Improvement of Surface Roughness by Ultrasonic Vibration of Aluminum Drilling

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Candidate's Declaration

This is to certify that the work presented in this thesis, titled, "Improvement of Surface Roughness by Ultrasonic Vibration of Aluminum Drilling" is the outcome of the investigation and research carried out by me under the supervision of Dr. Md. Anayet Ullah Patwari, Professor, Department of Mechanical& Production Engineering, Islamic University of Technology.

It is also declared that neither this thesis nor any part of it has been submitted elsewhere for the award of any degree or diploma.

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Abstract

Ultrasonic drilling is an advanced machining technique that utilizes high-frequency vibrations to facilitate the drilling process. This innovative method has gained significant attention in various industries due to its ability to overcome limitations associated with conventional drilling techniques. The aim of this abstract is to provide an overview of ultrasonic drilling, including its principles, advantages, and applications. The principles of ultrasonic drilling involve the conversion of electrical energy into high-frequency mechanical vibrations through the use of piezoelectric transducers. These transducers generate ultrasonic waves, typically in the range of 20 kHz to 50 kHz, which are then transmitted to the drill bit. As the drill bit contacts the workpiece, the ultrasonic vibrations create microscopic fractures and remove material in a highly efficient and controlled manner.

One of the major advantages of ultrasonic drilling is its ability to enhance the drilling process in challenging materials, such as brittle or hard-to-machine substances. By introducing ultrasonic vibrations, the drilling forces are significantly reduced, minimizing the risk of tool wear and workpiece damage. Additionally, the reduced frictional forces allow for higher drilling speeds and increased accuracy, resulting in improved productivity and precision. The applications of ultrasonic drilling are diverse and expanding across multiple industries. In the aerospace sector, ultrasonic drilling has been employed for the fabrication of turbine blades and engine components made of superalloys. The semiconductor industry utilizes ultrasonic drilling for precision hole drilling in electronic substrates.

In conclusion, ultrasonic drilling represents a promising advancement in the field of machining, offering numerous benefits over traditional drilling methods. Its ability to enhance productivity, accuracy, and tool longevity makes it a valuable tool in various industries. As research and technology continue to advance, further developments and optimizations in ultrasonic drilling are anticipated, enabling even more complex and demanding drilling tasks to be accomplished efficiently and effectively.

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Chapter-I

Introduction

Drilling is a fundamental machining operation used in various industries for creating holes in workpieces. Achieving desirable surface roughness and circularity index is crucial for ensuring the functional and aesthetic quality of the drilled holes. Traditional drilling methods, however, often struggle to attain the desired surface finish due to inherent limitations such as tool wear, heat generation, and material properties. To overcome these challenges, researchers and engineers have turned to ultrasonic vibration-assisted drilling as a promising technique to improve surface quality. This paper aims to investigate the effect of ultrasonic vibration-assisted drilling on surface roughness and circularity index, highlighting its potential for enhancing drilling performance. The mechanical phenomenon where a particle oscillates up and down staying in the same position while transferring energy from one place to another is called vibration. It is a type of periodic motion where the particles always pass through an equilibrium point at a certain amount of time. Vibration can be induced in many ways. Some of them are free, forced and damped. In our experiment we used forced vibration with the help of inducing ultrasonic frequency. Ultrasonic frequencies are those above 20 kHz, way more than the human auditory range. Vibrations emitted from emitting these types of frequencies have significant impact on machining process. In our case the frequencies ranged from 0 kHz to 80 kHz. These vibrations cancel out the vibrations generated from the machining process themselves. They help removing materials off the surface with great ease and precision by reducing the low amplitude vibrations by the high frequency ones. The grain sizes for abrasive substance range between 100 and 1000, with the smaller ones producing smoother surface finishes. Ultrasonic vibration machining is done on brittle materials due to their tendency of micro cracking. It also has uses for materials with varying levels of brittleness and sensitivity than typical machining metals because it doesn't use methods that could change the physical properties of a workpiece, including thermal, chemical, or electrical processes as well as create parts with high precision from hard, brittle materials that are often challenging to manufacture. Surface Roughness is the measure of the quality of a surface being smooth or not. Ultrasonic techniques are often used to machine materials like ceramics, carbides, glass, valuable stones, and hardened steels. It can create materials that cannot be produces using alternative methods like electrical discharge machining and electrochemical machining.

As there is no material distortion throughout the working process, ultrasonic machining can manufacture high-tolerance parts. The lack of distortion is a result of no heat being generated by the emitters in contact with the work piece, which is helpful because the part's physical characteristics will remain constant throughout. A final product can be produced with fewer steps because no burrs are produced during the process.

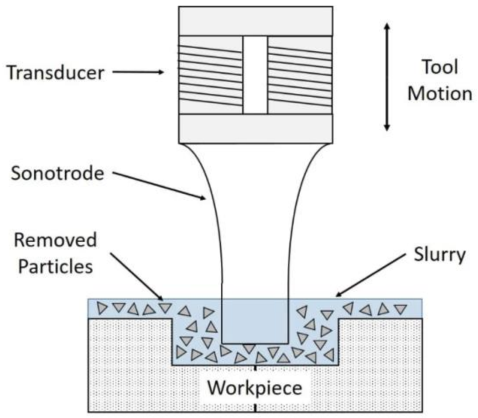


Figure 1: Various parts of an Ultrasonic Machining Process (A)

There are distinct parts on an ultrasonic machine. An electroacoustic transducer and a sonotrode, connected by a cable to an electronic control unit, make up the two main parts of an ultrasonically vibrating machine. The control unit's electronic oscillator generates an alternating current that oscillates at a high frequency, typically in the ultrasonic range. The oscillating current is transformed into a mechanical vibration by the transducer the low amplitude vibrations by the high frequency ones.

Drilling is a machining process where a drill bit is rotated at extremely high speeds to cut a circular hole through a surface constituting of varied materials. The drill bit is a multipoint cutting tool which is usually pressed against the workpiece. The speed, feed of the bit can be adjusted according to necessity and the types of materials used for drilling which can be automated or by human intervention. Drilling can be used to make through holes, to make countershaft, boring, counter boring etc. A drilling machine can move the tool bit to the pre requisite place, adjust the speed, feed and then by lowing it on the work piece it can be fed into the workpiece to create the desired hole on the workpiece. While doing the whole operation the workpiece must be securely placed on the worktable with the help of clamps and vice. Drilling can be done both vertically and horizontally depending on need and adjusting the position of the worktable and machine accordingly.

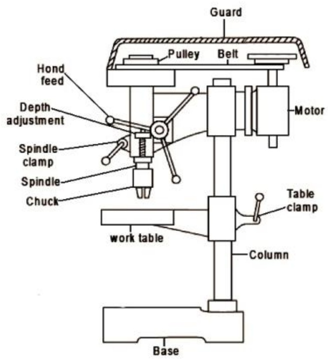


Figure 2: Drilling Machine (B)

CNC drilling machine has a few advantages such as holes can be made with high speed and precision. More holes can be made in the same time compared to earlier records. It is also easy to use and keep the operator's efficiency. They are more flexible as drills can be made at any place. Also, its maintenance cost is less compared to other operations and while keeping a long life for using. It can also be used with other operations.

Though there are advantages there are some disadvantages to drilling machining. They are:

- Only a small piece of job can be worked on
- There are chances of drill bits breaking.
- Worse surface roughness
- More chatter
- Larger chips
- More heat while drilling
- Worse circularity index
- Chances of a hole getting rough

To mitigate these problems ultrasonic machining can be used. In our instance, we employed ultrasonic drilling to compare the surface roughness of an aluminum body that had been machined while being subjected to ultrasonic vibration. A machining technique called ultrasonic vibration aided drilling (UVAD) combines conventional drilling with ultrasonic vibration in the feed direction. In this procedure, a voice-activated ultrasonic frequency generator was employed. The hole quality is affected by issues with the conventional drilling technique, including inappropriate chip evacuation, poor surface smoothness, roundness fluctuation, and high tool wear. Ultrasonic vibration-assisted drilling (UVAD) is used in this work to get around these restrictions. In our experiment, a thorough examination of the surface roughness of an aluminum plate utilizing UVAD showed that it offered improved machining performance in comparison to traditional drilling. Applying UVAD will

- Increase efficiency
- Produce high surface finish.
- Great accuracy can be reached.
- It produces less heat,
- Lengthens the life of the tool.
- Takes less time
- More cost-effective.

