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Broadening the bandwidth of energy harvesting devices by using different magnet configurations

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ABSTRACT – A nonlinear generator was originally intended to overcome the limitation of a linear resonant generator that is having small bandwidth. This paper presents the experimental results to illustrate the dynamic monostable behaviour of the nonlinear generator using magnetic levitation concept. A device was built to investigate the effectiveness of the different magnets configurations on the dynamics under harmonic excitation. The results show that the softening and hardening behaviours of the system due to the magnetic stiffness produce a broader bandwidth response.

1. INTRODUCTION

The importance of energy harvesting concept has emerged as a prominent research area especially in extracting energy from the ambient sources. Various applications are targeted as power source to power wireless sensor system. Among these ambient power sources, vibration emerges as one of the promising sources.

By applying the mechanical model in a single degree of freedom (SDOF) mass-spring-damper system, the maximum power can be harvested when the device is excited at resonance frequency [1]. However, if the frequency of the device is slightly mistuned from the natural frequency of the system, the performance of the device tends to decrease drastically. Frequency tuning methods (active and passive tuning) are introduced to track the natural frequency for all the time. An active tuning method is reported by Zhu et al. [2], who implemented a tunable electromagnetic vibration to alter its natural frequency. Eichhorn et al. [3] proposed a pre-stress generator to adjust the device natural frequency using passive tuning method.

Another approach to overcome the sensitivity due to mistune is by introducing nonlinearity into the system. The aim of this method is to broaden the bandwidth so that the device is able to function effectively in a wide frequency band. The most common types of nonlinearity used in energy harvesting mechanism are softening and hardening nonlinearity. These two nonlinearities are based on the stiffness nonlnearity. Ramlan et al. [4] implemented the theoretical and experimental studies for hardening behaviour of nonlinear system. Tang et al. [5] proposed a monostable harvester in both hardening and softening behaviours that appear by using two attractive and repulsive magnets. However, the use of magnetic levitation by various configurations magnets in nonlinear generator has not been greatly explored especially involving constant amplitude excitation thus the real benefits of each configurations under similar excitation is yet to be established.

This paper presents an experimental investigation on the use of different magnets configurations under similar excitation. By configuring the magnets under two basic modes (attractive and repulsive), the gap between the magnets are adjusted to investigate the effect on the system's stiffness and the frequency response

2. METHODOLOGY

2.1 Device Configuration

A magnetic levitation method is applied to the device to explore the nonlinearity concept. The masses with a NdFeB magnet (6m x 3 mm) is mounted on an aluminum cantilever beam (30 mm x 0.5 mm x 56 mm) fixed at one end. In this study, three configurations are investigated. This includes a single permanent magnet with a single attractive magnet configuration, double attractive magnet configuration and double repulsive magnet configuration (Figure 1). By altering the axial gap between the moving magnet on the beam and the fixed magnets, the stiffness of the system can be varied accordingly. In this measurement, the axial gaps, *d* are fixed at 1.5 mm, 1.8 mm and 2.5 mm.

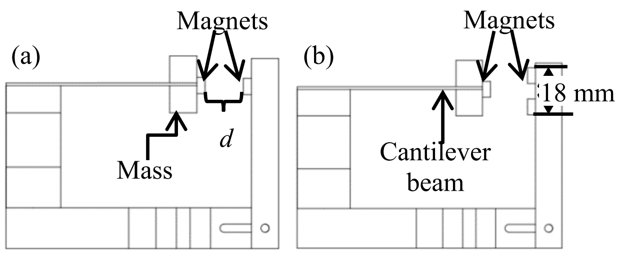

Figure 1: Schematic diagram of the configurations
(a) a permanent magnet with a single fixed magnet
(b) a permanent magnet with the double fixed magnets.

