

Nonlinear techniques for wide-bandwidth resonant energy harvesting

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ABSTRACT

Energy harvesting from motion is presently receiving great worldwide attention as a means to power autonomous systems. Conventional linear vibration energy harvesters are usually designed to be resonantly tuned to the ambient dominant frequency. They have a narrow operating bandwidth that limits their application in real-world environments where the ambient vibrations have their energy distributed over a wide spectrum of frequencies, with significant predominance of low frequency components and frequency tuning is not always possible due to geometrical/dynamical constraints [1, 2, 3, 4].

To overcome these difficulties, we propose different approaches based on the exploitation of the nonlinear properties of electromechanical oscillators. The first alternative consists in the use of the nonlinear frequency response characteristic in order to enlarge the band width on which the harvester operates. The resonator is designed to display a strong nonlinear spring softening effect in order to reach relatively low frequencies. This supposes a perfect control of the attraction basins in order to enable particular irregular jumps for an optimal energy pumping. The mixed hardening/softening behavior shown in Fig. 1, is highly unstable [5, 6, 7] and offers strange attractions which can be exploited in a nonlinear energy harvester. These phenomena have been observed in nonlinear microelectromechanical resonators [8] and it has been shown that the bifurcation topology of such behavior can be tuned in the frequency domain through an electrostatic mechanism [7] as well as in the amplitude domain using superharmonic resonance [9].

The second approach is based on internal resonances due to the high order nonlinearities which become significantly important for very large displacements. A Taylor series expansion of the nonlinear mechanical force due to mid-plane stretching presents nonlinear terms up to n^{th} order and consequently nonlinear superharmonic resonances can be activated for an excitation frequency $f = f_p/i$ with $i \in \{2 \dots n\}$. This enlarges the spectrum of frequencies on which the harvester can operate up to a lower bound f_p/n .

A third alternative involves self-oscillations in presence of nonlinearities. Basically, the oscillator undergoes a time delayed force proportional to its vibration amplitude which can be also modeled as a negative damping which corresponds to a component of the force acting in phase with the velocity. The faster the oscillator moves, the more it is pushed along the direction of its motion. The oscillator thus keeps drawing energy from its surroundings [10]. This is the essence of self-oscillation in linear systems. The amplitude of oscillation grows exponentially with time, until it becomes so large that nonlinear effects become relevant and somehow determine a limiting amplitude.

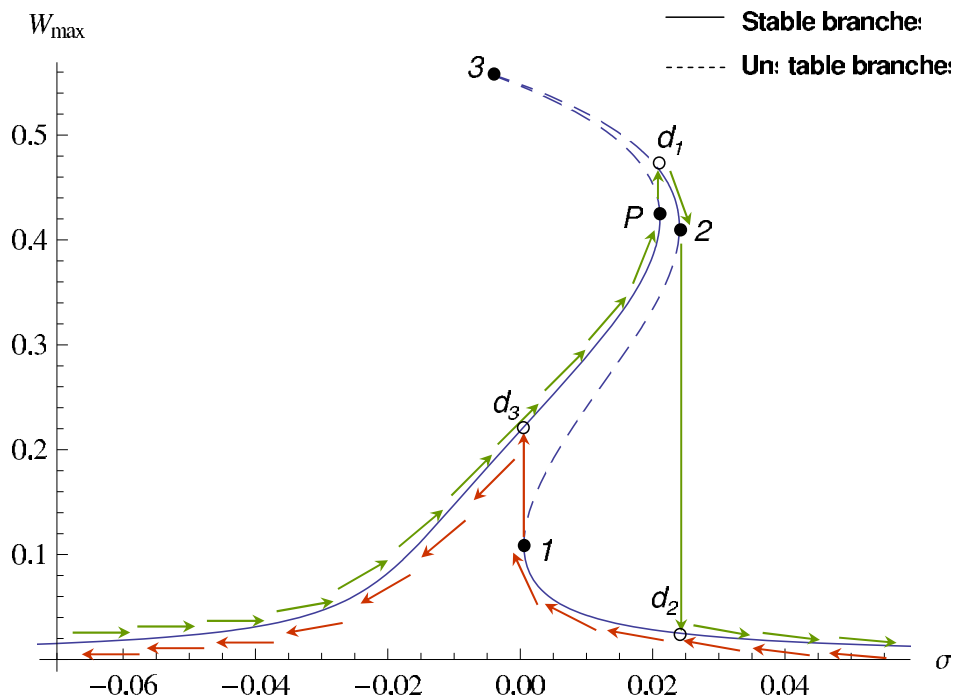


Figure 1: Identification of the nonlinear mixed behavior for a typical resonator. σ is the detuning parameter, W_{max} is the normalized displacement and $\{1, 2, 3, P\}$ are the different bifurcation points.

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