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Determining the Relationship between Temperature and Tuning Fork Frequency Changes with Polynomial Regression Modelling

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Abstract

A tuning fork is a special tool made of metal and shaped like the letter U with one handle. Tuning forks can produce certain frequencies; usually, the value is written on the handle. This study aims to investigate the relationship between temperature and changes in tuning fork frequency and model it using polynomial regression. This research uses laboratory experiments with tuning forks that have frequencies of 341.3 Hz, 426.5 Hz, and 512 Hz, then the temperature on the tuning fork is varied from 30°C to 220°C with a difference of 10°C. The study's results adjusted R-Square values sequentially 0.94745, 0.99565, and 0.97721, which stated the relationship between temperature and frequency changes. The Adjusted R-Square value close to 1 means that changes in temperature on the tuning fork greatly influence changes in the frequency produced by the tuning fork. The polynomial regression model used is very suitable.

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Introduction

Physics is a field of science that concerns natural phenomena or activities carried out by humans that can be explained experimentally or by mathematical equations. One of the activities that can be explained using the concept of physics is the heating of a tuning fork. When the tuning fork is heated to a high temperature and beaten, it emits various sounds. The variation in the sound of the tuning fork produced is caused by changes in temperature, frequency, and others [1], [2].

A tuning fork is a device made to have a specific frequency and can serve as a commonly used resonator [3], [4]. Physically the tuning fork consists of two arms (tines) and a handle forming the letter U and is made of various materials [1], [5]. Tuning forks can resonate with different frequencies that can be adjusted by placing an object on one of the tines [1], [5]–[7]. Changes in temperature on the tuning fork affect the frequency produced [1], [2]. The magnitude of the effect of temperature on changes in frequency can be known by using polynomial regression [8]–[20].

Previous research conducted by Schindel et al (1997) focused on the frequency response and young modulus of tuning forks on temperature changes without comparing existing frequency equations with experimental results [1]. The findings of this study the frequency of tuning forks decreases with increasing temperature. In another study conducted by Köhring et al (2013) obtained Quality factor and frequency response at high temperatures [2]. This study resulted in a decrease in frequency at high temperatures but did not compare with the existing equation by looking at what changed in the tuning fork after heating.

In addition to previous research, the purpose of this study is to compare existing equations with experimental results and see if the model used is appropriate in this study. By comparing existing equations, valuable input will be obtained regarding the experimental results of the tuning fork frequency whether it becomes a special form of equation or in accordance with existing equations. The main objective of this study is to determine the relationship between temperature and changes in tuning fork frequency by modeling using polynomial regression.

Derivation Of theTuning Fork Frequency Equation

A tuning fork can produce a frequency by vibrating the tines using a beater [21]. The vibration of a tuning fork in symmetrical mode can produce a frequency that can be written in equation (1) [1], [2], [4], [6].

$$f_n = \left(\frac{\pi K}{8L^2}\right)\sqrt{\frac{E}{\rho}}\,a_n \tag{1}$$

with f_n resonant frequency (Hz), K radius of gyration of the tines which has a value of $1/\sqrt{12}$ times bar thickness with rectangular cross section w (m), L length of tines (m), E Young's modulus (N/m^2), ρ density of tuning fork (Kg/m^3), and a_n multiplication factor that depends on order and has a value of 1.194^2, 2.988^2, 5^2, 7^2, …, $(2n\text{-}1)^2$. When the tuning fork is heated, there are changes in the density, length of the tines, thickness of the bar, and young's modulus of the tuning fork which cause changes in equation (1) [22], [23]. Using the Newton binomial series, these changes can be written into equation (2) [24]–[26].

$$f_n \approx \gamma a_n\left(1-\frac{\alpha}{2}T_0-\frac{\alpha^2}{2}T_0^2\right)+\gamma a_n\left(\frac{\alpha}{2}+\alpha^2 T_0\right)T+\left(-\gamma a_n\frac{\alpha^2}{2}\right)T^2 \tag{2}$$

$$\gamma = \left(\frac{\pi w_0}{16L_0^2}\right)\sqrt{\frac{E_0}{\rho_0}} \tag{3}$$

with γ initial values of w, L, E, and ρ of the tuning fork, T_0 initial temperature (°C), T final temperature (°C), α proportionality constant of material. Equation (2) is the form of a second-order polynomial with the independent variables x axis is T (tuning fork temperature) and dependent variables y axis is f_n (tuning fork frequency) [8], [10]–[13],

[17]–[19], [27]. The effect of temperature on the frequency change of the tuning fork can be determined by looking at the value of the adjusted coefficient of determination (Adj. R-Square) of the regression polynomial obtained. When the Adj. R-Square value is close to 1, the independent variable has a large effect on the dependent variable and the model made is suitable [9], [11], [27]–[31].

