Harvesting Energy through the Chaotic Motion of Double Pendulum

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Harvesting electric power for miniature sensors is known as energy harvesting. The technique has attracted a lot of interest in the past decade from industry, academia and research organizations due to exponential development in small and low powered electronics. Various energy harvester configurations have been studied, with basic concept remaining the same, harvest waste unwanted energy. Vibration based energy harvester scavenge power from the unwanted vibrations like noise, vehicular motion, structural vibrations, etc and therefore are energy-efficient. It is a challenge to power small sensor with their exponentially increased numbers over decades. They live on batteries and replacing millions of batteries yearly is a daunting task and causes severe environmental damage. Self-powered sensors with energy harvester do not require batteries and are hence environmental friendly. So energy harvesting has the potential to pave a way to low powered self sustaining sensors for various wireless operations. Vibration energy can be harvested using several methods, such as piezoelectric, electrostatic and electromagnetic, depends on the method of transduction [1, 2]. Energy harvesting over a broader band and increased average power generation attracts researchers to exploit nonlinear dynamic phenomenon for energy harvesting.

Double pendulum is a highly nonlinear system. In this paper we are trying to investigate and implement a double pendulum as an energy harvesting device whose chaotic movement provide energy in broadband. The equations of motion of a double pendulum system [3, 4], are given as follows:

$$\begin{aligned}(m_1+m_2)L_1^2\ddot{\theta_1}+m_2L_1L_2\ddot{\theta_2}\cos(\theta_1-\theta_2)+\\(m_1+m_2)L_1\ddot{x_g}\cos\theta_1+m_2L_1L_2\dot{\theta_2}^2\sin(\theta_1-\theta_2)\\+(m_1+m_2)gL_1\sin\theta_1=-(C_m)\dot{\theta_1}\end{aligned} \quad (1)$$

$$\begin{aligned}m_2L_2^2\ddot{\theta_2}+m_2L_1L_2\ddot{\theta_1}\cos(\theta_1-\theta_2)-\\m_2L_1L_2\dot{\theta_1}^2\sin(\theta_1-\theta_2)+m_2L_2\ddot{x_g}\cos\theta_2+\\m_2gL_2\sin\theta_2=-(C_m+C_e)\dot{\theta_2}\end{aligned} \quad (2)$$

Where L_1 and L_2 denotes length of pendulums, m_1 and m_2 denotes mass of bob. C_e and C_m are electrical and mechanical damping respectively. Figure 1 shows the poincare map of the double pendulum system. Distributed points in the poincare map show the chaotic behaviour of the double pendulum.

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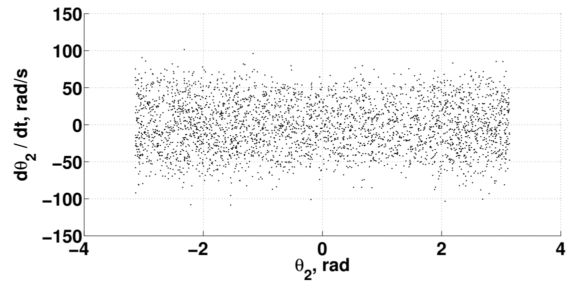

Figure 1: Poincare map of double pendulum system

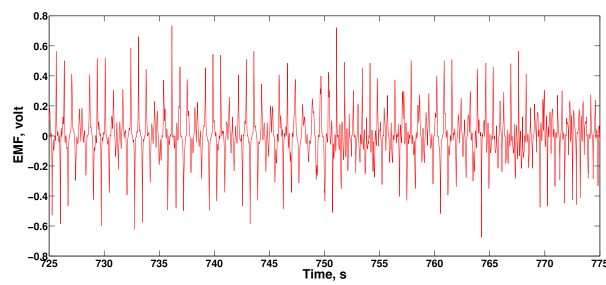

Figure 2: Variation of EMF with time

The bob of the second pendulum is replaced with a permanent magnet and coils have been placed beneath it with a little separation from the magnet. When pendulums get excited externally they start oscillating relative to the coils beneath and thereby generates electromotive force in the coils following the Lenz's law [1]. Figure 2, shows the sum total of the induced EMF plot as a function of time.

The chaotic nature of motion is evident from Fig. 1. Since the double pendulum system is highly chaotic, the EMF developed is also chaotic in nature. The power harvested can be increased further with proper placement of coils beneath the second pendulum and also with increase in the number of coils.

References

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