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# A frequency generator of 40-60 kHz based on arduino for ultrasonic cleaner applications

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**Abstract.** In this study, the design and implementation of a frequency generator of 40 to 60 kHz based on Arduino were carried out by using the pulse width modulation (PWM) technique for ultrasonic cleaner applications. The components used in the study are Arduino Uno, Stainless Tank, four digits seven segment, 4x4 keypad module, TM 1637 module, dimmer module, frequency generator module, and switching mode power supply (SMPS). Calibration of the voltage, frequency, and vibration strength using are multimeters, Equivalent Series Resistance (ESR) meters, and vibration meters. This study aims to design and analyze ultrasonic generator drivers used an Arduino for controlling frequency and time. The regulated input frequency of 50-200 Hz produces an output voltage of 0.3-4.0 volt and an output frequency of 40-60 kHz from an ultrasonic generator. The output voltage is more stable and precision than the frequency output. The ultrasonic cleaner produced has a very high level of precision and accuracy. The relationship of vibration to frequency is directly proportional, the greater the frequency, the greater the vibration produced. The voltage and frequency are inversely proportional; the greater the frequency, the voltage will be smaller.

**Keywords:** Arduino, ultrasonic cleaner, generator, vibration, PWM

## 1.    Introduction
The utilization of ultrasonic waves has increasingly developed in various devices. In medical, ultrasonic can be used for ultrasonography imaging. In chemistry, it is widely used to help the atomizing process, in industry, it can be utilized in the process of cleaning materials. In addition, ultrasonic is still widely used in various sciences such as physics, agriculture, and so on. Ultrasonic is a sound wave that has a frequency above the human hearing limit of 20 kHz to 1 GHz [1]. In the use of ultrasonic two basic components are needed, namely ultrasonic generators and transducers. Generators are used to generate electrical signals with frequencies above 20 kHz to 1 GHz. Ultrasonic transducers are used to convert electrical signals from generators into mechanical waves.

In this study, an ultrasonic generator will be made that can be used for transducers with a frequency of 40-60 kHz with a maximum power of 100 watts. The transducer used is piezoelectric, which will be applied to an ultrasonic cleaner. Before the ultrasonic cleaner was found, chlorine and fluorine solution was used as a cleaning solution in the laboratory. However, these solutions can cause environmental pollution.

The ultrasonic cleaner is a cleaner tool by using ultrasound waves. The principle of an ultrasonic cleaner starts from cavitation bubbles caused by high-frequency pressure or ultrasonication [2]. The bubble can vibrate the media through a piezoelectric membrane. Cavitation is a process of forming

micron-sized bubbles with temperatures reaching 5000 $^{o}$C and pressures of 700 N/cm$^2$. Both of these parameters can produce vibrations that can erode dirt such as oil and dust attached to the surface of the object to be cleaned [3].

The research on ultrasonic cleaner has been conducted by Yakut and team (2009) with a frequency range of 28 kHz using the pulse width modulation (PWM) technique with time control [4]. This study produced aluminum foil, which became damaged after cleaning. The research on ultrasonic cleaner has also been carried out in the application of cleaning conveyor belts and other industrial equipment from the Listeriamonocytogene bacteria [5]. The ultrasonic cleaner is very effective at cleaning industrial tools from bacteria, but the analysis of the tools is not explained in this research. The research on ultrasonic cleaner used for ginger extraction has been carried out [6]. The results of ginger extraction tested by scanning electron microscopy (SEM) showed that ultrasonic cleaner is easier to extract ginger oleoresin because about 80% of ginger cell walls have been damaged. The study only analyzes applications in chemistry but does not explain the analysis of the working system of the ultrasonic cleaner.

Based on the explanation above, an ultrasonic cleaner is useful in the world of research and industry. In this research, the design and implementation the frequency generator of 40 to 60 kHz is performed based on an Arduino Uno with PWM technique for ultrasonic cleaner applications. The principle of this tool is by controlling the frequency and time as input for transducers by using 4x4 keypad. The results of frequency and time input will be displayed on the seven segment TM 1637. The resulting ultrasonic cleaner then characterized by measuring physical parameters that included are voltage, frequency, vibration strength, and working time of the ultrasonic cleaner.