Experimental Method

The method used in this study includes several stages of data collection and processing which will be explained as follows:

Step a: Preparation of tools used are resonance boxes, tuning forks (which have frequencies of 341.3 Hz, 426.5 Hz, and 512 Hz), heaters, thermocouple sensors, beaters, external microphones, laptops, and digital thermohygrometers. The resonance box used has a length of 18 cm, a width of 9.3 cm, and a height of 5 cm. The tuning fork is placed correctly in the resonance box so that it can vibrate properly and emit its sound frequency. Then put the tools used as in Figure 1.

Step b: Checked the metal temperature of the tuning fork using a temperature sensor until it reaches 30°C. When the temperature of the tuning fork metal is appropriate, then beating on the metal tuning fork is done and recorded the resulting sound using audacity software [32]–[36]. Then for the next data at temperatures of 40°C to 220°C with a temperature difference of 10°C sequentially warmed up, when the temperature is appropriate, beating and recording is carried out as before.

Step c: Processing of experimental audio recordings by selecting the best audio recording that has a duration of 1 second. Then analyzing the spectrum plot using audacity software which will display the frequency value of the recorded audio by looking at the highest peak in the spectrum plot process [32]–[34], [37].

Step d: Make a graph of the temperature relationship to frequency changes using the temperature and frequency data of the tuning fork that has been obtained. Then from the distribution of data points on the graph, a second-order polynomial line is made with originlab software, making the polynomial line is used to see the relationship between temperature and changes in tuning fork frequency the suitability of the model used [8]–[20], [27]–[31].

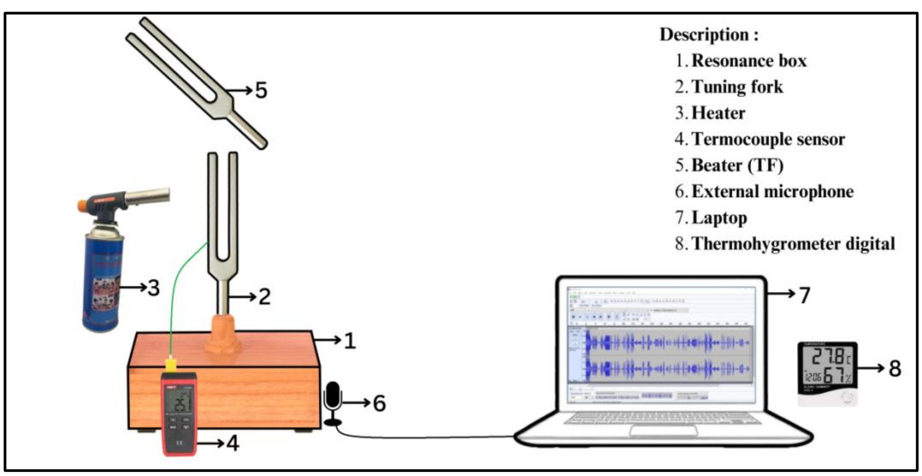

Figure 1 Experimental Setup

Result and Discussion

Frequency data of tuning fork sound wave from audio recordings experiments were obtained using Audacity software. The graph temperature relationship to changes in tuning fork frequency 341.3 Hz can be seen in figure 2.