One of the primary advantages of ultrasonic vibration-assisted drilling is its ability to reduce cutting forces and friction between the tool and workpiece. By introducing oscillatory motion to the drill bit, the material removal process becomes more efficient and less prone to tool wear. The reduced forces and friction contribute to lower heat generation, which is known to negatively affect surface quality. Consequently, the application of ultrasonic vibrations can lead to improved surface finish and reduced surface roughness.

Furthermore, the use of ultrasonic vibrations in drilling can enhance the circularity index of the resulting holes. Traditional drilling methods often introduce irregularities in the shape and geometry of the holes due to the inherent nature of the process. With ultrasonic vibration-assisted drilling, the oscillatory motion helps to minimize deviations, resulting in more precise and circular holes. This improvement in circularity index is particularly critical in industries such as aerospace, automotive, and medical, where tight tolerances and precise hole geometries are required. Several factors can influence the effectiveness of ultrasonic vibration-assisted drilling on surface roughness and circularity index. These factors include the amplitude and frequency of the ultrasonic vibrations, drilling parameters (e.g., feed rate, cutting speed), tool geometry, and material properties. Understanding the interplay between these parameters and their impact on surface quality is essential for optimizing the ultrasonic vibration-assisted drilling process.

In conclusion, the exploration of ultrasonic vibration-assisted drilling as a means to improve surface roughness and circularity index holds significant promise. By harnessing the benefits of ultrasonic vibrations, this technique has the potential to enhance drilling performance in terms of surface finish and hole geometry. Through systematic investigation and analysis, this paper aims to contribute to the understanding of the effects of ultrasonic vibration-assisted drilling on surface roughness and circularity index, providing valuable insights for researchers, engineers, and practitioners in the field of machining.

1.1 Expected Outcome

High-frequency vibration-assisted drilling, has altered both the drilling technique and the conditions under which the drilled chips develop. The cutting force, friction, and heat generated while cutting are all decreased. The machined surface is of higher quality, bit wear is reduced, and bit durability is increased. The chip length is lower and chip break-off is more helpful, increasing the rate of material removal. With an increase in UVAD vibrating frequency and amplitude, the hole oversize, displacement of the hole center, and surface roughness of the drilled wall are all reduced.

1.2 Objectives

- Apply ultrasonic vibration-assisted drilling (USVAD) and observe the drill hole. The aim is to get proper chip evacuation, better surface roughness and exact roundness.
- Use continuous drilling process for the desired shorter chip formation which is easily removable.
- Obtain the correct roundness of the hole seeing the circular indexes for different ultrasonic vibration.
- Measure the surface roughness of drill holes done by different frequencies with profilometer.
- Compare the surface roughness's found in the experiment figuring out the frequency for the best surface roughness of the Aluminum

1.3 Thesis Organization

In our experiment, Ultrasonic voice aided sound has been used in the drilling process. For this, a separate voice module setup was introduced that influences the whole drilling process.

Description of Voice module: In our module, the entire system was based upon a printed circuit board (PCB). The module consists of several parts such as LED display, two emitters, a microphone, microcontrollers, push buttons, etc. The frequency values were given as the input through the microphone, which were shown in the LED display. The module was trained for 5 different values of frequencies (0, 20,40,60,80 kHz) are taken as inputs through human voice. For pursuing the experiment, we had to mount the emitters in two orientations. Two emitters were used for the frequency to be exerted. Experiment was at first done with those emitters keeping between the relative motion of the tool tip and the workpiece and the other part of the experiment was conducted keeping the emitters at the shank side. For the mounting of those emitters, separate mounting method was introduced to hold the emitters.

The workpiece was attached transversely with the vice. The 10 mm (about 0.39 in) drill bit was used to make 5 holes using 5 different frequencies as discussed in the orientation part in two distinct positions to see the outcomes achieved by these two different orientations. Rpm and feed were fixed at 600 and 120 mm/rev respectively and command was given with the CNC's central processing unit and keeping these parameters as this, the drilling operation was pursued. The distance between each hole was kept exactly at 1.5 mm and the workpiece thickness was 21mm. Circularity index was measured with the help of solidworks. Then with the help of a saw, the holes were cut apart to a cross-section and surface roughness was measured by an instrument called profilometer. After finishing all the proceedings, circularity and surface roughness were compared among the holes drilled with both of the orientations that are explained in our work. The whole experiment was divided into two parts. For the first half of the experiment, the spindle speed and the feed rate were kept constant whereas the frequency values were varied. So, the results were derived only with respect to the frequency. In the second half of the experiment, all the parameters used in the experiment were kept variable. So, in this part of the experiment, the outcomes which were circularity index and surface were measured with respect to the variable parameters which were spindle speed (RPM), feed rate and frequency. After the completion of the whole experiment, change in circularity index and surface roughness was measured individually with respect to RPM, feed rate and frequency. And thus, the most desirable outcomes were observed. In organizing the whole experiment in this paper, about 33 novel literatures have been reviewed to have the idea of relevant parameters. In chapter 3, experimental setup was introduced with proper schematics and diagrams along with the flowcharts, orientation about how the emitters from which the vibration will be emitted were set and two sets of machining parameters one of which is for the fixed parameters and the other is on the variable parameters. Next the specification of the CNC machine was given by which the whole experiment has been conducted. In chapter 4, results and discussions were added with all the insights and desirable outcomes. In chapter 5, conclusion and future works have been added. The whole research is organized in the sequence below:

1. Literature review: In this section relevant publications are discussed briefly in order to get the idea of the trend of is going on around in this research discipline.

2. Experimental Set up: In this section all the methods and procedures which are related to this study is discussed in detail

3. Result and Discussion: In this section of the thesis the outcome of the study is illustrated with their adequate significance

4. Conclusion and recommendation for further study: This section deals with the concluding outcomes of the research and recommends the further scope of research in this field

5. Bibliography: Reference of all the research work and publications are mentioned in this chapter.

Chapter-II

Literature Review

Many studies have been published on ultrasonic vibration assisted drilling. They have tried many ways including different methods of drilling, different orientation of drilling, different size drill bits, different feed and rpm. Some have studied about the effects of variation of feed and rpm and orientation on hole size, surface roughness, circularity etc. Others applied a specific frequency of Ultrasonic Vibration while drilling and observed the changes on the hole parameters. The most relevant studies are described here.

