



NANOSCALE MEASUREMENTS OF WATER LOSS DURING DRYING USING ULTRASOUND RESONANT SENSOR

Surbhi Mittal
M.S. Candidate

Faculty Advisor: Dr. Ram Devireddy

ABSTRACT

The conventional method adopted for breeding and maintaining endangered species in captivity is not only very difficult but also expensive, limiting the genetic diversity of an endangered species. The most current methodology to achieve this long-term storage protocols is by storing them at low temperatures or cryopreservation. In contrast, desiccation, or the phenomenon of anhydrobiosis, offers the attractive possibility of low cost, long term storage of reproductive tissues and cells from endangered species at ambient temperatures. Biophysical optimization of anhydrobiosis procedures requires dynamic and accurate quantification of the rate of moisture loss during a prescribed desiccation protocol. This can be achieved by engineering microplatforms that can serve as highly sensitive method to measure the rate of moisture loss.

Currently available methods to measure the loss of moisture during a prescribed desiccation protocol include the use of a gravimetric analysis using an analytical balance [1]. In this method, the percent moisture in the biological cell suspension is found as a function of the dried weight and wet weight; where dried weight is weight of the sample after the drying protocol using the convective drying stage and wet weight is the initial weight or the starting weight of the sample. This technique suffers from an inherent limitation in its sensitivity of the rate of moisture loss (~0.1 mg) and that the measurements are made at various discrete times (~5 min intervals).

In order to quantify the water loss during the drying of reproductive cell suspensions, an ultrasound based resonant sensor is to be designed. The geometrical configuration of the vibrating structure is fixed to be rectangular owing to their high rigidity and the directional sensitivity [2]. By considering a thin simply supported rectangular plate with a concentrated load as the sensor [3, 4], the closed form characteristic frequency equation is used as shown in Equation 1:

$$1 = \frac{4m\omega_{p,q}^2}{abD_E} \sum_{p=1}^r \sum_{q=1}^s \frac{(\sin^2 p\pi x_c/a)(\sin^2 q\pi y_c/b)}{\pi^4 [(p/a)^2 + (q/b)^2] - \omega_{p,q}^2 \rho/D_E}$$

$$\omega_{1,1}^2 = \frac{\eta\beta^{(0)}}{\alpha^{(0)} + \eta\kappa}$$

$$\text{where } \alpha^{(0)} = \sin^2\left(\frac{\pi x_c}{a}\right) \sin^2\left(\frac{\pi y_c}{b}\right) \quad \beta^{(0)} = \pi^4 \left(\frac{1}{a^2} + \frac{1}{b^2}\right)^2$$

$$\eta = \frac{D_E ab}{4m} \quad \kappa = \frac{\rho}{D_E}$$

where m denotes the mass on the plate, ω_{pq} is the frequency, D_E denotes the flexural rigidity of the plate, ρ denotes the density per unit area a & b denotes the linear dimension, η, κ are constants based on the flexural rigidity and dimension of the sensor. In the current study the vibrating element is modeled to be a thin plate made of titanium. The material properties for titanium are chosen to be: Young's modulus of 116 GPa, Poisson ratio of 0.34 and a density of 4500 kg/m³. In order to select the suitable design parameters the basic dimensions of the vibrating microplatform for an ultrasonic sensor, fundamental frequency of the rectangular plate are evaluated by varying the length and the aspect ratio of the structure. The aspect ratio of the plate is defined by the ratio of its length to the width of the plate. The natural frequency of the vibrating plate is plotted as a function of its length for various aspect ratios Figure 1(a). Since we are developing an ultrasound based resonant mass sensor the fundamental frequency of the vibrating structure has to be close to the ultrasound vibration range which is of the order of 20 kHz. The fundamental frequency value corresponding to various aspect ratios has been calculated and it has been observed that for higher aspect ratios, of the order of 8, the fundamental frequency of vibrating plate lies in the ultrasound region (i.e. 20 kHz) as shown in Figure 1(a). The

effect on the fundamental frequency due to the change in thickness is also modeled, as shown in Figure 1(b).