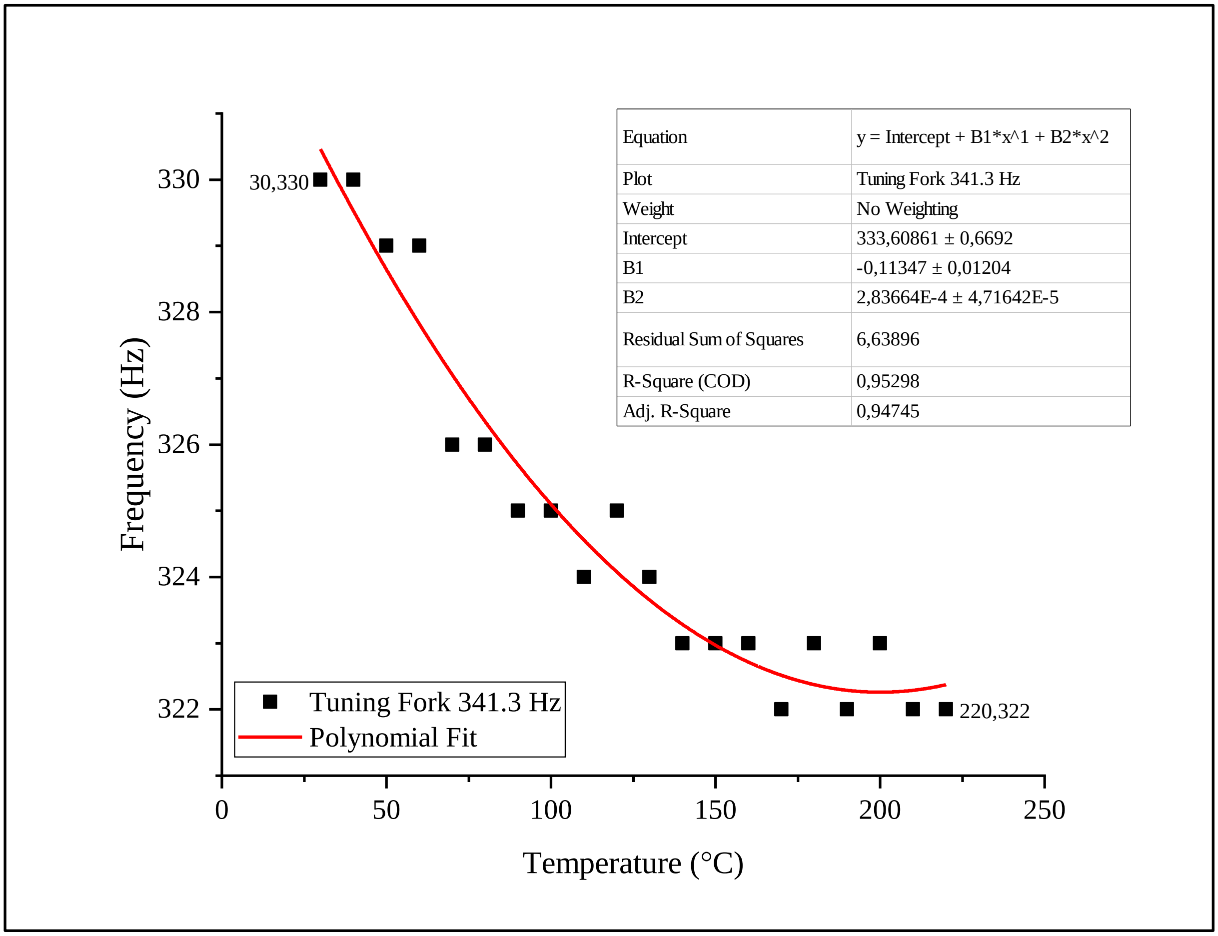

Figure 2 Graph of temperature to frequency relationship at 341.3 Hz tuning fork.

Based on Figure 2, the highest frequency value obtained is 320 Hz when the metal temperature of the tuning fork reaches 30°C and 40°C, there is a difference in the experimental frequency and that written on the tuning fork at room temperature by <5% [38]. Then the frequency of 330 Hz decreased to 322 Hz at temperatures of 170°C, 190°C, 210°C, and 220°C. The physical phenomenon that occurs in tuning forks producing high frequencies at low temperatures is caused by the natural frequency possessed by tuning forks that do not undergo physical changes. Then when heated there are changes in w, L, E, and ρ tuning forks which cause a decrease in the frequency produced. The distribution of data on the graph produces a 2nd order polynomial line equation, namely $y = intercept + B1x^1 + B2x^2$ and the value of the Adjusted R-Square value obtained is 0.94745. The Adjusted R-Square value produced is close to 1, meaning that the temperature of the tuning fork metal greatly affects the frequency by 94.7% and the line model used is very suitable. The equation and the Adjusted R-Square value obtained in the graph support the validity of equation (2) in this study.