## 2. Method

The materials used in this research are: Arduino Uno, stainless tank, 4 digit seven segment, 4x4 keypad, TM 1637 module, cable, switch button, acrylic, and wooden box. This research was conducted in three stages. First, hardware design and manufacturing. At this stage, electronic devices are arranged to form a system that will be realized as a tool. The hardware design of the ultrasonic cleaner shown in Fig. 1,
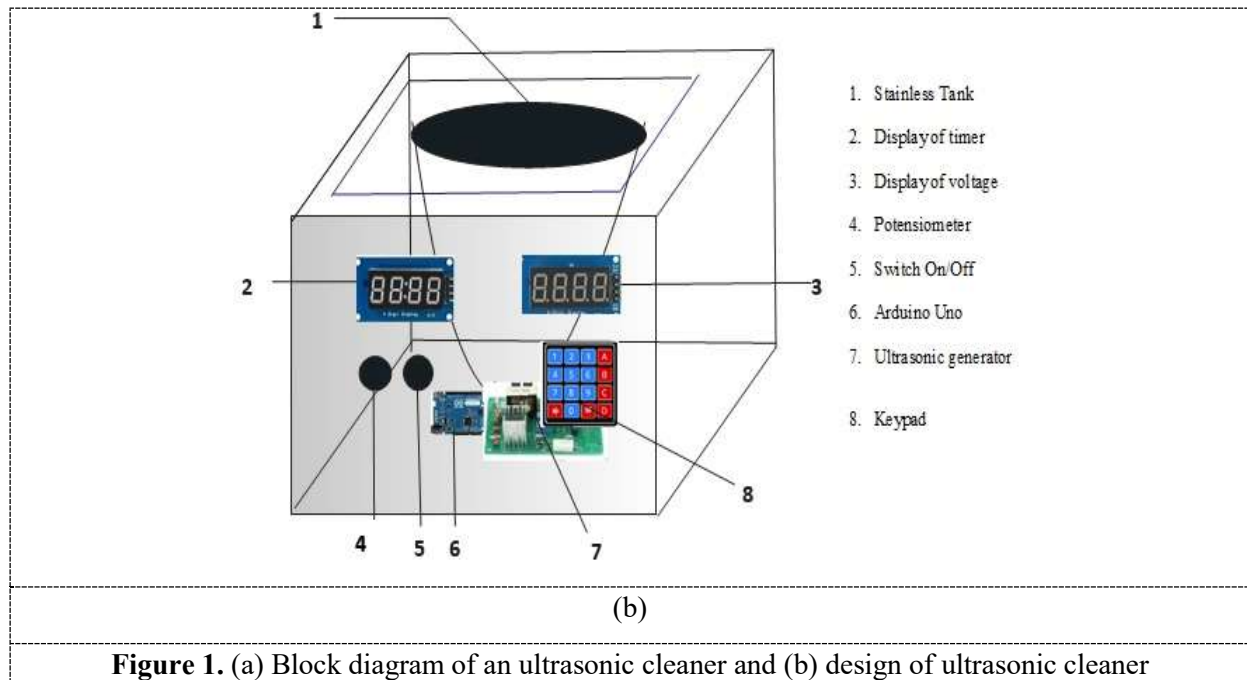


(a)

