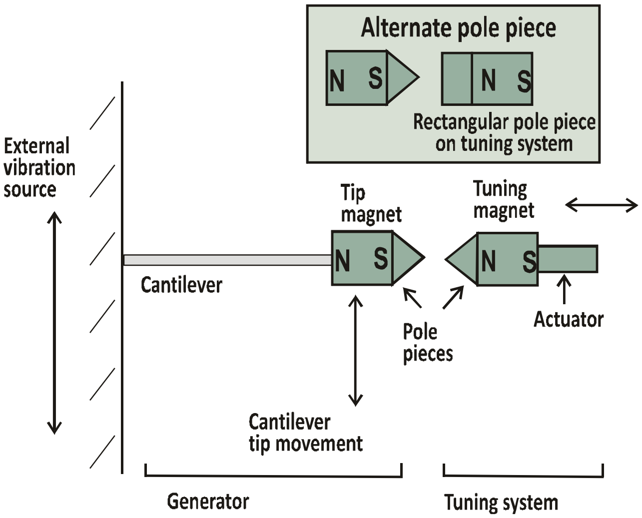

Fig 1: Tuning concept including magnetic potential well.

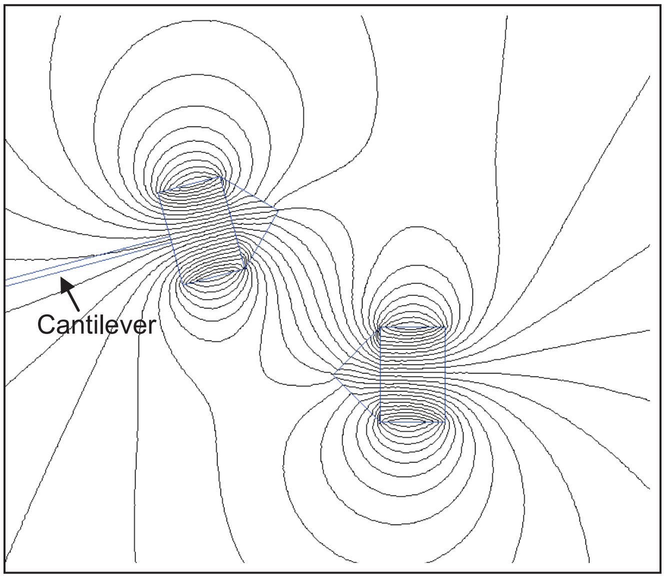

Fig 2: Simulated magnetic field lines with shaped pole pieces.

Fig 3 shows the simulated potential well for wedge shaped pole pieces on both tuning and cantilever tip magnets, for various separations between the pole pieces. It can be seen that the depth of the potential well changes as the space between the magnets is changed, thus altering the resonant frequency by modifying the spring constant.

Fig 4 shows the potential wells for wedge-wedge and wedge-rectangle pole piece configurations and it can be seen that there is a considerable difference in the depth of the wells, the wedge pole piece providing a deeper well due to the greater variation of magnetic field gradient and force as the tip is moved.

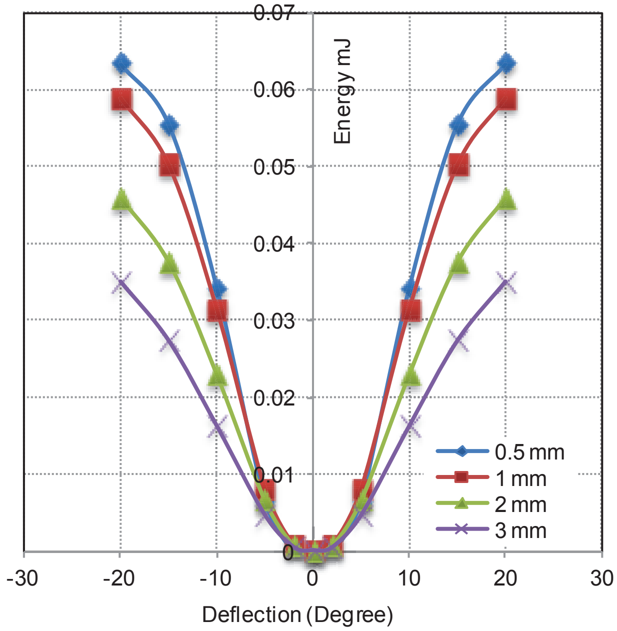

Fig 3: Simulation of potential energy well with wedge pole pieces at various tuning magnet spacings.