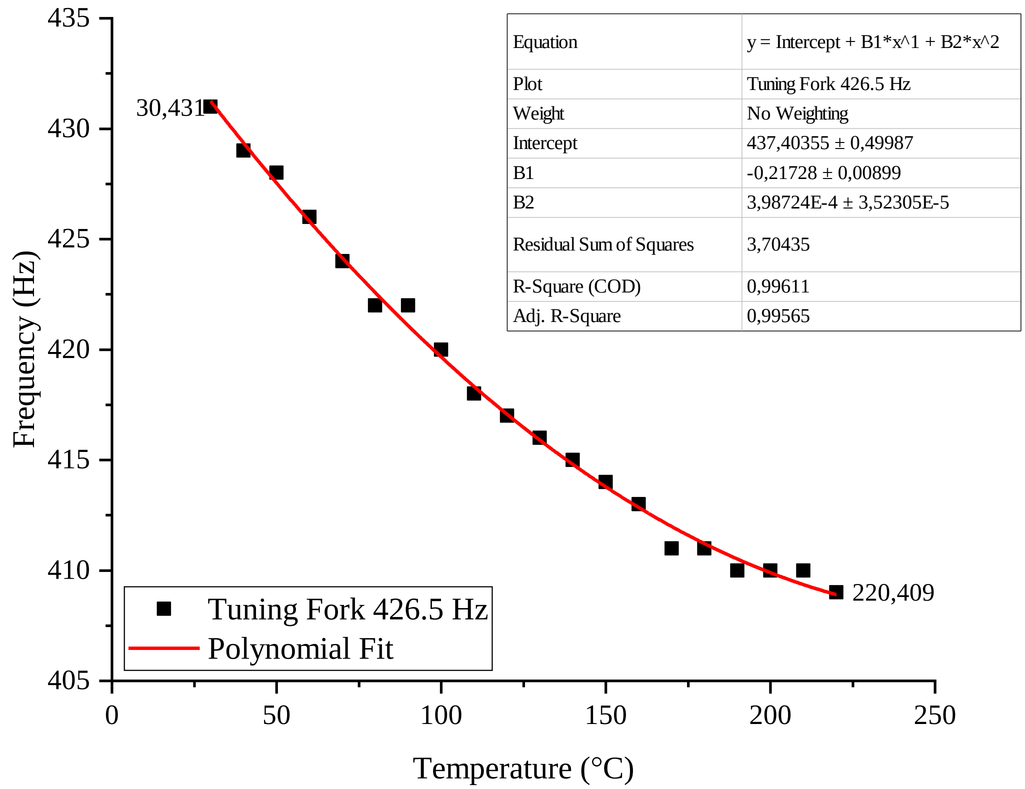

Figure 3 Graph of temperature to frequency relationship at 426.5 Hz tuning fork.

Can be seen in Figure 3, the highest frequency value obtained is 431 Hz at room temperature [38]. Then the frequency decreases to 409 Hz at 220°C. The physical phenomenon that occurs in tuning forks producing high frequencies at low temperatures is caused by the natural frequency possessed by tuning forks that do not undergo physical changes. Then when heated there are changes in w, L, E, and ρ tuning forks which cause a decrease in the frequency produced. On the graph, the data points are scattered which produces a line that has the equation $y = intercept + B1x^1 + B2x^2$ and an adjusted R-Square value of 0.99565 is obtained. The adjusted R-square value obtained is close to 1, which means that the temperature on the tuning fork greatly affects the frequency by 99.5% and the line model used is very suitable. The equation and Adjusted R-Square value obtained from the graph support the validity of equation (2) in this study.