M. Willert et al. [1]explained ultrasonic assisted diamond cutting procedure. As the diamond tool utilization for creating optical molds is still hindered by the significant tool wear, they experience when machining steel and creating tools for injection molded objects with complex geometry and good surface quality is quite difficult, the authors established the most suitable method, ultrasonic assisted diamond cutting to prevent tool wear. S. Chen et al.[2] performed Ultrasonic assisted vibration drilling to improve the surface finish for drilled holes. It was found that it reduced the tool wear improving the quality of drilling and also induces a better chip breaking effect. M. Lotfi and S. Amini et al. [3] applied Harmonic movement on the drill bit to investigate heat generation and found that interrupted movement of drill bit caused less heat generation, lower built-up edge, linear motion of tool increases chances of chips breaking and increase chip strain. Y. S. Liao et al. [4] performed the research and found that chip size and the torque required for drilling was reduced in the ultrasonic vibration assisted drilling of Inconel superalloy. Findings showed that tool life gets increased for a shorter amplitude. The best performance was found for frequency of 31.5 kHz and work time was also saved greatly. E. Yarar and S. Karabay et al. [5]determined the effects of cutting parameters on various scenarios, such as surface roughness, tool wear, etc., ultrasonic assisted drilling was performed on two distinct types of heat treated AA6061 materials, namely T6 and T1. Both TiN-coated and uncoated HSS-G drill bits were used in this project. Different effect graphs were produced once the experiment's findings were analyzed. The best drilling parameters were determined to be AA6061-T6, uncoated HSS-G drill bits, 1520 rpm spindle speed, and maximum ultrasonic vibration frequency at 22.5 kHz. Cutting force and surface roughness were also optimized. The authors found that though surface roughness increased with increased cutting forces, the spindle speed does not have a significant effect on this, chip formation is also better in T6 than T1 and uncoated HSS-G is more potent than TiN coated one. Results showed that though ultrasonic assisted drilling at high frequencies reduced cutting forces and surface roughness, it increased in low frequency ones, it also reduced build up edge formation. O. Georgi et al. [6] explained that UA enables less tool wear, enhanced chip breaking and burr reduction. Experiment was done on both continuous and intermittent cutting conditions. It was found that UAD leads to shorter chips but while intermittent it leads to needle chips, it also produces instability using acoustic measurement and UAD can lead to negative clearance angles and plowing effects. Results showed that depending on the shaft geometry of the tools, superimposed vibrations occur and UAD with disabled modulation produces shorter chips too, which is supposed to be related to the increase of chip curvature in UAD. J. Rajaguru and N. Arunachalam et al. [7] imparted the high-frequency vibrations into the ASTM A36 steel to induce reciprocating motion, which is mounted over a transducer. A special fixture arrangement was fabricated to hold the transducer in the drill bed. Results suggested that a reduction in cutting force and torque was observed for UVADD. Hole quality showed a drastic decrease in burr formation and surface roughness along with a uniform radius around the periphery. As this drilling process encounters problems such as improper chip evacuation, poor surface finish, roundness variation, and high tool wear, which affects the hole quality, their observation suggested that ultrasonic vibration-assisted drilling (UVADD) led to effective penetration of coolant, thereby reducing the cutting temperature and tool wear. The enhanced performance by UVADD also reduced the friction and built-up edge formation on the cutting edges. G. L. Chern and H. J. Lee et al. [8] investigated the effects of assisted vibration on the drilling quality of aluminum alloy (Al 6061-T6) and structure steel (SS41). In the past, research methodology of vibration drilling on small-diameter holes has mainly involved vibrating from the spindle side. The authors showed a new approach to obtain the desired vibration proposed from the workpiece side, by a self-made, vibrating worktable. S. Chen et al. [9]showed an investigation on the thickness analysis of chips, chip shapes in conventional and ultrasonic assisted drilling. A comparative difference of CD and UAD in tool wear and surface quality was analyzed. The results showed that chip shape in CD is hard wearing, bigger and wraps in the region of the drill. On the other hand, chips made in UAD is smoother and it doesn't hold any jagged edge like CD.UAD decreases tool wear and the experiments showed that amplitude of 25μm causes the minimum tool wear in UAD. After illustrating the surface roughness curve for different amplitude and rotating speed, the authors found that surface quality in UAD is better than CD. Y. Tian et al. [10] analyzed the tool wear of Ti-6Al-4V alloy. Using longitudinal torsional composite UAD on this alloy and the results showed that it reduces tool wear in drilling over conventional drilling process. After analyzing the separation cutting in LT-UAD a periodic curve was found which indicates that it reduces cutting force and cutting heat in ultrasonic assisted drilling. A vibration converter was designed for different parameters. It proved that UAD can convert more effectively the longitudinal vibration into L-T composite vibration. X. Peng et al. [11] explained different mechanism of ultrasonic vibration assisted drilling rock and analyzed the ultrasonic and mechanical energy in the process of ultrasonic vibration assisted drilling. Three rocks named travertine, marble and basalt was taken to drill for experimental purpose. As the wight on bit (WOB) in UAD remains smaller than conventional drilling, drilling process gets easier and findings showed that experiments conducted on the rocks showed improved drilling performance. Different equations of energy in ultrasonic drilling process as energy density over the arbor, energy flow density, ratio between ultrasonic and mechanical energy was developed. Results showed that optimization of assistant effect of ultrasonic vibration and drilling efficiency is an important task in the drilling process. J. Pujana et al. [12] analyzed different parameters in the ultrasonic assisted drilling of Ti-6Al-4V. The findings showed in the vibration system feed force decreased in the order of 20% for ultrasonic vibration. Figures of chip formation with and without ultrasonic vibration were taken to compare. In the process of temperature measurement applying vibration of 9μm resulted that Ti-6Al-4V needed the feed force which is 10-20% less and the temperature of the tool was high. W. Huang *et al.* [13] observed the tool wear of Carbon fiber reinforced polymers with high-speed twist drill using the ultrasonic spindle. Comparing the tool wear in 3 different types or drilling as conventional drilling, rotary ultrasonic drilling and high-speed drilling marked that rotary ultrasonic drilling provides best performance in CFRP. Evaluating the tool wear in two methods revealed that ultrasonic drilling gives better output. On the cutting edge and non-worm area, the flank face gets smaller adhesion of matrix and chips in UAD over conventional drilling. Analyzing EDS also showed that in UAD, the oxidation wear of the tool used in drill is lower than CD. This verified that UAD generates less temperature which is very efficient. Y. Wang et al. [14] found that Hard and brittle materials can be processed effectively using ultrasonic vibration assisted grinding (UAG) and UAG improves both work piece grinding power and surface quality. In this research, a mathematical model for system alignment in UAG of brittle materials is presented in order to gain insight on the mechanism of grinding force reduction and grinding quality enhancement in UAG. V. V. Silberschmidt et al. [15] researched and found that ultrasonically assisted machine is a hybrid technique that has a relatively smaller amplitude (20 microns) of vibrations. The authors presented an analysis of the effects of ultrasonic assisted turning (UAT) on the surface roughness of a wide range of metals and alloys, from copper, aluminum and stainless steels to Ni and Ti based alloys. Results showed that Hybrid Turning Technology UAT – yields significant improvements in surface roughness for all alloys studied, primarily due to the inherent reduction in cutting forces. Z. Feng and F. Jiao et al [16]showed how to fix the problems of tearing and burr damage of carbon fiber reinforced plastics using UVAD with different speeds, cutting ability gets improved, stiffness value is also larger in this process. S. Amini et al. [17] investigated that using UVAD gives better surface quality, thrust force is decreased to 35%, chip formation was also satisfactory. After designing a longitudinal torsional vibratory tool, different experiments were performed. Findings showed that for aeronautical materials, where conventional drilling creates several difficulties. J. Akbari et al. [18] performed different experiments in ultrasonic assisted drilling of Inconel 738-LC to visualize the improvement of hole quality comparing with conventional drilling. Different spindle speeds, feed rates were applied and the drill hole was analysed.60% improvement was found in average surface roughness and circularity. Hole oversize and chip formation were also better for UVAD. Y. Feng et al. [19] investigated the dynamical properties of TiBw/TC4 composite using UVAD. Forming a single directional three degree of freedom dynamical system, the drilling results were analyzed. Results showed that the deformation of drilling system gets more simplified forming a damping system. Tool vibration curves signified the effect of UVAD as measured and fitted amplitudes become 0.1124 and 0.1151mm with 2.402% difference. For stability of the machine in UVAD, amplitude of ultrasonic vibration shows improved result. M.A. Kadivar et al. [20] analyzed the performance of UVAD over conventional drilling for cutting force. Drill hole was created for different feed rates and cutting speeds using UVAD. Results showed that thrust force gets reduced comparing with conventional drilling. But when the time is extended, thrust force was increased for tool wear and the distance from peak point of vibration. S.H. Alavi et al. [21] showed that convective heat transfer increases for UVAD. For greater amplitude, the expulsion of melt gets increased efficiently. Application of Ultrasonic Vibration Assisted Drilling provides higher aspect ratio holes. It is also observed that lower power is required for laser drilling. G.M. Bone et al. [22] represented a novel analytical burr height model of aluminum 6061-T6 for UVAD and conventional drilling. The model shows an improved result for the existing analytical burr height and accuracy is improved by 36% over conventional drilling process. Also, for the prediction of favorable vibration frequency, this model with UVAD is accurate. V.I. Babitsky et al. [23] presented experimental and numerical simulation with the application of UVAD and found strong vibration mode conversion characteristics for the drill bit. Several considerations and requirement were found from the analysis as the development of a vibrating system is required for experimental and numerical simulation. M.A. Short et al. [24] performed drilling tests on 4340 steels with the application of UVAD in CNC system. After the experiments done, results showed that torque and the thrust force both are reduced by 24 and 42%. Also, the surface roughness of the hole gets improved by 53% and the chip removal process is more convenient for better chip formation. M. A. Moghaddas [25] et al. compared five different temperature measuring methods and came to the conclusion that embedded thermocouples in the drill's cooling channels produce the best accurate data. Without using coolant, a preliminary investigation into the impact of ultrasonic vibrations on the heat produced in UAD for aluminum 6061, alloy steel 4340, and stainless steel 316 revealed that increasing vibration amplitude decreased force while increasing heat was produced.

