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تاثیر نیروی کازیمیر بر رفتار دینامیکی کلید های نانوالکترومکانیکی

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دانشکده فیزیک، دانشگاه صنعتی شیراز

چکیده- در این مقاله، تاثیر نیروی کازیمیر بر رفتار دینامیکی کلیدهای نانوالکترومکانیکی شبیه سازی شده است. سیستم مطالعه شده در این پژوهش یک کلید نانوساختار الکترومکانیکی از نوع Cantilever-beam **می باشد. با درنظر گرفتن پارامترهای اساسی مربوط به کلید های نانوالکترومکانیکی، تاثیر نیروی کازیمیر و ولتاژ اعمالی برروی عملکرد کلیدزنی بررسی شده است. نتایج بدست آمده نشان می‌دهد که این دو عامل نقش بسزایی را در هرنوعی از کلیدهای نانوالکترومکانیکی ایفا می‌کنند و با افزایش یا کاهش آن‌ها می‌توان میزان خم شدگی صفحات الکترود و در نهایت عمل کلیدزنی را کنترل کرد.**

کلید واژه- نیروی کازیمیر، نانوساختار الکترومکانیکی، کلید Cantilever-beam type

The Effect of Casimir Force on Dynamical Behavior of Nano-electromechanical Switches

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Abstract- The effect of Casimir force on dynamical behavior of nanoelectromechanical switches is simulated in this paper. The system investigated in the current study is an electromechanical nanostructure switch such as cantilever-beam type. Considering basic parameters of nanoelectromechanical switches, the effect of Casimir force and pull-in voltage on the process of switching has been investigated. Results demonstrate that these two factors play a significant role in every type of nanoelectromechanical switches. Thus, bending rate of plates and finally the performance of switching can be controlled by increasing or decreasing these two elements.

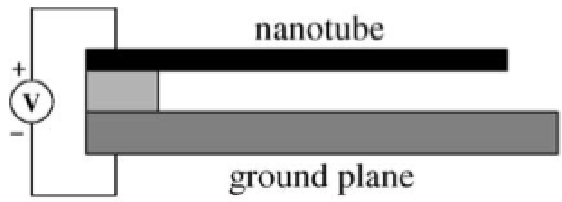
Keywords: Casimir force, Nanoelectromechanichal switches, Cantilever-beam type switch.

1. Introduction

The Casimir effect was first represented by Hendrik Brugt Gerhard Casimir in 1948 [1]. He realized when two perfectly uncharged conducting plates are located closely in parallel together usually distances in nanoscales, the result is a small attractive force between them that called Casimir force. This is because of the fluctuations of particles and alternating the ground-state energy of photons. The fundamental idea of Casimir effect derives from quantum theory in [2], which express about fluctuations of electromagnetic field in a vacant region. Although these fluctuations are not considerable, they cannot be ignored either. This electromagnetic nature would keep influencing them in the attendance of conducting materials. Another remarkable feature is that they can be limited by a conducting surface. Therefore, when the two conductive plates are aligned parallel the fluctuations are limited between them. Hence, the fluctuations and pressure between plates are less in comparison of outside the plates and this would lead to collapse them together. His discoveries attracted the attention of many researchers in that time, and various experiments in different fields have been carried out on this work in the last decade. One of the capability applications of Casimir effect is related to the nanoelectromechanical systems (NEMS). A NEM switch is commonly assembled from two conducting electrodes such that one of the electrodes is fixed and the other is movable and the system is working by electrostatic forces. [3]-[4]. For switches with a distance of less than 100 nm, the Casimir force prevents particles from sticking together. This feature of the Casimir force indicates the importance of examining its presence in nano-electromechanical switches. In this paper, we just consider cantilever-beam type switch. The objective of the present paper is to study of the dynamical behavior of NEM switches in the presence of Casimir force and pull-in voltage by a numerical method, in contrast to other studies which have been mostly emphesized on static behaviors [5]-[7].

2. Theory

In the following section, the theoretical analysis of cantilever-beam structure is discussed. The first step is modeling of the forces involved in the structure. The next step would be to find the equation governing the model and finally is characterizing the parameters influencing the system function. Fig. 1 (a), shows the schematic view of the structure. By keeping the simplicity and generality the geometry is dumbed to a one-dimensional (1D) lumped model as shown in Fig.1 (b). When voltage is applied between two electrodes, the formed electrostatic force causes the plates to collapse on the ground state if the applied voltage goes over the limit of certain amount. This specific voltage is called pull-in voltage and the arisen space is called pull-in gap respectively.



(a): schematic of cantilever switch

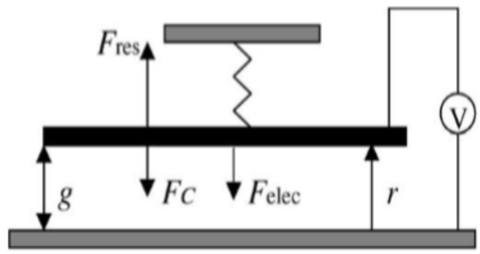


Fig. 1: (a) schematic of cantilever switch, (b) One-dimensional lumped model for the pull-in parameters estimation [2]-[7]