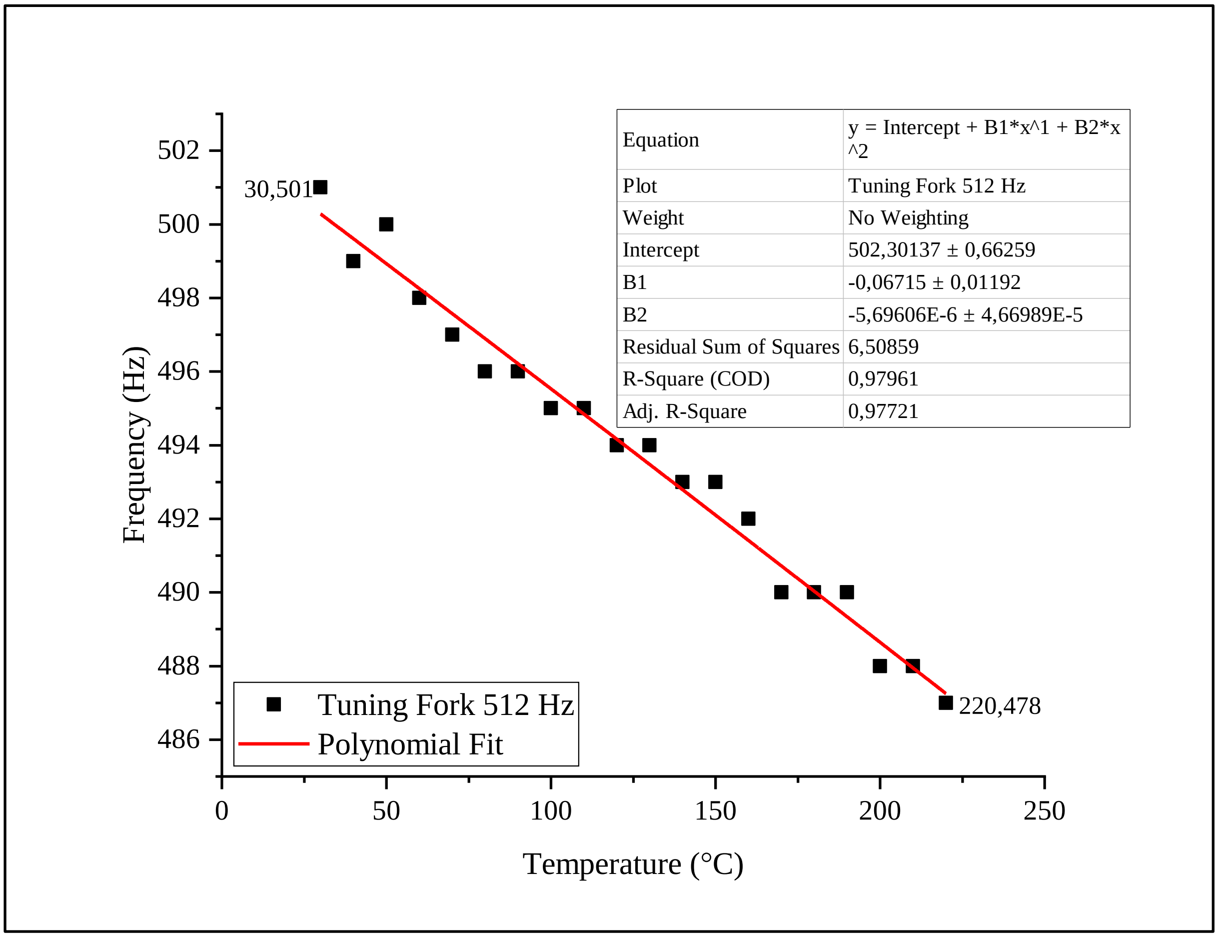

Figure 4 Graph of temperature to frequency relationship at 426.5 Hz tuning fork.

In Figure 4, it can be seen that the highest frequency value obtained is 501Hz at 30°C [38]. Then the frequency of the tuning fork at room temperature decreases to 487Hz at 220°C. The physical phenomenon that occurs in tuning forks producing high frequencies at low temperatures is caused by the natural frequency possessed by tuning forks that do not undergo physical changes. Then when heated there are changes in w, L, E, and ρ tuning forks which cause a decrease in the frequency produced. The line equation obtained in the distribution of data points has the form $y = intercept + B1x^1 + B2x^2$ and the adjusted R-square value obtained is 0.97721. The temperature of the tuning fork greatly affects the frequency change by 97.7% and the line model used is very suitable as seen from the adjusted R-Square value obtained which is close to 1. The validity of equation (2) in this study is supported by the Adjusted R-Square value and the equation obtained from the graph.

Conclusion

Based on the results of the analysis, it can be concluded that the temperature and frequency have a strong correlation on the tuning fork. The increase in temperature of the tuning fork results in a decrease in frequency caused by physical changes in the tuning fork. The relationship between the increase in temperature and the decrease in tuning fork frequency can be made in the form of a second-order polynomial line equation. The suitability of the line equation made against the data distribution can be seen in the Adjusted R-Square value obtained.

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