V.I. Babitsky et al. [26] demonstrated that adding ultrasonic vibrations to drilling bits significantly enhances their cutting performance by increasing cutting efficiency and lowering cutting forces. The dynamic properties of the transducer and drill bit must be matched with the dynamic loads generated by the cutting process in order for this technology to be successfully applied. This stable generation and maintenance of an intense nonlinear resonant mode of vibration is possible with an auto-resonant control system.

Mohammad Baraheni et al. [27] compared the effectiveness of conventional friction drilling (CFD) and ultrasonic friction drilling (UFD) on aluminum plates through experimental and numerical analysis. The findings showed that axial force is decreased and surface hardness is increased by ultrasonic vibration. Also, axial force and surface hardness values are mainly affected by feed rate, while rotating speed and ultrasonic vibration are important factors. The experimental results were confirmed by finite element analysis, which showed that ultrasonic vibration can enhance frictional drilling.

Ngoc-Hung Chu et al. [28] developed a new approach for understanding torque variations in depth drilling the cutting, rubbing, and stick-slip torque components were separated from the overall torque. Al6061-T6 dry drilling with ultrasonic-assisted deep drilling (UAD) was shown to improve machinability. In comparison to conventional drilling, UAD demonstrated a decrease in rubbing and stick-slip torque, leading to higher rates of material removal and deep drilling.

Khaled Giasin et al. [29] examined how GLARE fiber metal laminates are affected by ultrasonic-assisted drilling. According to the study, UAD drilling can lower thrust force by up to 65% when compared to traditional twist drilling. Indicating that the use of vibration during drilling of GLARE laminates will not considerably improve the surface quality, surface roughness values were comparable under CD and UAD regimes. For reducing thrust force, a low feed rate and a high spindle speed were suggested.

Hossein Paktinat et al. [30] investigated the advantages of ultrasonic-assisted drilling (UAD) over conventional drilling (CD) through experimental and numerical methods, UAD demonstrated a notable decrease in thrust force, and up to 40% improvement in drill circularity, and a decrease in temperature and pressure in the machining zone. The study showed that chips are produced in small segments with lower deformed chip thickness in UAD, also UAD has clear advantages over CD, except for the initial cost of preparing ultrasonic devices.

Song Dong et al. [31]studied burr development in RRUD of CFRP/aluminum stacks and showed a prediction model for burr height. The model has two steps: "RRUD parameters to thrust force" and "thrust force to burr height," and considers various factors. The predicted values from the model can be utilized for predicting burr height in RRUD of CFRP/aluminum stacks and relate well with experimental findings.

X. Li et al. [32]compared three feedback control strategies in ultrasonic vibration machining: mechanical feedback, electrical feedback, and power feedback. The application of autoresonant control technology is constrained by the ultrasonic transducer's driving power, although mechanical feedback showed greater control over the other two options. The effectiveness of electrical feedback is affected by the size of the drill bit. In order to increase the linear operation zone of supplied voltage and mechanical vibrations, further study in the design of an ultrasonic transducer's actuation parts is recommended.

Chao Quan Wu et al. [33] examined the impact of various drilling circumstances on delamination in CFRP drilling with an emphasis on internal delamination damage. The results showed that increasing feed rates and conventional drilling can lead to delamination and spindle speed and workpiece supports can reduce it. Additionally, delamination at the hole exit can be avoided with variable feed rate drilling.

Summary

We can observe that numerous studies have been conducted to reduce surface roughness. Different process parameters, such as feed, depth of cut, cutting speed, etc., have been utilized for this to select different settings. Additionally, a number of methods have been created to lessen the machining responses, such as surface roughness, that may have been attained with conventional drilling. Ultrasonic aided drilling is one such method that has shown a lot of promise (UAD). Therefore, the author of this study has attempted to develop a novel method of applying ultrasonic sound waves externally. Here, the external machining vibrations and the ultrasonic air waves interacted. In order to evaluate the effect, a variety of cutting severity levels were-used-in-this-experiment.

Chapter III

Experimental setup

This paper portrayed the impact of an ultrasonic sound signal during drilling of an aluminum metal. After applying the impact of ultrasound, a suitable outcome was discovered. There are two modules for producing ultrasonic sound effects. The outcome of regular cutting was discovered to be considerably worse than the ultrasonic sound effect. There have been many changes discovered when assessing surface roughness and circularity.

The figure below shows the Ultrasonic sound emitting device:

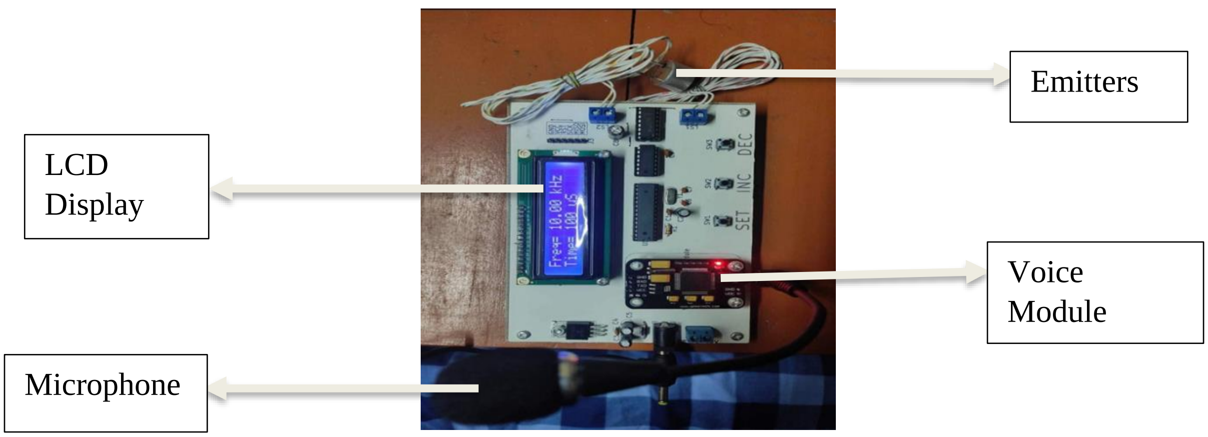


Figure 3: Ultrasonic Sound Emitting Device

Specification of the components:

16x2 Character LCD with LED Backlight	
Size	85.0 x 29.5 x 13.5 mm
Viewing Area	64.5 x 16.4 mm
Minimum logic voltage	4.5 V
Supply Current	2 mA

Table 1: Specification of LCD Display

Voice Recognition Module Kit V3	
Input Supply Voltage	4.5-5.5 V
Current	<40 mA
Digital Interface	5V TTL level
Dimensions	6 x 8 x 2 cm

Table 2: Specification of Voice Recognition Module with Microphone

The complete circuit diagram of the ultrasonic device is given below:

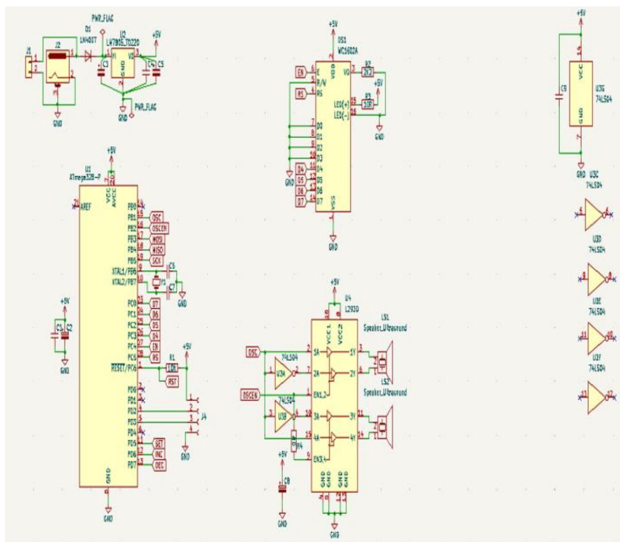
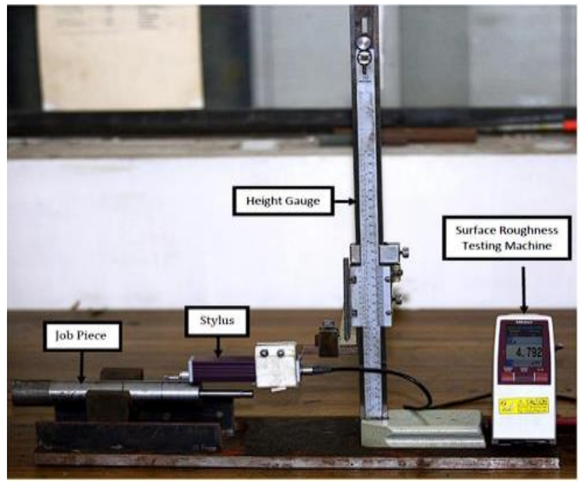


Figure 4: Complete circuit diagram of the ultrasonic sound emitting device.

The surface roughness was tested using the **profilometer**. It was mounted vertically on a stand over the plate. When turned on, the needle on the tip of the device moves back and forth. This was done on different locations of the drilled holes by adjusting the location of the needle. After coming back and forth for some time it spits out the result and displays on the screen.



A B

Figure 5: (A)Image of Mitutoyo SURFTEST SJ 210-Profilometer (B)Mounting of Profilometer over the plate

Mitutoyo Surface Roughness Tester SJ-210	
Measuring Range	16mm
Cable Length	1m
Measuring Speed	.25 mm/s
Power Supply	7.5 V

Table 3: Surface Roughness Tester SJ-210

3.1 Flowchart:

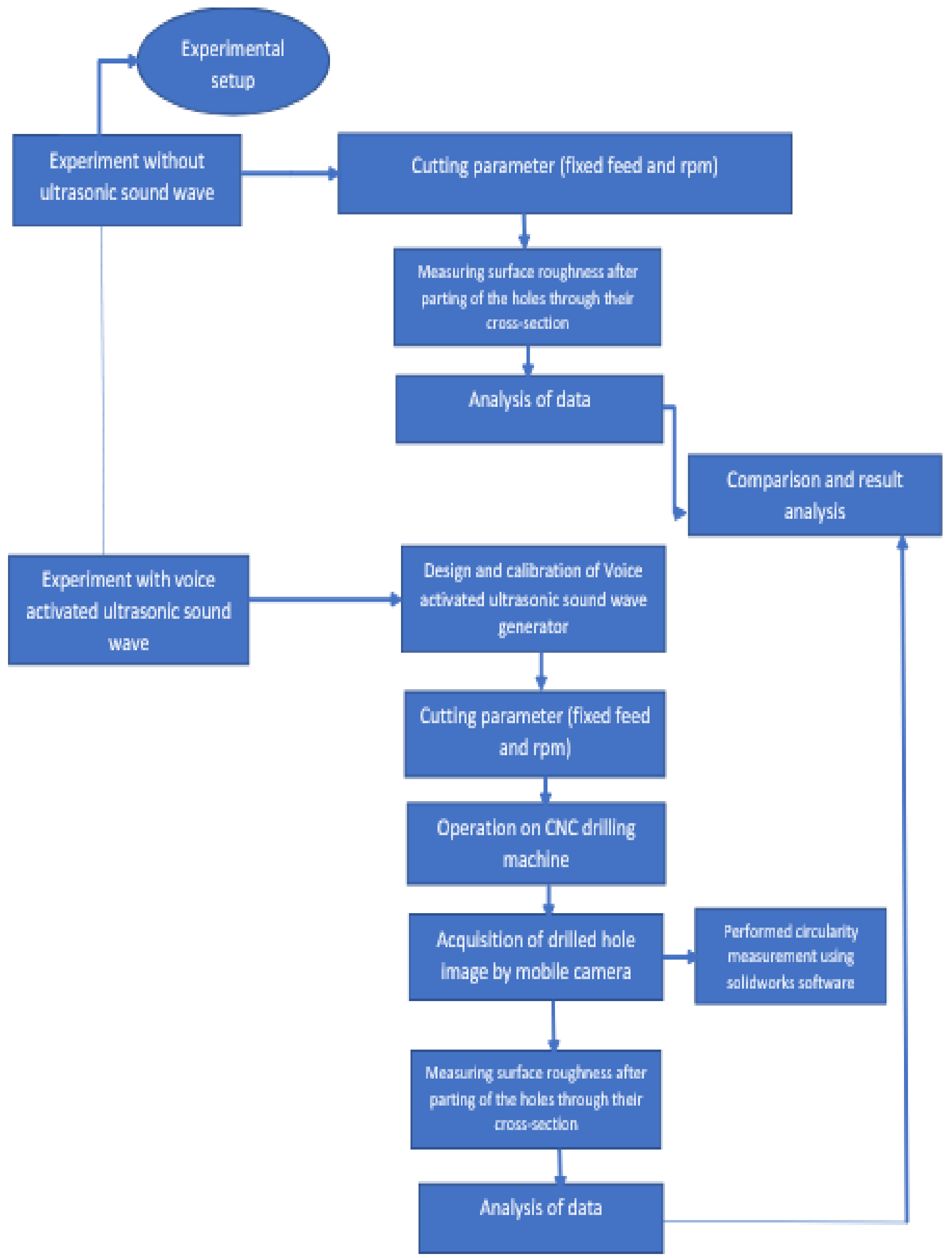


Figure 6: Flow diagram of the work procedure

3.2 Orientation:

The above module was used for generating frequency for this experiment. In two ways the frequencies were exerted upon the tool. Two emitters were used for the frequency to be exerted. Experiment was at first done with those emitters keeping between the relative motion of the tool tip and the workpiece and the other part of the experiment was conducted keeping the emitters at the shank side.

(a) (b)

Figure 7: (a) On the workpiece (b) On the spindle

This is the second orientation of the experiment as described in its description. Two C shaped brackets were made and then they were drilled to hold the two emitters between then. The module was kept resting for easy access to the microphone.

3.3 MACHINING PARAMETERS

Speed and feed are the main considerations in any drilling operation. Although there are added factors that affect the cutting conditions, such as the type of material used, the material of the tools, and the coolant used, these are the ones that can be adjusted by changing the controls in the machine.

Throughout the first half of the experiment, feed and speed have remained unchanged. The only parameter that was changed during the experiment was the sound wave's frequency because the entire process took place in the presence of ultrasonic sound waves. The term "feed" is always used to describe the cutting tool and describes how quickly it travels down its cutting path. The feed rate, which is measured in millimeters (mm) per spindle revolution, or mm/rev, is related to spindle speed. In the second half of the experiment, spindle speed, feed rate and frequencies were varied and based on these variables, outcomes were measured.

3.4 Specified parameters:

Spindle speed	600 RPM
Feed	120 mm/min
Frequency	0, 20, 40, 60, 80 kHz
Drill Diameter	10mm
Workpiece	Aluminum

Table 4: Fixed Parameters (Spindle Speed, Feed rate)

Here frequencies were taken ranging from 10 to 80 kHz. And different feed and RPMs were taken with the associated frequencies. This was done in order to find the effects of varying RPMs and feed on the circularity of the hole and also the surface roughness. For 10 kHz we took one rpm and feed, for 15 we took two, for 30 we took different feed for the same rpm and also varied the rpm from most to least, two were taken for 60 and one was taken for 80 kHz.