(b)
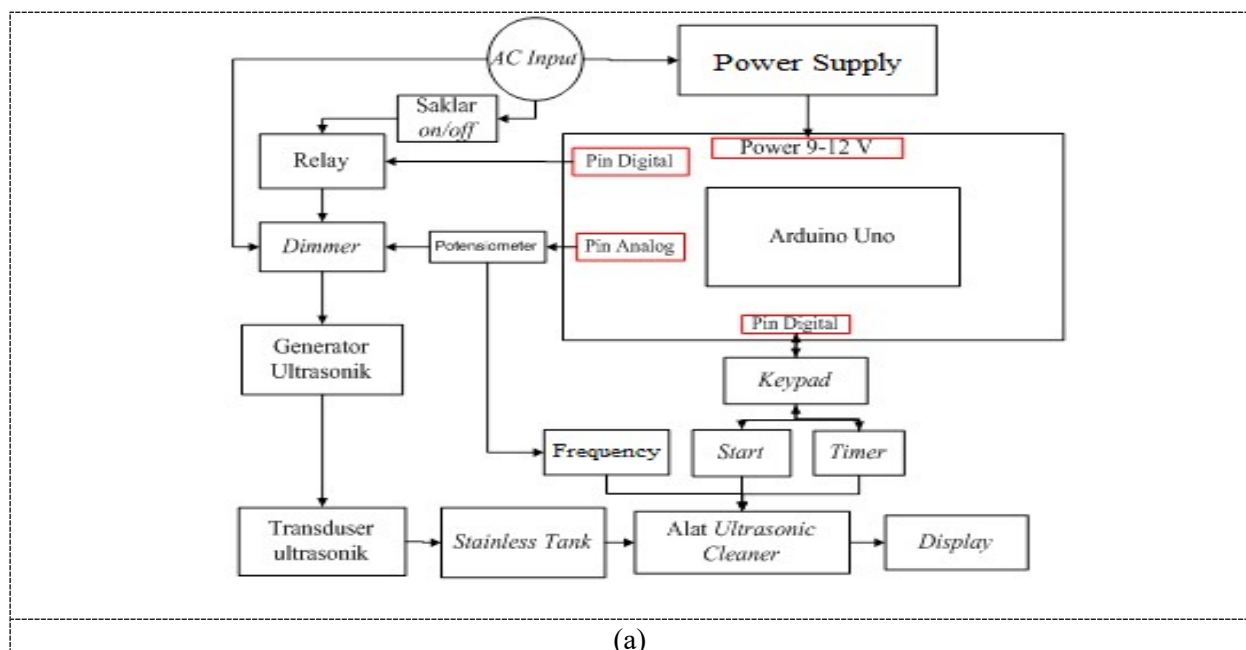
**Figure 1.** (a) Block diagram of an ultrasonic cleaner and (b) design of ultrasonic cleaner

The second stage is the design of ultrasonic cleaner software. In this study, the Arduino IDE application used to program an ultrasonic cleaner that includes a time program with a millis program. The frequency display of 40-60 kHz results from the conversion of the analog input potentiometer input with 0-5 VDC input from Arduino. The time input value is from the 4x4 keypad, the program deletes the time value if an error occurs, and the program stops. The input voltage value displayed on display is obtained from the Arduino voltage value using Equation 1. The voltage value is then converted to the frequency on the seven segment display as in Equation 2.

$$V = \frac{ADC\ Sensor}{1023} \times 5 \tag{1}$$

$$f = \frac{(20V) + 110}{3.5} \tag{2}$$

The third stage is the ultrasonic cleaner calibration. Observational data taken are voltage, frequency, period, vibration strength of the piezoelectric transducer, and working time. The period value is obtained from the frequency value that converted to a period using the equation f = 1/T. Verification tools used when data collections are multimeter and vibration meter. The test is carried out when the 50-200 Hz input frequency is controlled via a potentiometer. Voltage and frequency values are observed to determine the level of precision of this tool. The level of precision can be analyzed by calculating the% RSD (Relative Standard Deviation), i.e., if a data is smaller than other data, it means that the data has a high level of accuracy. % RSD can be obtained using Equation 3 and 4.

