American Journal of Mechanical Engineering, 2017, Vol. 5, No. 3, 91-93
Available online at http://pubs.sciepub.com/ajme/5/3/4

DOI:10.12691/ajme-5-3-4

Does Temperature Effects Tpropagation and Growth of Cracks in a Wine Glass Tuning Nearest to a Sound Machine

M. Tsili*, **D. Zaxaropoulos**

School of Engineering, Democritus University of Thrace, Xanthi, Greece
*Corresponding author: martsili@otenet.gr

Abstract In this paper we investigated if temperature effects the propagation and growth of cracks in a wine glass tuning nearest to a sound- machine. We based upon the laws of classic and fracture mechanics and we showed that the wine glass breaks when initially its temperature overcomes the temperature of the room and at continuity starts decreasing before equalizing.

Keywords: *sound machine, wine glass, temperature of wine glass temperature of the room*

Cite This Article: M. Tsili, and D. Zaxaropoulos, "Does Temperature Effects Tpropagation and Growth of Cracks in a Wine Glass Tuning Nearest to a Sound Machine" *American Journal of Mechanical Engineering*, vol. 5, no. 3 (2017): 91-93. doi: 10.12691/ajme-5-3-4.

1. Introduction

All material bodies: solids, liquids and gasses are vibrating. The wine glass is vibrating nearest to 5.5Hz. [1,2] and its acoustics has been considered by many researchers [3-16].

The purpose of this paper is to investigate if temperature plays any role to propagation and growth of cracks in a wine glass, tuning nearest to a sound machine.

For that reason we will base upon the laws of classic mechanics: balance of mass, momentum and energy.

2. The Problem and Its Physical Approximation

i) The mathematical modeling

We assume that at t=0, the wine glass had a density of mass ρ_o, a temperature θ_o and an internal energy per unit volume e_o. Also its displacement and velocity were x_o and v_o respectively. Finally the room had a temperature θ_1 and the sound machine indicated in Figure 1 was non-activated.

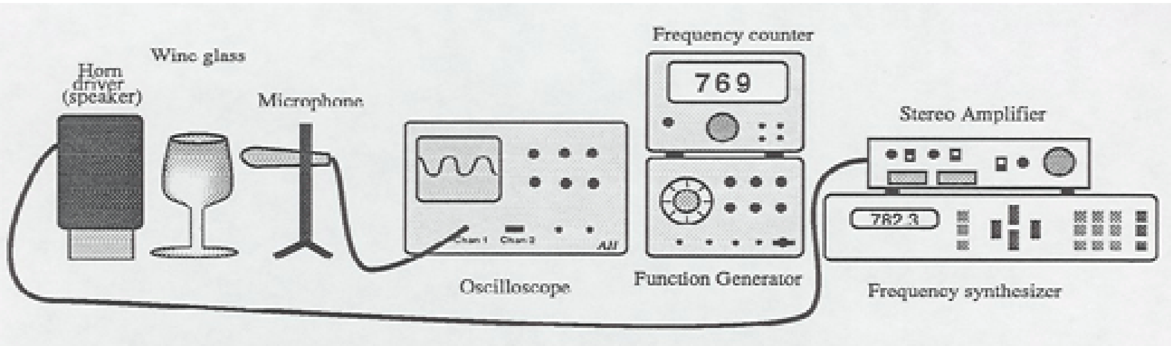

Figure 1. A sound machine near a wine glass. Taken from [17]

At t>0 the sound machine starts vibrating tuning nearest the wine-glass. Therefore the wine glass is under a constraint resonated vibration without damping, due to the sound wave of sound machine described by the following differential equation:

$$m\ddot{u}_x + ku_x = F_o\cos\omega_o t \quad \text{for } t > 0 \qquad (1)$$

where u_x, m and k are respectively: the horizontal displacement, the mass and the stiffness constant of the wine glass, while F_o is the amplitude of vibration of sound machine. We assume that the rest displacements vanish.