Frequency(kHz)	RPM	Feed(mm/min)
10	550	90
15	850	130
15	360	60
30	550	90
30	1000	90
30	550	150
30	550	50
30	550	90
30	300	90
60	850	60
60	360	130
80	550	90

Table 5: Variable Parameters (Spindle Speed, Feed rate, Frequency)

3.5 CNC Machine Specification:

CNC Drilling Machine (Table Type)	
Z height	350 mm
Positioning Accuracy	±0.1 mm
Drilling Capacity	Ø6~50 mm
Rotation Speed	10 ~ 2,300 rpm

Table 6: CNC Machine Specification

Figure 8: CNC Drilling Machine (C)

Chapter IV

Results and Discussion

Table 7 shows the effect of applying frequencies on the aluminum plate ranging from 0 kHz to 80 kHz. The table shows that the smallest diameter was found for an 80 kHz frequency. We can also see that the perimeter for this specific frequency is the least which shows that the drill bit has penetrated the work piece perfectly without any types of irregularities. As the drill bit penetrated the work piece with the least issues, its effects can also be seen from the table where we can see that the surface roughness was the best for 80 kHz one and the circularity was the best.

On the work piece				
Frequency	Diameter (Exp)	Perimeter (Exp)	Circularity Index	Surface Roughness
0	10.195	32.8	0.95351278	3.6
20	10.265	34.5	0.873734456	4.58467
40	10.365	33.6	0.939203719	2.99167
60	10.26	34.2	0.888264396	2.6693
80	10.175	32.3	0.979407751	2.20167

Table 7: Effect of different frequencies on the circularity index, surface roughness while applying on aluminum plate

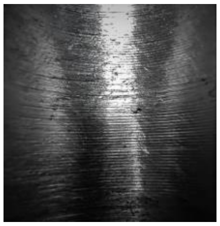
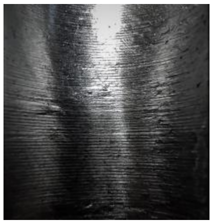
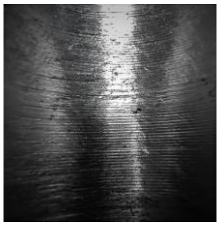
SL No	Figure	Frequency(kHz)	Feed(mm/min)	RPM	Ra(µm)
1		0	120	600	3.6
2		20	120	600	4.58467
3		40	120	600	2.99167
4		60	120	600	2.6693
5		80	120	600	2.20167

Table 8: Surface Roughness associated with their Frequencies (On the Workpiece)

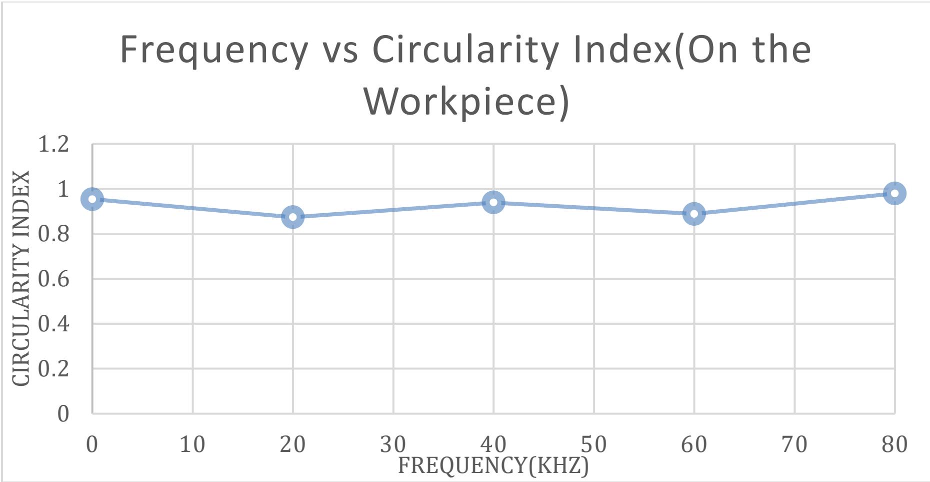


Figure 9: Frequency vs Circularity Index (on work piece)

Figure 9 depicts the change of circularity index based on the application different frequencies on the work piece. The circularity index is found to be the best for 80 kHz frequency which suggests that the frequency reduced the chatter produced while machining.

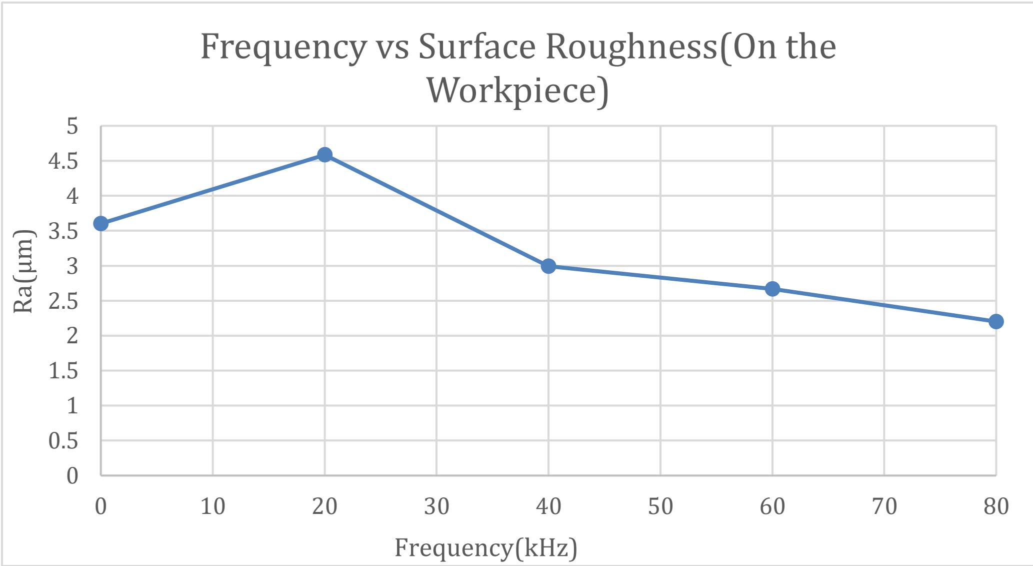


Figure 10: Frequency vs Surface Roughness (on work piece)

Figure 10 stands for the effect of frequency on surface roughness and was found in the 80 kHz one. Due to reduced chatter while machining, the drill easily penetrated the aluminum plate without issue and resulted in the best diameter close to the drill bit size.

Here are some figures of the readings of surface roughness taken by profilometer:

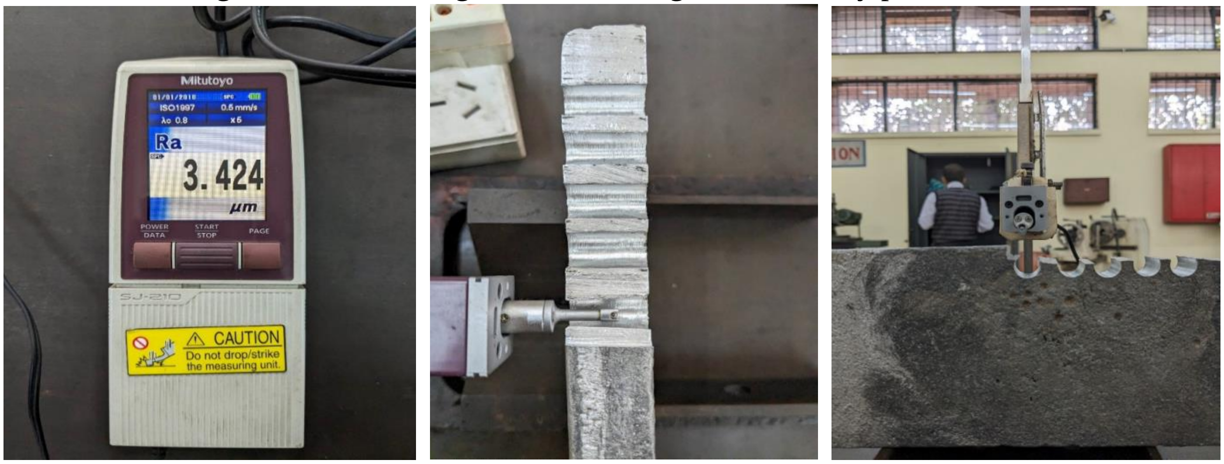


Figure 11: Vertically mounted Profilometer

The diameter taken here were taken with the help of Vernier calipers and the perimeter was measured using a string and a ruler. The circularity index was found using the formula $Circularity\ Index = \frac{4\pi A^2}{P^2}$ where A and P are the area and perimeter of the holes, respectively.