$$SD = \sqrt{\frac{\sum x^2 - \frac{(X)^2}{n}}{n-1}} \tag{3}$$

$$\%RSD = \frac{SD}{\bar{x}} \times 100\% \tag{4}$$

## 3.  Result and Discussion

The principle of ultrasonic generators is almost the same as the principle of switching mode power supply (SMPS). As an input source is 220 VAC/50 Hz by converted to a DC voltage using a bridge diode. This rectified voltage will supply the capacitor, which is then stored by the capacitor and is used to repair the voltage waveform (ripple) produced by the diode bridge or rectifier. The hardware is one of a series of ultrasonic generators. Ultrasonic generator is essential to determine the success or failure of this research. The ultrasonic generator is shown in Figure 2.
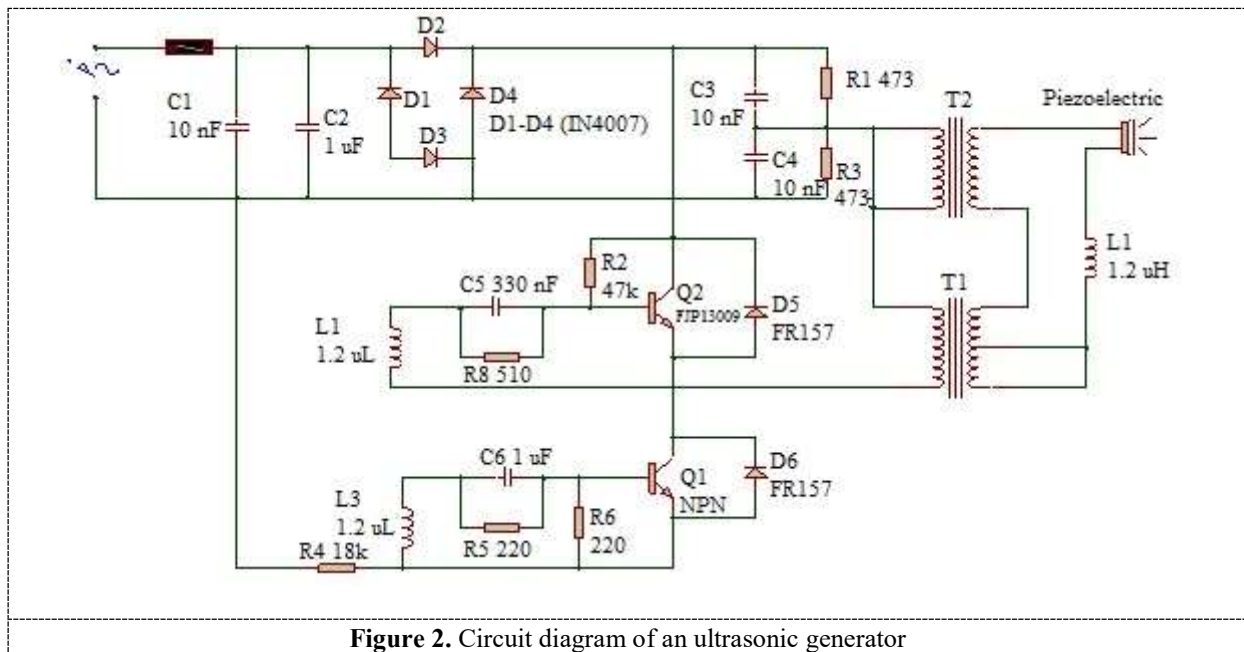


**Figure 2.** Circuit diagram of an ultrasonic generator

Figure 2 shows the T1 section of the primary transformer at the midpoint, and the second section T1 amplifies the voltage of Q1 and Q2. While T2 acts as a filter to produce output waves. T2 is only used as a conductor, so it not produce any voltage. Firstly, the inductor coil (L1) is connected directly to the ultrasonic transducer as a producer of mechanical oscillations. Next, the oscillations are taken by L1 and sent to Q1 and Q2 through L3 and L2. These relationships are interconnected to transmit and run the transducer oscillation until the generator turned off [7-9].

