

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

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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

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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_0 , a temperature θ_0 and an internal energy per unit volume e_0 . Also its displacement and velocity were x_0 and v_0 respectively. Finally the room had a temperature θ_1 and the sound machine indicated in Figure 1 was non-activated.

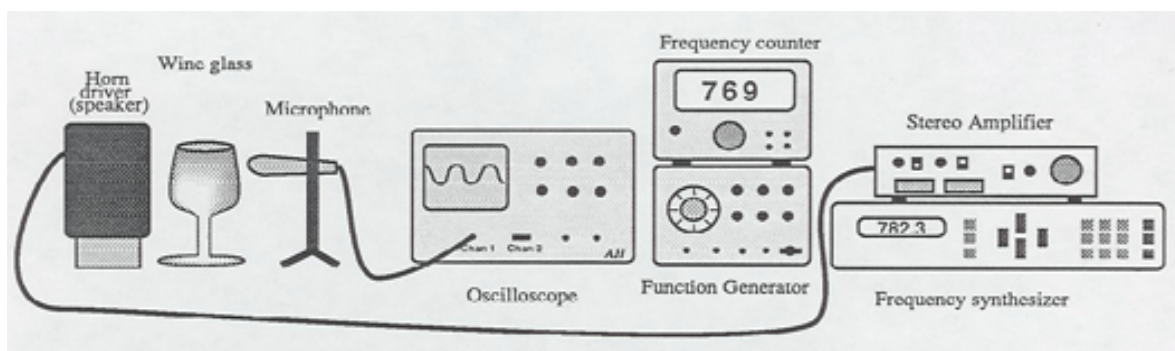


Figure 1. A sound machine near a wine glass. Taken from [17]

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:

$$m\ddot{u}_x + ku_x = F_0 \cos \omega_0 t \text{ for } t > 0 \quad (1)$$

where u_x , m and k are respectively: the horizontal displacement, the mass and the stiffness constant of the

wine glass, while F_0 is the amplitude of vibration of sound machine. We assume that the rest displacements vanish.

The above equation is written as:

$$\ddot{u}_x + \omega_0^2 u_x = f_0 \cos \omega_0 t \text{ for } t > 0 \quad (2)$$

where $\omega_0 = \sqrt{k/m}$ is the radial frequency of the wine glass in units of rad/sec and $f_0 = F_0/m$. The general solution of the above is:

$$ux(t) = v_o(\sin\omega_o t) / \omega_o + x_o \cos\omega_o t + f_o t \sin\omega_o t \quad (3)$$

$$= \sin\omega_o t(f_o t + v_o / \omega_o) + x_o \cos\omega_o t \text{ for } t > 0.$$

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

$$ux(t) = tf_o \sin\omega_o t. \quad (4)$$

Therefore the velocity of material particles of wine glass is:

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

while its acceleration is:

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

The balance of mass of wine glass is:

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

where $\rho(t)$ is its density. Substituting (5) into (7) it follows:

$$d\rho(t) / dt = 0 \rightarrow \rho(t) = \rho_o. \quad (8)$$

The dynamics stress - equation for the wine glass are:

$$\sigma_{xx,x}(t) + \sigma_{xy,y}(t) + \sigma_{xz,z}(t) = \rho_o \omega_o f_o [2\cos\omega_o t - \omega_o t \sin\omega_o t],$$

$$\sigma_{xy,x}(t) + \sigma_{yy,y}(t) + \sigma_{yz,z}(t) = 0 \quad (9)_{1-2-3}$$

and

$$\sigma_{xz,z}(t) + \sigma_{yz,z}(t) + \sigma_{zz,z}(t) = 0.$$

We assume that:

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

Inserting the above into (9)₁₋₂₋₃ it is possible to obtain:

$$\sigma_{xx}(t) = \rho_o \omega_o f_o [2\cos\omega_o t - \omega_o t \sin\omega_o t]x + A(t)$$

$$\sigma_{yz}(t) = Bt + C \quad (11)_{1-2-3}$$

$$\text{and } \sigma_{yy}(t) = Dt + E$$

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

The balance of energy is:

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

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:

$$q_i = \theta_{,j} = 0 \text{ and } W_1 = 1/2 M \omega_o^2 x^2 \quad (13)_{1-2}$$

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:

$$W_2 = \pm 1/2 K \Delta \theta^2(t) = \pm 1/2 K [\theta(t) - \theta_1]^2 \quad (14)$$

where K and $\Delta\theta(t)$ are respectively a thermal constant and the difference of temperature between wine glass $\theta(t)$ 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:

$$W_2 = 1/2 K \Delta \theta^2 = 1/2 K [\theta(t) - \theta_1]^2 \quad (15)_{1-2}$$

for $0 < t \leq t_1$ and $W_2 = 0$ for $t > t_1$

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 $0 < t \leq t_1$.

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

$$W_2 = -1/2 K \Delta \theta^2 = -1/2 K [\theta(t) - \theta_1]^2 \quad (16)_{1-2}$$

for $0 < t \leq t_2$ and $W_2 = 0$ for $t > t_2$

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 loses an amount of thermal energy for $0 < t \leq t_2$.

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

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

The above satisfies the initial condition:

$$e(0) = e_o. \quad (18)$$

ii) The solution of the problem:

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

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

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)₁₋₂ is written as:

$$de(t) / dt = [M f_o^2 t^2 \sin^2 \omega_o t + K \Delta \theta^2(t)] / 2 \rho_o > 0$$

for $0 < t \leq t_1$ and $(20)_{1-2}$

$$de(t) / dt = M f_o^2 t^2 \sin^2 \omega_o t / 2 \rho_o > 0 \text{ for } t_1 > 0.$$

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)₁₋₂ is written as:

$$de(t) / dt = [M f_o^2 t^2 \sin^2 \omega_o t - K \Delta \theta^2(t)] / 2 \rho_o$$

for $0 < t \leq t_2$ and $(21)_{1-2}$

$$de(t) / dt = M f_o^2 t^2 \sin^2 \omega_o t / 2 \rho_o > 0 \text{ for } t_2 > 0.$$

If $0 < t \leq (K \Delta \theta^2(t) / M f_o^2)^{1/2}$ then (21)₁ takes the form:

$$de(t) / dt \leq (\sin^2 \omega_o t - 1) K \Delta \theta^2(t) = -\cos^2 \omega_o t K \Delta \theta^2(t) < 0 \text{ for } 0 < t \leq t_2. \quad (22)$$

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 $e(t) < e_0$. Consequently the internal energy of wine glass $U(t) = \int \rho_0 e(t) dv < U_0 = \int \rho_0 e_0 dv = \rho_0 e_0 \int dv$ 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 $0 < t_k \leq K \Delta \theta^2(t_k) / M f_0^2$ 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.

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