Table 9 shows the results of applying frequency on the spindle of the drill bit. The frequencies were as same as the ones applied on the plate mentioned in the above table. The diameter was found to be the best on the hole done with 80 kHz frequency. The outcome of this is the better circularity index compared to the other ones. The perimeter is also found to be the least for this hole. This shows that the chatter has been greatly reduced because of this frequency which has also allowed the drill to go through the plate more easily.

On the spindle			
Frequency	Diameter (Exp)	Perimeter (Exp)	Circularity Index
0	10.153	33.1	0.928608234
20	10.146	32.8	0.944369112
40	10.163	33.5	0.908351594
60	10.12	32.4	0.96287686
80	10.106	31.8	0.996790966

Table 9: Effect of different frequencies on the circularity index while applying on spindle of the drill

SL No.	Figure	Frequency(kHz)	Feed(mm/min)	RPM	CI
1		0	120	600	0.928608234
2		20	120	600	0.944369112
3		40	120	600	0.908351594
4		60	120	600	0.96287686
5		80	120	600	0.996790966

Table 10: Circularity Index with their associated Frequencies (On the Spindle)

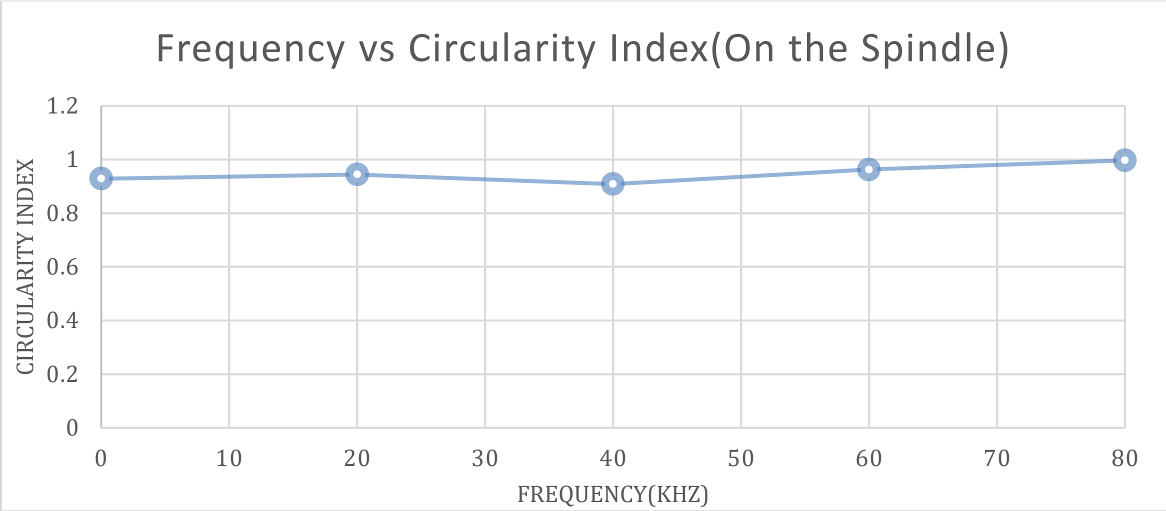


Figure 12: Frequency vs Circularity Index (on spindle)

SL No	Figure	Frequency(kHz)	Feed(mm/min)	RPM	Ra(µm)
1		0	120	600	3.3646
2		20	120	600	3.151

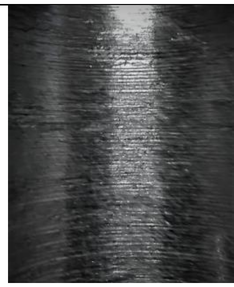
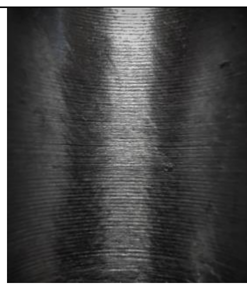
3		40	120	600	3.683
4		60	120	600	2.426
5		80	120	600	3.6846

Table 11: Surface Roughness with associated Frequencies (On the Spindle)

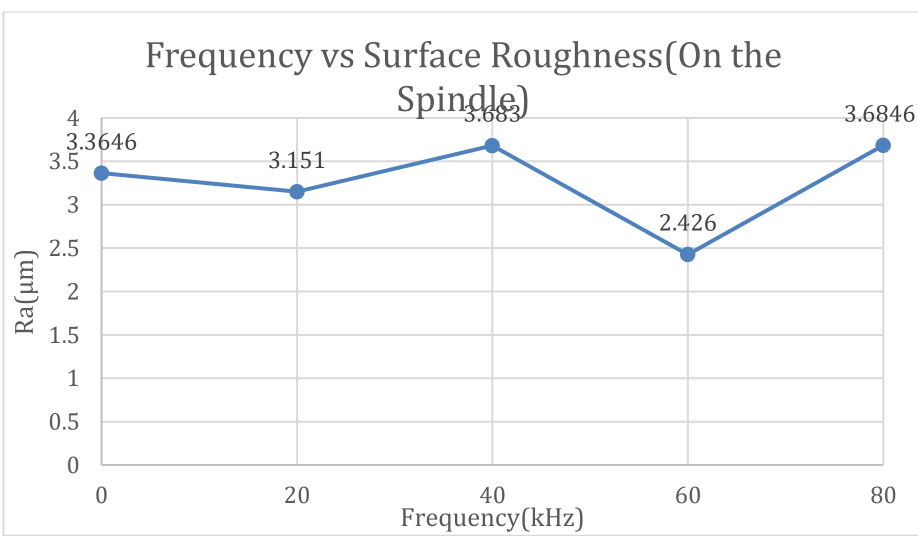


Figure 13: Frequency vs Surface Roughness (on spindle)

Figure 13 stands for the effect of frequency on surface roughness and was found in the 60 kHz one. Due to reduced chatter while machining, the drill easily penetrated the aluminum plate without issue and resulted in the best diameter close to the drill bit size.

Deviation of Surface Roughness

From the first part of the experiment, for two different orientations, deviation of the outcomes for both vertical and horizontal orientation are shown here.

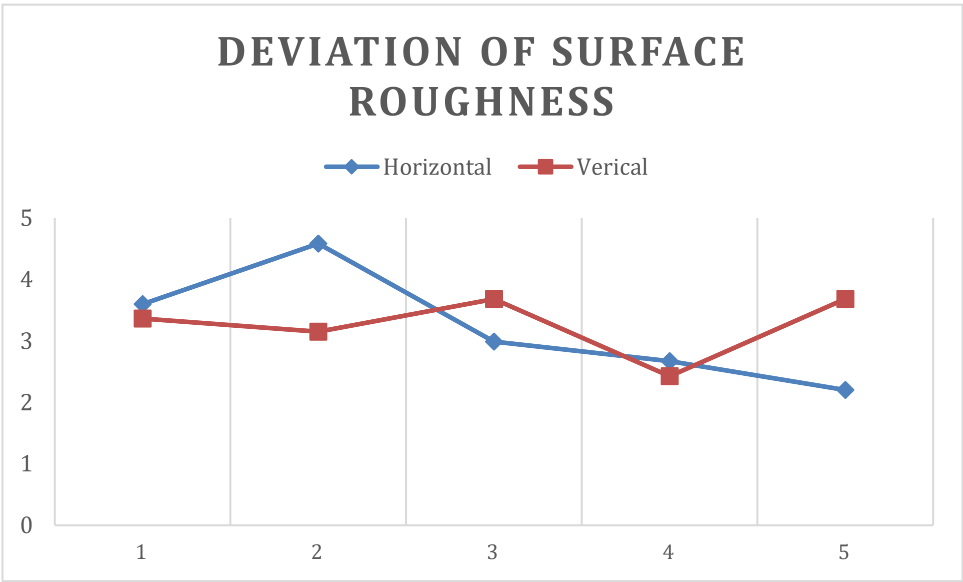


Figure 15: Deviation of surface roughness for applying frequency on the workpiece and the spindle