The data measured from the ultrasonic cleaner is a data analysis of the relationship of voltage to the frequency with precision level analysis, time accuracy data, and vibration relationship data to the input frequency. Variables that are set when taking ultrasonic cleaner data are time and frequency input. The frequency is controlled using a dimmer of 50-200 Hz as the input frequency to the ultrasonic generator. The ultrasonic generator produces an output frequency of 40-60 kHz and a voltage of 0-5 V. The working time of the ultrasonic cleaner is regulated via a 4x4 keypad. The relationship of vibration to frequency is obtained by analyzing the vibrations that occur in the piezoelectric when the ultrasonic generator frequency control. Figure 3 shows an ultrasonic cleaner based on Arduino Uno. Figure 3 shows the realisation of an ultrasonic cleaner based on Arduino Uno [10].
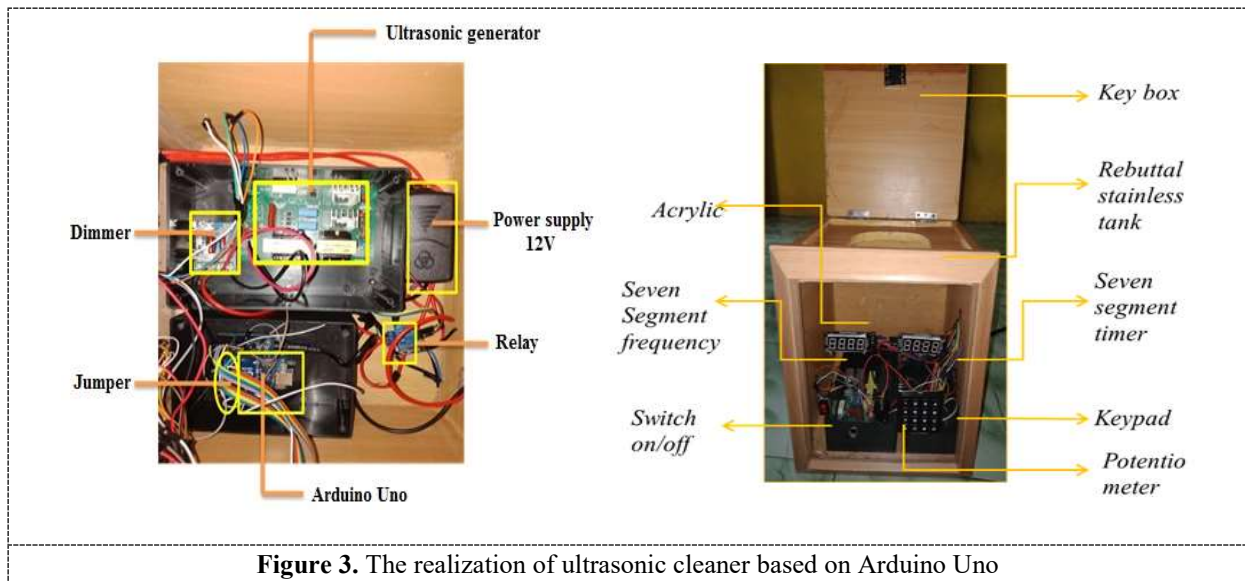
**Figure 3.** The realization of ultrasonic cleaner based on Arduino Uno

Retrieval of data analysis of the voltage repeatability of the input frequency is repeated five times. The level of precision can be analyzed from the %RSD value contained in Table 1 and Table 2. The value of% RSD is the value generated from calculations using Equation 4. When% RSD is 0 (zero), it means that the data is very precise. The input frequencies are very precise data at 65 Hz, 75 Hz, 80 Hz, 90 Hz, 100 Hz, and 200 Hz, which produce a constant output voltage. The graph of the input frequency to the output voltage and output frequency is shown in Figure 4. Analysis of the repeatability of the output frequency to the input frequency is done the same as when analyzing the voltage repeatability of the input frequency. The resulting voltage is 0.30 to 4.00 V. Table 1 shows that the effect of controlling the frequency to the output voltage.

**Table 1.** Calculation of the precision of the output voltage

| No | Input frequency (Hz) | Output voltage (V) | | | | | Average voltage (V) | %RSD (%) |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | | |
| 1. | 50.00 | 4.00 | 3.90 | 3.90 | 3.90 | 4.00 | 3.94 | 1.30 |
| 2. | 55.00 | 2.30 | 2.30 | 2.30 | 2.30 | 2.40 | 2.32 | 1.90 |
| 3. | 60.00 | 2.10 | 2.10 | 2.00 | 2.10 | 2.10 | 2.08 | 2.10 |
| 4. | 65.00 | 1.70 | 1.70 | 1.70 | 1.70 | 1.70 | 1.70 | 0.00 |
| 5. | 70.00 | 1.50 | 1.50 | 1.50 | 1.60 | 1.50 | 1.52 | 2.80 |
| 6. | 75.00 | 1.30 | 1.30 | 1.30 | 1.30 | 1.30 | 1.30 | 0.00 |
| 7. | 80.00 | 1.20 | 1.20 | 1.20 | 1.20 | 1.20 | 1.20 | 0.00 |
| 8. | 90.00 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 0.00 |
| 9. | 100.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.00 |
| 10. | 150.00 | 0.80 | 0.80 | 0.80 | 0.80 | 0.07 | 0.78 | 5.60 |
| 11. | 200.00 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.00 |

Table 2 shows that the greater the switching frequency, the output frequency increases. The observations also show that the output frequency repetition data varies more points compared to the output voltage repetition data. At the level of precision that results from the relationship of the output frequency to the input frequency only at 55 Hz and 70 Hz frequencies that experience an adequate level of accuracy. The greater the switching frequency, the voltage will decrease [12].

