Vibrational Resonance of a Driven Charged Bubble Oscillator

U. E. Vincent[†*], O. T. Kolebaje[†**], B. E. Benyeogor[†] and P. V. E. McClintock[*]

[†] *Department of Physical Sciences, Redeemer's University, Ede, Nigeria, ORCID 0000-0002-3944-726X*

[*] *Department of Physics, Lancaster University, Lancaster, United Kingdom, ORCID 0000-0003-3375-045X*

[**] *Department of Physics, Adeyemi College of Education, Ondo, Nigeria, ORCID 0000-0002-7557-0257*

Abstract. Vibrational resonance (VR) in a modified Rayleigh-Plesset oscillator for a charged bubble oscillating in a compressible fluid while driven by an amplitude-modulated acoustic force has been investigated. A novel equation of motion for the charged bubble as an oscillator moving in a potential well was obtained. It is shown that the bubble moved in a single-well potential when uncharged, while it can move in varieties of potential wells when charged. In the presence of an amplitude-modulated acoustic wave, an increase in the quantity of charge leads VR, i.e. an increased response of the bubble to the acoustic wave. Furthermore, different patterns of VR can occur with variations of other cavitation properties.

Introduction

The phenomenon of vibrational resonance (VR) [1] was first introduced in 2000 by Landa and McClintock [1]. It is the amplification of a weak signal input by means of high-frequency driving signal, whose frequency $\Omega \gg \omega$, where ω is the frequency of the weak signal. Due to its numerous potential applications, VR has been receiving considerable research attention in the last two decades in many different field, including bubble dynamics [2, 3]. Studies of VR in bubble oscillators are relatively new and were investigated only for uncharged bubble oscillator moving in an incompressible liquid [3]. Research interests in bubble oscillation and cavitation are largely motivated by their applications in fluid engineering (e.g. industrial waste water treatment), sonochemistry and medical diagnostics and therapy. When irradiated by acoustic driving fields, electrostatic charges can be deposited on the bubble surface, thereby negatively charging the bubbles due to the migration of ionic charge from the fluid onto the bubble surface [4, 5]. The effects of charge on bubble dynamics is a longstanding problem, but has not been investigated in relation to VR phenomenon, to best of our knowledge.

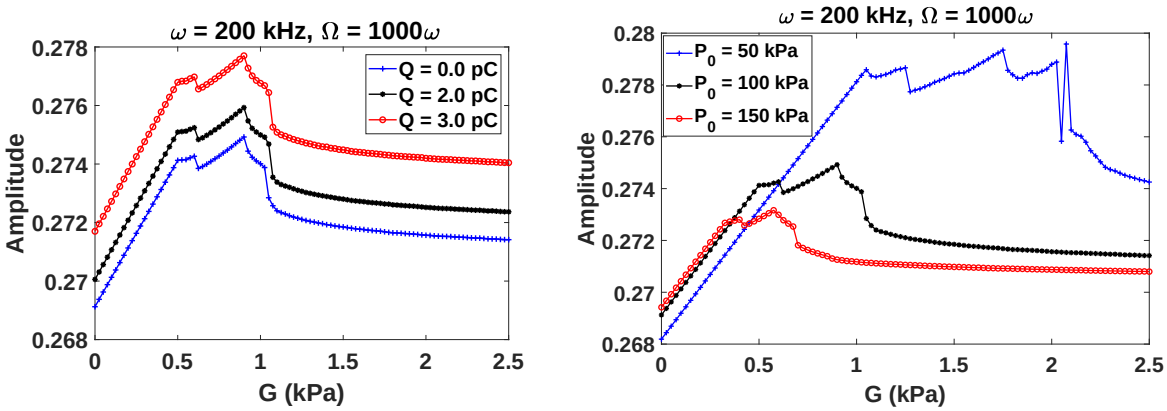

Figure 1: The response amplitude (A) as a function the amplitude of the modulation G for three different quantities of the charge, Q.

Results and discussion

Vibrational Resonance was numerically investigated using Matlab Simulink model of the charged bubble oscillator. The main effect of charge on VR is shown in Figure 1 for different values of the quantity of charge, $Q = 0, 2.0\ pC$ and $3.0\ pC$. An increase in Q leads to an increased response of the bubble to the amplitude modulation, namely, enhancement of VR. Furthermore, in the presence of electrostatic charge, variation of other cavitation properties impacts on the occurrence of VR in different pattern, either by enhancing VR or suppressing it - implying that the cavitation properties can be exploited in the presence of charge to control the bubble dynamics for the desired application.

References

[1] Landa P. S. and McClintock P. V. E. (2000) Vibrational resonance. *J. Phys. A: Math. & Gen.* **33**: L433.

[2] Vincent U. E., McClintock P. V. E., Khovanov I. A. and Rajasekar S. (2021) Vibrational and stochastic resonance in driven nonlinear systems. *Phil. Trans. R. Soc. A* **379**:20210003.

[3] Omoteso K. A., Roy-Layinde T. O., Laoye J. A., Vincent U. E. and McClintock P. V. E. (2021) Acoustic vibrational resonance in a Rayleigh-Plesset bubble oscillator. *Ultrason. Sonochem.* **70**:105346.

[4] Lee Hyang-Bok and Choi Pak-Kon (2020) Electrification of Sonoluminescing Single Bubble. *J. Phys. Chem. B* **124**:3145.

[5] Hongray T., Ashok B. and Balakrishnan J. (2015) Effect of charge on the dynamics of an acoustically forced bubble. *Nonlinearity* **27**:1157.