The above equation is written as:

$$\ddot{u}_x + \omega_o{}^2 u_x = f_o\cos\omega_o t \text{ for } t > 0 \qquad (2)$$

where $\omega_o=\sqrt{(k/m)}$ is the radial frequency of the wine glass in units of rad/sec and $f_o = F_o/m$. The general solution of the above is:

$$\begin{aligned} ux(t) &= v_o(\sin\omega_o t)/\omega_o + +x_o\cos\omega_o t + f_o t\sin\omega_o t \\ &= \sin\omega_o t(f_o t + v_o/\omega_o) + x_o\cos\omega_o t \text{ for } t > 0. \end{aligned} \tag{3}$$

Assuming that $x_o=0$ and $v_o=0$ the above reduces to the form:

$$ux(t) = tf_o\sin\omega_o t. \tag{4}$$

Therefore the velocity of material particles of wine glass is:

$$v_x = du_x(t)/dt = f_o(\omega_o t\cos\omega_o t + \sin\omega_o t) \tag{5}$$

while its acceleration is:

$$\ddot{u}_x(t) = \omega_o f_o[2\cos\omega_o t - \omega_o t\sin\omega_o t]. \tag{6}$$

The balance of mass of wine glass is:

$$d\rho(t)/dt + \rho(t)\left(v_{x,x} + v_{y,y} + v_{z,z}\right) = 0 \tag{7}$$

where ρ(t) is its density. Substituting (5) into (7) it follows:

$$d\rho(t)/dt = 0 \to \rho(t) = \rho_o. \tag{8}$$

The dynamics stress - equation for the wine glass are:

$$\begin{aligned} &\sigma_{xx,x}(t) + \sigma_{xy,y}(t) + \sigma_{xz,z}(t) \\ &= \rho_o\omega_o f_o[2\cos\omega_o t - \omega_o t\sin\omega_o t], \\ &\sigma_{xy,x}(t) + \sigma_{yy,y}(t) + \sigma_{yz,z}(t) = 0 \qquad (9)_{1\text{-}2\text{-}3} \\ &\text{and} \\ &\sigma_{xz,z}(t) + \sigma_{yz,z}(t) + \sigma_{zz,z}(t) = 0. \end{aligned}$$

We assume that:

$$\sigma_{xy}(t) = \sigma_{xz}(t) = \sigma_{zz}(t) = 0. \qquad (10)_{1\text{-}2\text{-}3}$$

Inserting the above into $(9)_{1\text{-}2\text{-}3}$ it is possible to obtain:

$$\begin{aligned} &\sigma_{xx}(t) = \rho_o\omega_o f_o[2\cos\omega_o t - \omega_o t\sin\omega_o]x + A(t) \\ &\sigma_{yz}(t) = Bt + C \qquad (11)_{1\text{-}2\text{-}3} \\ &\text{and } \sigma_{yy}(t) = Dt + E \end{aligned}$$

where A(t) is an unknown function, while B, C, D and E are unknown constants.

The balance of energy is:

$$\begin{aligned} \rho_o(de/dt) = \sigma_{xx}v_{x,x} + \sigma_{yz}v_{y,z} + \sigma_{yy}v_{y,y+}q_{x,x} \\ + q_{y,y} + q_{z,z} + W_1 + W_2 \end{aligned} \tag{12}$$

where q_j, W_1 are respectively: the thermal flux and the energy transferred by the sound wave and added to wine glass given by:

$$q_i = \theta,_j = 0 \text{ and } W_1 = 1/2Mux^2 \qquad (13)_{1\text{-}2}$$

where M is a vibration constant of sound wave. Finally W_2 is the energy supply due to thermal reasons added /subtracted to /from the glass, given by:

$$W_2 = \pm \tfrac{1}{2}K\Delta\theta^2(t) = \pm \tfrac{1}{2}K\left[\theta(t) - \theta_1\right]^2 \tag{14}$$

where K and Δθ(t) are respectively a thermal constant and the difference of temperature between wine glass θ(t) and room θ_1. The temperature of room θ_1 assume to be constant.

If initially $\theta_o = \theta_1$ then $\Delta\theta(t)=0$ and therefore W_2 vanishes.

If $\theta_o < \theta_1$ then the energy supply W_2 should be written as:

$$\begin{aligned} &W_2 = \tfrac{1}{2}K\Delta\theta^2 = \tfrac{1}{2}K\left[\theta(t) - \theta_1\right]^2 \qquad (15)_{1\text{-}2} \\ &\text{for } 0 < t \le t_1 \text{and } W_2 = 0 \text{ for } t > t_1 \end{aligned}$$

because the temperature of the wine glass increases for t>0 and tends to be equal with that of room at a particular time moment t_1. At this case the last is heating, that is an amount of thermal energy is added to it for $0<t\le t_1$.