2.2 *Experimental Set-Up*

Dynamic measurement is implemented to investigate the behaviour of frequency response curve of the proposed configurations. In this measurement, the whole device was placed on the shaker and excited with constant amplitude excitation (2.5 mm) from 4 Hz to 40 Hz and 40 Hz to 4 Hz respectively. Two Dytran accelerometers were used to record the acceleration of the tip mass and the base of the device. All the data were analysed by using Data Physics signal analyser.

3. RESULTS AND DISCUSSION

The responses of the system under different magnet configurations are observed to operate in softening and hardening mode. The gap between the magnets determines the behaviour of the system. In monostable case, the frequency response curve (FRC) of softening and hardening behaviours can be determined by analysing the jump up and jump down in dynamic experiment. The FRC for softening behaviour tends to shift to the left and vice versa.

For two attractive magnets shown in Figure 1(a), with the increase of the gap between magnets, the FRC of the system shifted slightly to the left accordingly. In this configuration, the jump down frequencies are occurred between 14 Hz to 16.5 Hz as shown in Figure 2.

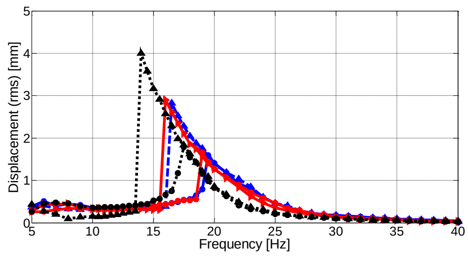

Figure 2: Measured frequency response curve for two attractive magnets with the gaps 1.5 mm [jump up (○- -), jump down (△ -)], 1.8 mm [jump up ○- - --), jump down (-- △--)] and 2.5 mm [jump up (...○..), jump down (..△...)].

For the permanent magnet and two attractive magnets configuration shown in Figure 1(b), when the gaps are fixed at 1.5 mm and 1.8 mm, the system operates in softening mode. However, as the gap is increased to 2.5 mm, the frequency response changes to hardening mode as shown in Figure 3.

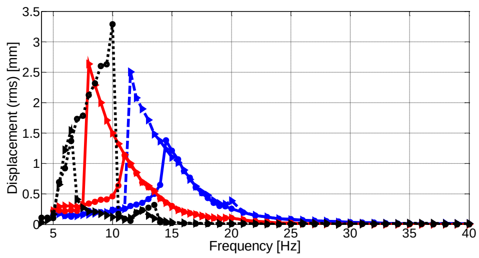

Figure 3: Measured frequency response curve for a permanent magnet with two attractive magnets at 1.5 mm [jump up (-○- -), jump down (△ -)], 1.8 mm [jump up (--△--), jump down (--○--)] and 2.5 mm [jump up (...△...), jump down (...○...)].

The response of the system between the permanent magnet and double repulsive magnets (Figure 1(b)) are similar to the two attractive magnets i.e. softening mode as shown in Figure 4. However, the configuration results in a higher jump-up and jump-down frequency

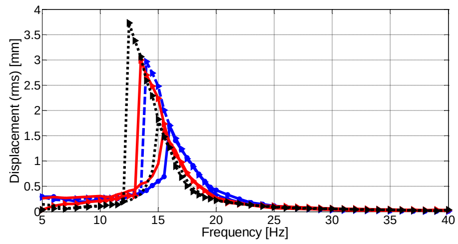

Figure 4: Measured frequency response curve for a permanent magnet with two repulsive magnets at 1.5 mm [jump up (-○- -), jump down (△ -)], 1.8 mm [jump up (--○--), jump down (--△--)] and 2.5 mm [jump up (...○...), jump down (... △.)].

4. CONCLUSIONS

This paper presents the experimental results for both softening and hardening behaviours of nonlinear system resulting from different magnetic stiffness. A device using magnetic levitation method was proposed in this study. By applying appropriate magnet arrangements, the gap between the magnets can be altered to change the stiffness of the system so that it can operate in either softening or hardening mode. Either of the nonlinear mode is capable of broadening the bandwidth and improving the response.

5. ACKNOWLEDGEMENT

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