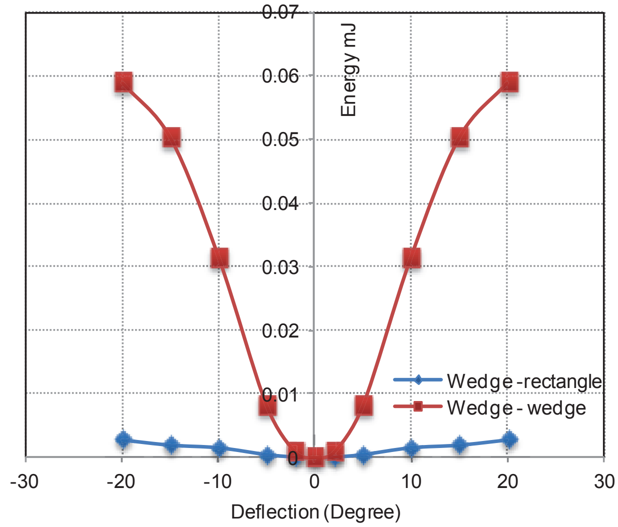

Fig 4: Simulated potential wells with different shapes of pole pieces at 1 mm separation.

EXPERIMENT

Fig 5 shows the experimental set-up used to validate the concept of the potential well tuning technique. Measurements were made as the excitation frequency was scanned with amplitude of 0.1g, for different separations of the tuning magnets, and the resulting forces on the tuning magnet were measured by means of a force transducer attached to the tuning system.

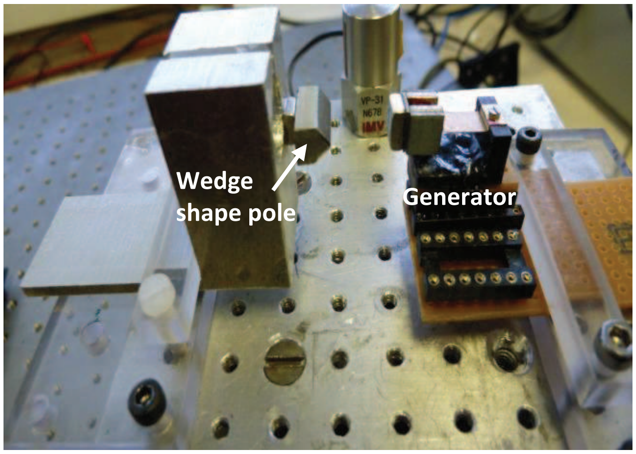

Fig 5: Experimental set up for magnetic potential well tests.

Fig 6 shows the generator output voltage, without an electrical load applied, vs. frequency, using rectangular or wedge shaped pole pieces on the tuning magnet only, and different separation distances. These results show that the tuning range increases from 50 % with rectangular pole pieces to 67 % with wedges due to the stronger field shaping in the latter case.

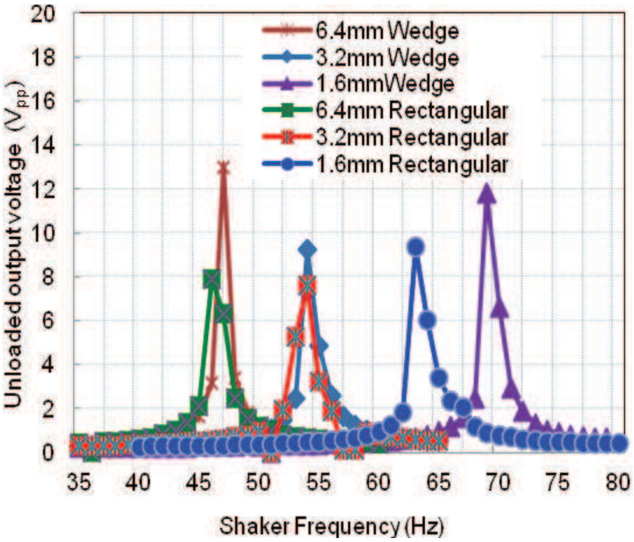

Fig 6: Generator unloaded output with wedge and rectangular shaped pole pieces on tuning magnet only.

Fig 7 shows the test results with identically shaped pole pieces on the tip and tuning magnets to shape the potential well. It was again found that the wedge shape provides a greater tuning range. The resonance of the generator has shifted to a lower frequency, as the pole piece attached to the tip has increased the tip mass of the generator.