**Table 2.** Calculation of the precision of the output frequency

| No | Input frequency (Hz) | Output frequency (kHz) | | | | | Average frequency (kHz) | %RSD (%) |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | | |
| 1. | 50.00 | 41.00 | 42.00 | 41.00 | 41.40 | 42.00 | 41.40 | 0.72 |
| 2. | 55.00 | 43.00 | 43.00 | 43.00 | 43.00 | 43.00 | 43.00 | 0.00 |
| 3. | 60.00 | 44.00 | 44.00 | 48.00 | 48.00 | 48.00 | 45.00 | 2.22 |
| 4. | 65.00 | 46.00 | 46.00 | 49.00 | 49.60 | 50.00 | 46.60 | 0.64 |
| 5. | 70.00 | 47.00 | 47.00 | 47.00 | 47.00 | 47.00 | 47.00 | 0.00 |
| 6. | 75.00 | 53.00 | 53.00 | 53.00 | 53.00 | 53.00 | 49.00 | 0.60 |
| 7. | 80.00 | 50.00 | 51.00 | 50.00 | 51.60 | 51.00 | 50.60 | 0.59 |
| 8. | 90.00 | 52.00 | 53.00 | 53.00 | 53.80 | 53.00 | 52.80 | 0.37 |
| 9. | 100.00 | 53.00 | 54.00 | 54.00 | 54.80 | 54.00 | 53.80 | 0.37 |
| 10. | 150.00 | 55.00 | 57.00 | 56.00 | 55.60 | 57.00 | 55.60 | 1.43 |
| 11. | 200.00 | 60.00 | 59.00 | 69.00 | 60.00 | 60.00 | 59.60 | 0.50 |

Figure 4(a-b) is the result of the analysis of the relationship between the output voltage and frequency of the ultrasonic generator and the switching input value. The results obtained were eleven data. At the lowest input frequency of 50 Hz produces an output voltage of 4 V, and the largest input frequency of 200 Hz produces an output voltage of 0.30 V. When the input frequency of 65 to100 Hz experiences a slow voltage drop by a difference of 10 to 20 Hz at each data. The slow voltage drop is due to the selected input frequency range, with a small difference of 5 to 10 Hz. The results of the relationship between the two parameters can be concluded inversely. The greater the switching frequency is applied, the resulting output voltage is lower [12-13].
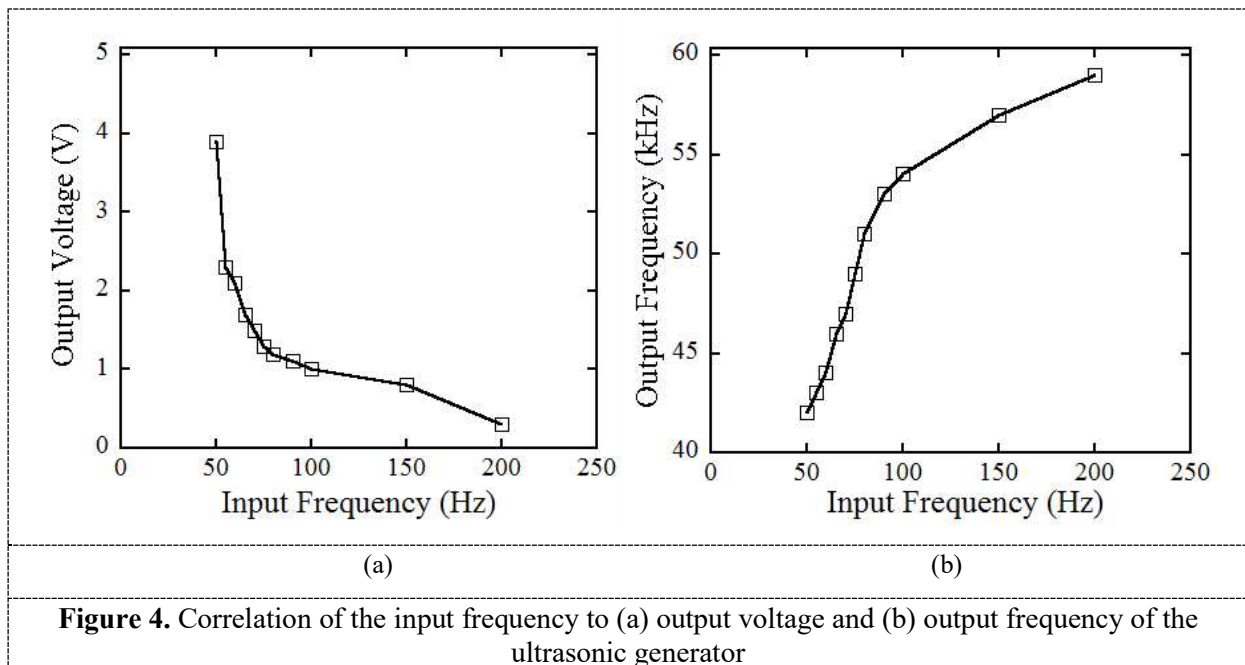