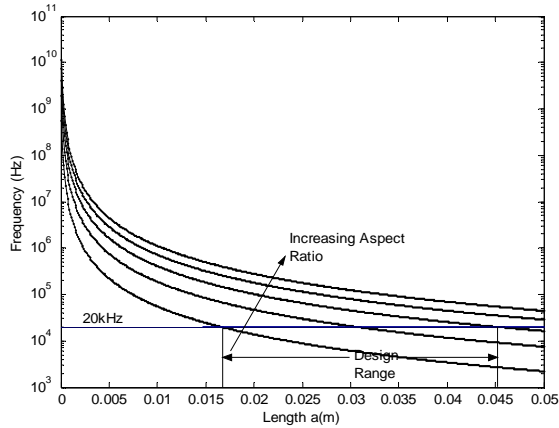


Figure 1(a). Variation of frequency with change in length of the plate.

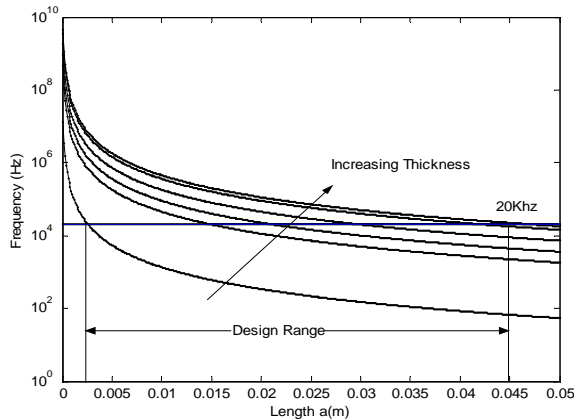


Figure 1(b). Variation of frequency with change in thickness of the plate.

It can be seen that with increasing aspect ratio and increasing thickness the vibrating plate can be operated in the ultrasonic range. Based on Figure 1(a) and (b) the dimensions of the plate are evaluated to be of the order of 0.04m x 0.055m cross section and 450 μ m thickness. It can be observed from the initial modeling results that the width of the plate is chosen to be of the order of 5mm based on the observation that a 1mg cell suspension forms a droplet of approximately 3mm. The fundamental frequency of the titanium plate with these dimensions with a centrally located mass of 1 mg is found to be 36.83 KHz which is well above the ultrasonic range which makes measurement possible. After establishing the design parameters the spectral behavior of the vibrating plate is analyzed. The fundamental frequency is obtained for varying mass by assuming the loss of moisture that takes place during a drying process. The change in frequency (in Hz) with change in mass is shown in Figure 2. A linear change in the shift of the frequency of the vibrating micro platform i.e. the plate is observed with the change in mass.

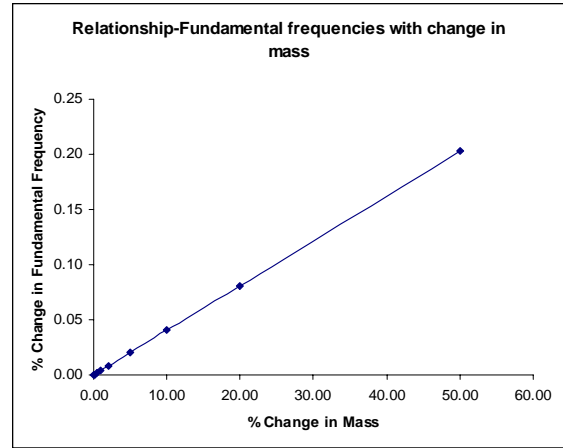


Figure 2. Variation of frequency with change in length of the plate.

CONCLUSION

It is expected that the ultrasound resonant sensor technique outlined in the present study for quantifying dynamically the rate of drying of cell suspension will help to improve our understanding of desiccation process.

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