According to Fig. 1 (b) three different forces are involved in this system which two of them (Electrostatic and Casimir forces) are attractive and the other one (restoring force) is repulsive. Thus, we have a system with one degree of freedom that is the gap distance r, between the beam and the ground plate. By applying voltage to the upper movable conductor making it to deflect downward towards the ground plate due to the electrostatic attraction. At a certain voltage, the upper conductor becomes unstable and spontaneously collapse (or pull-in) to the ground plate. The voltage and the deformation of the actuator at the onset of pull-in are referred to as the pull-in voltage and pull-in deformation, respectively [8]. Corresponding to Fig. 1 (b) and considering Newton second law, equation of motion of the system achieves as [2]

$$m\frac{d^2r}{dt^2} = F_{res} - F_{elec} - F_C \qquad (1)$$

Where m is the mass of the conducting plate. Similarly the forces involved in the equation are defined as follows:

$$F_{res} = k(g-r) \qquad (2)$$

F_{res} or the restoring force of the movable plate assumed to take the standard mass-spring form, where k is the spring constant, g is the initial distance between electrods. The electrostatic force:

$$F_{elec} = \frac{\varepsilon_0 wLV^2}{2r^2} \qquad (3)$$

Which ε_0 is the permittivity of vacuum, w and L are the width and the length of the beam and V is the applied voltage. Casimir force:

$$F_c = \frac{\pi^2\hbar cwL}{240r^4} \qquad (4)$$

Where $\hbar$ is Pelank's constant divided by 2π, c is the speed of light. By changing parameters and using some dimensionless variables the transformed equation obtains as the form

$$M\frac{d^2u}{d\tau^2} = 1 - u - \frac{b}{2u^2} - \frac{a}{240u^4} \qquad (5)$$

submitting dimensionless variables $u = \frac{r}{g}, \tau = \frac{t}{T}, M = \frac{m}{kT^2}, a = \frac{\pi^2\hbar cwL}{kg^5}, b = \frac{\varepsilon_0 wLV^2}{kg^3}$ Where a and b illustrate the amount of Casimir force and pull-in voltage respectively, M is the magnitude of ratio between the inertia and the restoring forces and considered equal to 1 in this simulation. T is the attribute time which is considered as the interval from 0 to 10. The objective of this report is to find a numerical simulation for the above dimensionless differencial equation (5) and investigate the impact of Casimir force and pull-in voltage on the behavior of switching. Therefore, in the case of accomplishing this purpose the Runge-Kutta (RK4) numerical method has been used. It is a useful method to solve ordinary differential equations and coupling differential equations that is first introduced by C. Range in 1895 [9].

2.1. Results and discussion

We now discuss the effect of the Casimir force and pull-in voltage on the switching process. Referring to Eq. 5, Fig. 2 is related to the variation of pull-in gap with the parameter a related to the Casimir force when the pull-in voltage is a constant value equal to 0.25. While Fig. 3 presents the variation of pull-in gap with parameter b related to the pull-in voltage when the Casimir force is constant value equal to 30. As shown in Fig. 2 three different curves are displayed for three different values of Casimir force (30, 40, 60) respectively. Regarding to a =30 which is the lowest value in this given interval the pull-in gap has the maximum amplitude and continuously decreases by applying next quantities a =40 and a =60. It is due to the fundamental nature of Casimir force. As the Casimir force increases the attraction between plates is also enhance and as a result, the pull-in gap is reduced. It means that the Casimir force is effective in the pull-in process and collapsing down the conducting plate Which is the same results as derived in [2]. With Approximately identical reasons the variations of pull-in voltage is also effect the magnitude of pull-in gap. Referring to Fig. 3 we consider three different amount of pull-in voltage as 0, 0.5, and 1. It is clear to see when b =0 the amplitude is much greater than those values of b =0.5 and b =1. This is also illustrates the impact of pull-in voltage on the distance of conducting plates. So,as the parameter b increases the space between plates decreases.

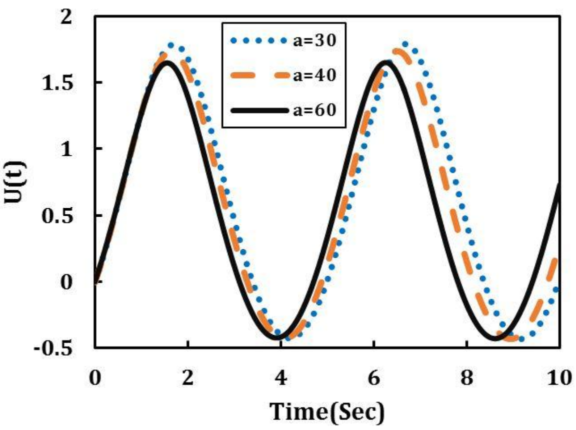


Fig. 2: Variation of pull-in gap with respect to time for three different values of a=30, a=40, a=60

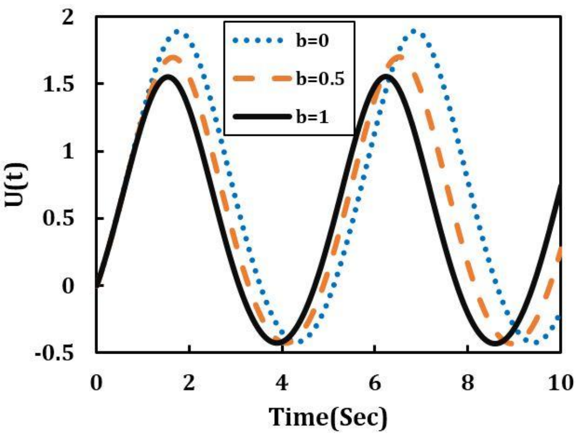


Fig. 3: Variation of pull-in gap with respect to time for three different values of b=0, b=0.5, b=1

3. Conclusion

In this study, a numerical simulation for computing and investigating the dynamical effect of Casimir force and pull-in voltage in a cantilever-beam type switch is presented. Results show that the Casimir force and the pull-in voltage have significant effect on nonoelectromechanical switches. By considering three different values for both Casimir and pull-in voltage we assumed that, as these two elements increase the gap distance between parallel conducting plates decreases. Consuquently, process of switching can be controled by increasing and decreasing them.The advantage of this method are faster and more accurate calculations.

Acknowledgements

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