(a)                                                                (b)

**Figure 4.** Correlation of the input frequency to (a) output voltage and (b) output frequency of the ultrasonic generator

The next observation is to analyze the relationship of vibration to the input frequency. Vibration is produced from the piezoelectric, which is at work when connected to an ultrasonic generator. The analysis process uses a VB-8213 vibration meter by attaching the instrument horizontally to the piezoelectric. The variable chosen as the vibration parameter is acceleration. The graph of repeatability or precision of voltage and frequency output of ultrasonic cleaner is shown in Figure 5(a-b). For the

graph of vibration strength as a function of the input frequency and time accuracy of the ultrasonic cleaner are shown in Figure 5(c-d).
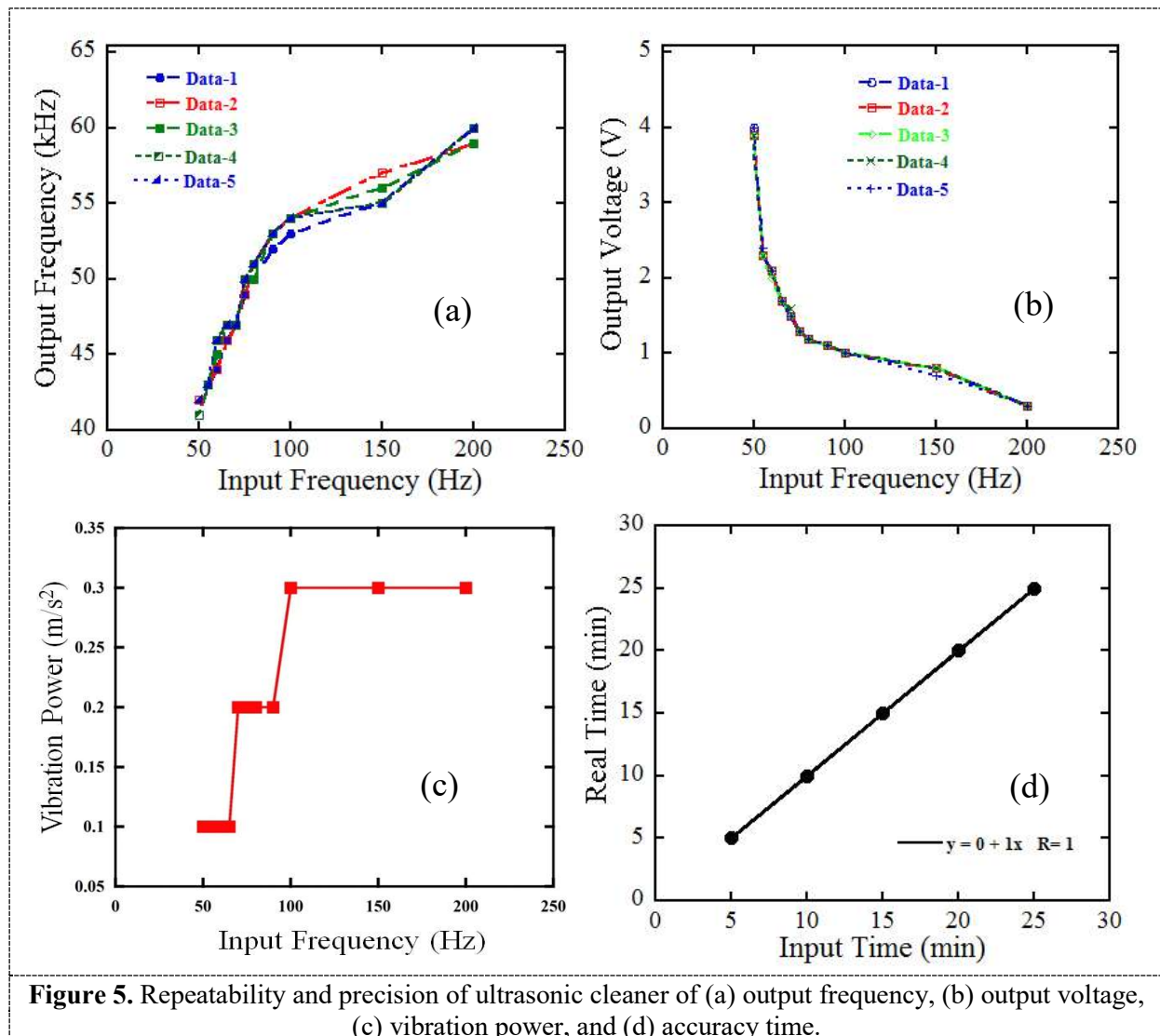


