Energy harvesting using nonlinear damping

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Summary. In this paper, energy harvesting using nonlinear damping is presented. A nonlinear cubic damper is introduced to a mechanical oscillator subject to harmonic excitation and the average harvested power is obtained. The nonlinear damper can increase the dynamic performance range of the harvester. The effect of friction is also investigated on the harvested power.

Introduction to nonlinear energy harvesting

Energy harvesting from ambient vibration has attracted significant attention in recent years. Some interesting applications include low-power wireless sensors, harvesting power from human motion and large-scale energy harvesters. In order to increase the frequency range of the excitation amplitude over which the vibration energy harvester operates, various nonlinear arrangements have been suggested, particularly using nonlinear springs [1-4].
In this paper, a nonlinear cubic damper is introduced into a vibration energy harvester in order to increase its dynamic range.

Energy harvesting

A mechanical single degree-of-freedom nonlinear oscillator is considered, as shown in Figure 1, which is subjected to a harmonic base excitation. The relative displacement and the average harvested power are obtained for different sinusoidal base excitation amplitudes and frequencies both analytically, using the harmonic balance method, and numerically, using the time integration ode45 in Matlab.

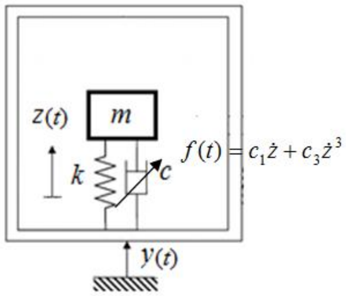
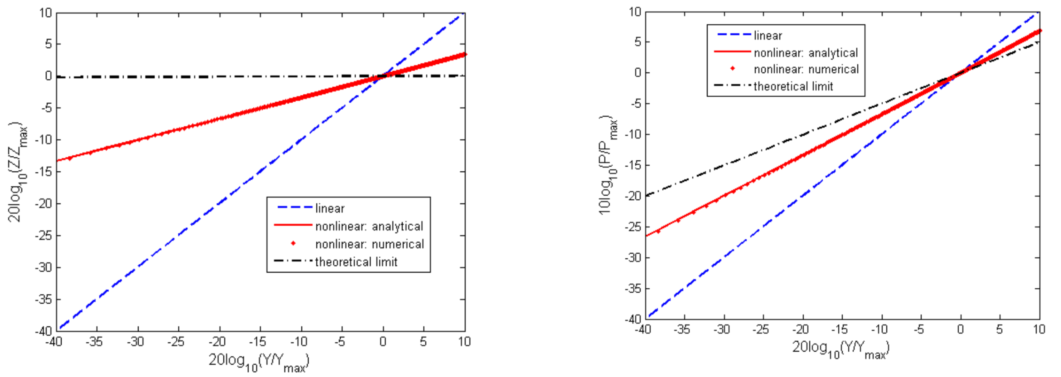


Figure 1. Single degree-of-freedom, base excited, energy harvesting system with a nonlinear damper

Simulation results

The performance of the nonlinear harvester is compared with a linear harvester, which has the same maximum relative displacement at resonance, when driven at maximum amplitude, as shown in Figure 2(a). From Figure 2(b), it can be seen that the harvested power, which is assumed to be equal to that dissipated by the nonlinear damper, can be significantly larger than a linear energy harvester, when driven at an amplitude below the maximum operational limit, therefore expanding its dynamic range [5].



(a) (b)

Figure 2. (a) Relative displacement and (b) average harvested power at resonance as a function of input excitation amplitude for the linear and nonlinear systems with cubic damping, together with the theoretical limit of a highly nonlinear system.

A linear damper is then added to the cubic damper, to give a "polynomial" damper representing the sources damping whose power dissipation is not converted into electrical energy, and it is demonstrated that for low level of excitation, the average harvested power from the nonlinear polynomial damper tends towards the linear one and for high excitation levels below the maximum threshold, the performance follows the harvester with pure cubic damping.
The effect of Coulomb damping as a source of loss is also considered, for the harvesters with a linear damping and a cubic damping. The damping parameters in the two systems are chosen such that the equivalent linear dampers are the same at resonance, when excited at maximum amplitude. Due to the coulomb damping, there is a significant reduction in the average harvested power at low excitation amplitudes. However, Figure 3 shows that the average harvested power is higher for the nonlinear systems compared to the linear system below the maximum amplitude, hence maintaining its improvement in the dynamic range, even in the presence of Coulomb damping.

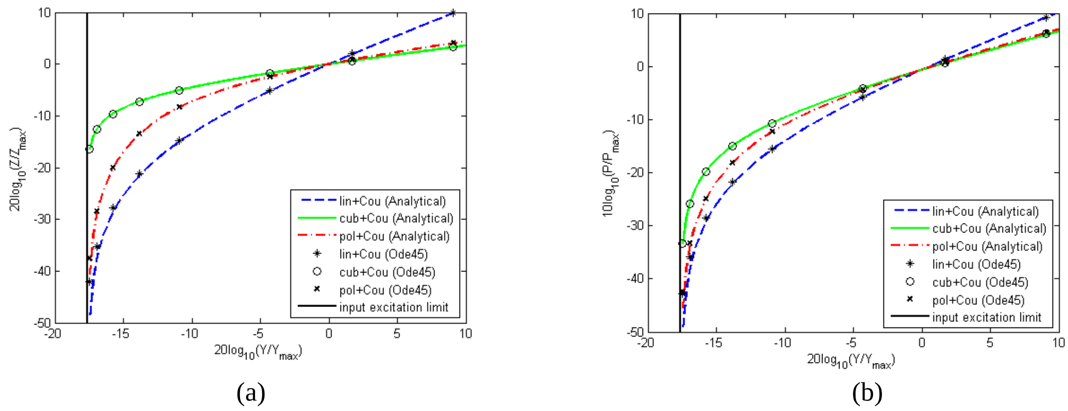


Figure 3. (a) Relative displacement and (b) average harvested power at resonance as a function of input

Practical implementation

Finally, a potential approach for practical implementation of the nonlinear damping is proposed. An idealised electromechanical system shown in Figure 4 is considered, which couples the relative motion of the inertial mass to a nonlinear electrical device and the current is proportional to the cube of the voltage across it. If there is a good coupling between the electrical and mechanical parts, it can be shown that the force due to the shunted electromechanical system is proportional to the cube of the velocity, which provides the cubic mechanical damping.

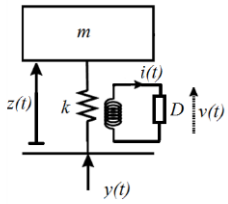


Figure 4. An idealised electromechanical system

Conclusions

In this paper, nonlinear damping is introduced into a mechanical system for energy harvesting and its performance, including the relative displacement and the average harvested power, is compared with the linear model, using numerical and analytical solutions. The nonlinear harvester can harvest significantly more power at resonance, compared to the linear harvester, when excited below its maximum excitation level, as set by the maximum throw of the device. A potential implementation using an electromechanical device with a nonlinear electrical load is suggested.

References

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