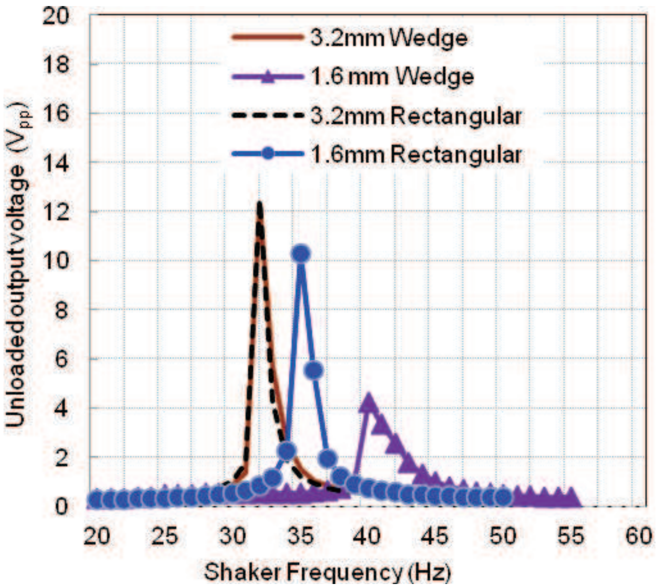

Fig 7: Generator unloaded output voltage with wedge and rectangular shaped pole pieces on both magnets.

Measurements of the force on the tuning magnet are plotted in Fig 8. A tuning range of 25% of the untuned resonant frequency is achieved with the wedge-shaped pole-pieces, approximately double that achieved with rectangular pole-pieces, and with a smaller tuning force.

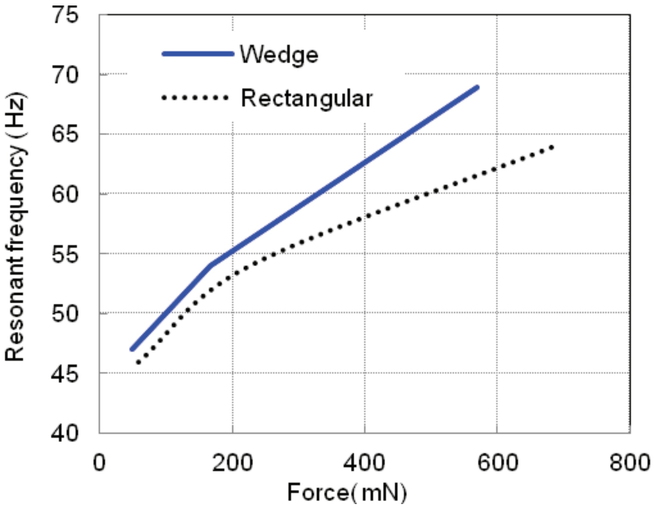

Fig 8: Dependence of resonant frequency on tuning magnet force for shaped pole pieces.

In Fig 9 the energy required to tune to a desired resonant frequency is estimated from the measured tuning force and movement of the tuning magnet. It is seen that less energy is required to achieve the same tuning range using magnetic field shaping.

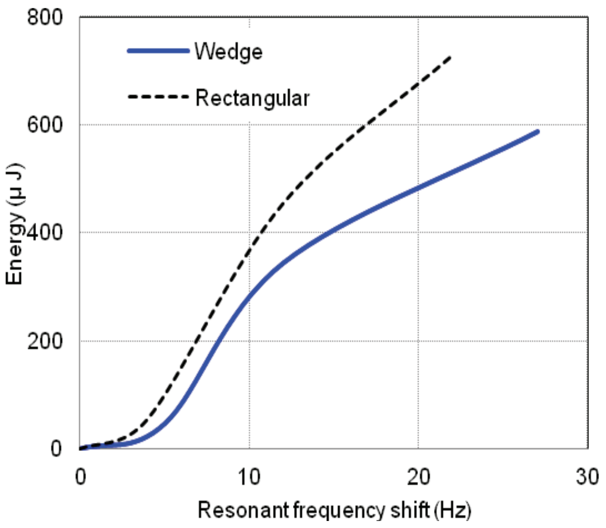

Fig 9: Energy required for tuning with different shaped pole-pieces.

DISCUSSION

The required tuning force is an important parameter for the tuning mechanism of a cantilever energy harvester. Simulations have been performed for wedge and rectangular shaped pole pieces. It can be seen from the measurement results that the required tuning force for a particular tuning range can be greatly reduced by correct design of the pole piece shape. This is confirmed by the results of the simulations which show that the shape of the potential well, and thus the tunability of the cantilever system, can be greatly changed by use of shaped pole pieces. Since the tuning effect caused by stretching of the cantilever is present regardless of the type of pole piece, this indicates that the virtual spring created by magnetic field shaping can add substantially to the tuning range afforded by the stretching method.

CONCLUSION

A limited set of field shaping pole pieces has been explored in this work to demonstrate the potential of the method. Future work will include optimization of the pole-piece shape to further reduce the energy required for tuning, and the addition of closed loop control to dynamically tune the cantilever harvester as the source frequency varies.

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Website: www.holistic.ecs.soton.ac.uk.

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