**Figure 5.** Repeatability and precision of ultrasonic cleaner of (a) output frequency, (b) output voltage, (c) vibration power, and (d) accuracy time.

For Figure 5(a), the results of the precision calculation of the output voltage are listed in Table 2 using Equation (4). The results obtained are %RSD values below 6.00%. The highest value of %RSD is 5.73% when the input frequency is 150 Hz. The smaller the value of% RSD, the greater the precision level. Figure 5(b) shows that when the frequency at the switch causes a change in the output voltage. The greater the input switching frequency, the voltage will decrease [7]. Repetition data that has been obtained then analyzed to determine the level of precision. The %RSD value of one data is smaller than other data, meaning that the data has a high level of precision Figure 5(c) shows the relationship of vibration to the input frequency, where the 50 to 65 Hz input frequency produces an acceleration of vibration of 0.1 m/s$^2$, at a frequency of 70 to 90 Hz produces an increase in vibration acceleration of 0.2 m/s$^2$, and at an input frequency of 100 to 200 Hz it produces an acceleration of vibration which also increases from the previous 0.3 m/s$^2$. Based on the research, the results show that the amount of acceleration is directly proportional to the magnitude of the switching frequency. According to Newton's law, the amount of acceleration is directly proportional to the amount of force experienced by an object. Based on Newton's law, the acceleration experienced by piezoelectric is directly proportional to the vibrational force it produces. The greater the acceleration, the greater the vibration force and is directly proportional to the switching frequency [14-15].

The accuracy of time is obtained by comparing working time with actual time using a timer for 25 minutes every 5 minutes, as shown in Figure 5(d). The working time of the ultrasonic cleaner is similar to the stopwatch. Therefore, it can be said that the accuracy rate of time is very high. By obtaining the value of y = 0 + 5x with the value linearity is 1, it means that the relationship is very linear and the relationships x and y are perfect and positive [16-17]. The ultrasonic cleaners are developed as laboratory equipment for the cleaning and synthesizing processes in the field of nanomaterials such as nanowires [18-19].

## 4.  Conclusion

The ultrasonic generator works by frequency output of 40 to 60 kHz, a voltage of 0.30 to 5.00 V, and an input frequency of 50 to 200 Hz, which is regulated using a dimmer. The greater the frequency of the switch, the smaller the voltage generated. The ultrasonic cleaner that is made has a good level of accuracy and can be used for cleaning applications of nanomaterial synthesis tools in the laboratory.

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