If $\theta_o > \theta_1$ then the energy supply W_2 should be written as:

$$\begin{aligned} &W_2 = -\tfrac{1}{2}K\Delta\theta^2 = -\tfrac{1}{2}K\left[\theta(t) - \theta_1\right]^2 \qquad (16)_{1\text{-}2} \\ &\text{for } 0 < t \le t_2 \text{and } W_2 = 0 \text{ for } t > t_2 \end{aligned}$$

because the temperature of wine glass decreases for t>0 and tends to be equal with that of room at a particular time moment t_2. At this case the last is cooling, that is it looses an amount of thermal energy for $0<t\le t_2$.

Then (12) because of (4), (5), (11),(13) and (14) concludes to:

$$\rho_o(de/dt) = \tfrac{1}{2}(M(f_o t)^2\sin^2\omega_o t \pm K\Delta\theta^2). \tag{17}$$

The above satisfies the initial condition:

$$e(0) = e_o. \tag{18}$$

ii) The solution of the problem:

1) If $\theta_o = \theta_1$, then (17) reduces to:

$$de(t)/dt = Mf_o{}^2t^2\sin^2\omega_o t/2\rho_o > 0 \text{ for } t > 0. \tag{19}$$

From the above it is possible to conclude that E(t)=de(t)/dt is an increasing function, that is $e(t)>e_o$. Consequently the internal energy of wine glass $U(t)=\int\rho_o e(t)dv > U_o=\int\rho_o e_o dv=\rho_o e_o\int dv$ which means that the last is under an elastic deformation.

2) If $\theta_o < \theta_1$, then (17) due to $(15)_{1\text{-}2}$ is written as:

$$\begin{aligned} &de(t)/dt = [Mf_o{}^2t^2\sin^2\omega_o t + K\Delta\theta^2(t)]/2\rho_o > 0 \\ &\text{for } 0 < t \le t_1 \text{ and} \qquad (20)_{1\text{-}2} \\ &de(t)/dt = Mf_o{}^2t^2\sin^2\omega_o t/\ 2\rho_o > 0 \text{ for } t_1 > 0. \end{aligned}$$

From the above it is possible to conclude that E(t)=de(t)/dt is an increasing function in both branches, that is $e(t)>e_o$ for t>0 and the same goes as at previous case.

3) If $\theta_o > \theta_1$, then (17) due to $(16)_{1\text{-}2}$ is written as:

$$\begin{aligned} &de(t)/dt = [Mf_o{}^2t^2\sin^2\omega_o t - K\Delta\theta^2(t)]/2\rho_o \\ &\text{for } 0 < t \le t_2 \text{ and} \qquad (21)_{1\text{-}2} \\ &de(t)/dt = Mf_o{}^2t^2\sin^2\omega_o t/2\rho_o > 0 \text{ for } t_2 > 0. \end{aligned}$$

If $0<t\le(K\Delta\theta^2(t)/Mf_o{}^2)^{1/2}$ then $(21)_1$ takes the form:

$$\begin{aligned} &de(t)/dt \le (\sin^2\omega_o t - 1)K\Delta\theta^2(t) \\ &= -\cos^2\omega_o tK\Delta\theta(t)^2 < 0 \text{ for } 0 < t \le t_2. \end{aligned} \tag{22}$$

From the above it is possible to conclude that $E(t)=de(t)/dt$ is a decreasing function for $0<t\leq t_2$, that is $e(t) < e_o$. Consequently the internal energy of wine glass $U(t)=\int\rho_o e(t)dv < U_o=\int\rho_o e_o dv = \rho_o e_o\int dv$ for $0< t \leq t_2$. Accordingly to Griffith's energy criterion [18,19] macroscopically propagation and growth of crack will be arised which microscopically due to the breaking of the chemical connections between atoms. Therefore at time $t_k < t_2$ that satisfies the condition $0<t_k\leq K\Delta\theta^2(t_k)/Mf_o^2$ the wine glass will be fractured.

3. Discussion and Conclusion

Our model is verified by experimental studies. Particularly it has been shown that a sound machine resonated nearest to wine glass can break it [1,2,9,17,20-30].

From the above we result that temperature effects the propagation and growth of cracks in a wine -glass tuning nearest to a sound machine. The last happens when temperature of wine glass overcomes the temperature of room and starts decreasing before equalizing.

References

[1] Rueckner W., Goodale D, Rosemberd D, et., al., (1993). "Lectures demonstrations on wine glass resonates", Amer. Journal of Physics, vol. 61, issue 2, pp. 184.

[2] In html: "How to break glass with sound". Acoustics, audio and video. University of Salford.

[3] French A. (1983). Veritas – A study of wineglass acoustics" Am. J. Phys., Vol.51, No. 8, August 1983

[4] Morse Ph (1983). "Vibration and Sound", Chapter 4, pp 151-166. The American Institute of Physics,

[5] Apfel R. E, (1985). "'Whispering' Waves in a Wineglass," Am. J. Phys. 53, 1070

[6] Rossing, T. D. (1994). "Acoustics of the glass harmonica". The Journal of the Acoustical Society of America, 95(2), 1106-1111.

[7] Oku K., Yarai A. and Nakanishi T. (2000). "A new tuning method for glass harp based on a vibration analysis that uses a finite element method". Journal of the Acoustical Society of Japan 21(2): 97-104,

[8] Raymond A. Serway and John W (2003). "Physics for Scientists and Engineers, Brooks Cole; 6 edition (July 21, 2003).

[9] Oscillation Waves and Wine Glasses (2004). Harvard University Faculty of Arts and Sciences, in www.fas.harvard.edu/~scdiroff/lds/OscillationsWaves/Shattering Wineglass/ShatteringWineglass.html.

[10] Chen, K. W., Wang, C. K., Lu, C. L., & Chen, Y. Y. (2005). Variations on a theme by a singing wineglass. Europhysics Leters, 70(3), 334.

[11] Jundt, G., Radu, A., Fort, E., Duda, J., Vach, H., &Fletcher, N. (2006). "Vibrational modes of partly filled wineglasses." The Journal of the Acoustical Society of America, 119(6), 3793-3798.

[12] Courtois, M., Guirao, B., & Fort, E. (2008). "Tuning the pitch of a wine glass by playing with the liquid inside. European Journal of Physics, 29(2), 303.

[13] in http://www:usc.edu/CSSF/History/2007/Projects/J1624.pdf.

[14] in: http://large.stanford.edu/courses/2007/ph210/scodary2/.

[15] Courtois, M., Guirao, B., & Fort, E. (2008). "Tuning the pitch of a wine glass by playing with the liquid inside. European Journal of Physics, 29(2), 303.

[16] Technological University. (2014). Physics of Music in http://www.phy.mtu.edu/~suits/notefreqs.html.

[17] in http://demoweb.physics.ucla.edu/content/50-breaking-glass-sound.

[18] Grifith A. (1921). "The phenomena of rupture and flow in solids" Philosophical Transactions of the Royal Society of London A 221, pp., 163-198.

[19] Griffith A. (1924). "The theory of rupture". In: Proc., Ist., Int., Congr., Appl., Mech. Biereno, C.B. Burgers, J.M(eds). Delft: Tech. Boekhandel en Drukkerij. J. Waltman Jr., pp. 54-63.

[20] Walker W. C. (1977). ''Demonstrating Resonance by Shattering Glass with Sound,'' Phys. Teach.15, pp.294-296.

[21] Jones G.E and Gordon W.P, (1979). "Apparatus for a Shattering Experience," Am. J. Phys.47, 828-829.

[22] Skeldon K.D, Nadeau V.J, and Christopher Adams C. (1998). "The resonant excitation of a wineglass using positive feedback with optical sensing, Am. J. Phys., Vol. 66, No. 10, October pp.851-860.

[23] Chen Yoh Yuh. (2005). "Why does Water Change the Pitch of a Singing Wineglass that Way it does?." American Journal of Physics. 73. 2-6.

[24] Scodary A. (2007): In http://large.stanford.edu/courses/2007/ph210/scodary2/ Shattering a Wine Glass with Sound December 9, 2007.

[25] Colín J., Marisol. Argos R, Musalem K.(2014). A singing wine glass as an instrument for teaching acoustics: in http://www1.unipa.it/girep2014/accepted-papers proceedings/254_Colin.pdf, p.5.

[26] in http: //www.acoustics.salford.ac.uk/acoustics_info/glass/.

[27] in html :breaking glass with sound_:Lecture demonstration-Manual | Instructional Research Lab : ucla physics.

[28] in html: glass breaking with sound 3D.40.55 pdf

[29] https://www.youtube.com/watch?v=cPALfz-6pnQ Shattering Wineglass by Harvard Natural Sciences Lecture Demonstrations.

[30] https://www.youtube.com/watch?v=CdUoFIZSuX0Breaking Glass with Sound Massachusetts Institute of Technology (MIT).