Deviation of Diameter taken using Software:

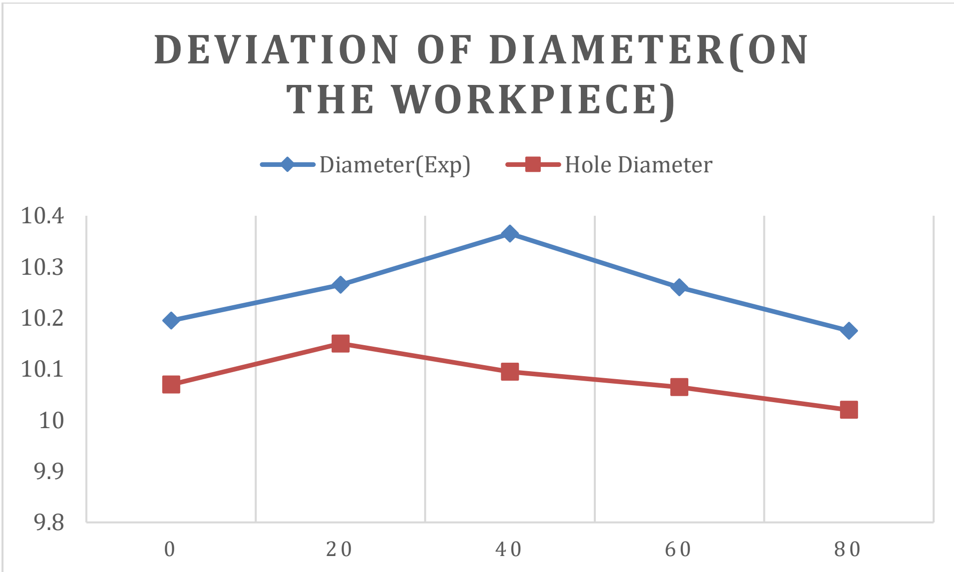


Figure 16: Deviation of diameter taken using software (Solidworks) when frequency applied on workpiece

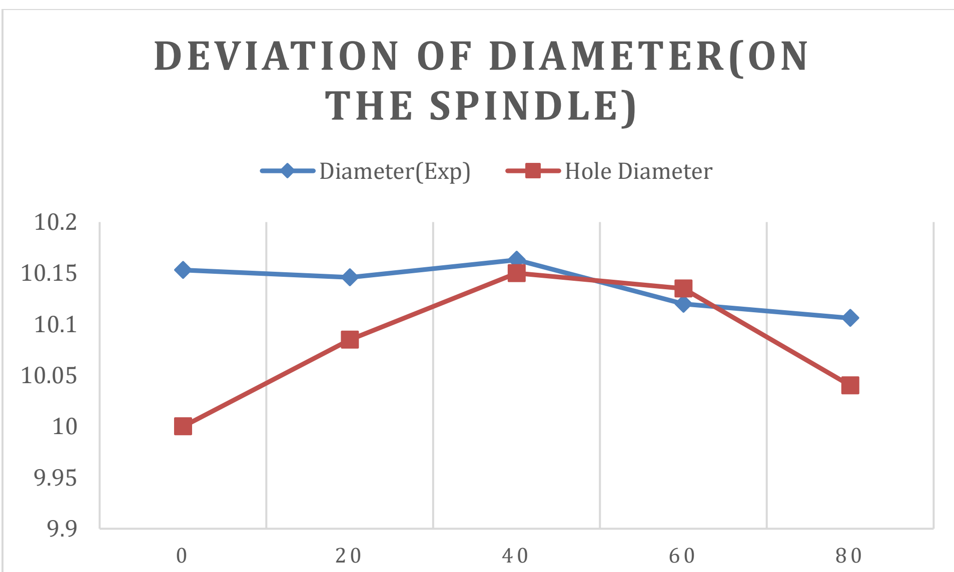


Figure 17: Deviation of diameter taken using solidworks software when frequency applied on spindle

Deviation of Diameter with respect to Drill Bit:

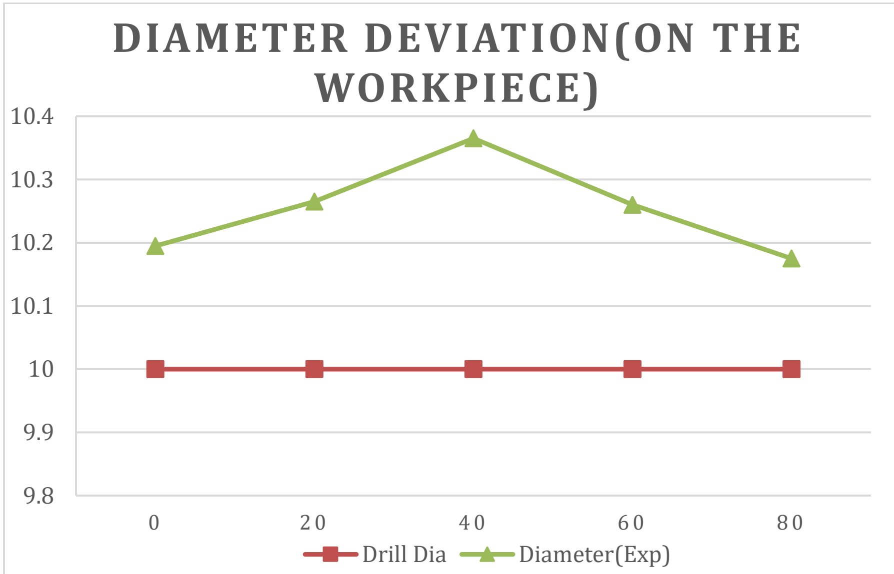


Figure 18: deviation of diameter from the experimental one to the drill bit diameter

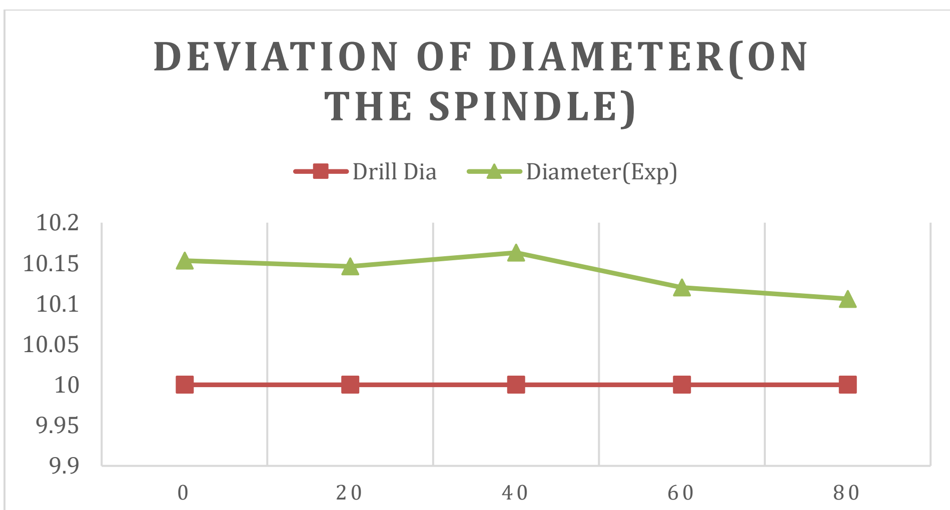


Figure 19: Deviation of diameter with drill bit when frequency applied on spindle

Deviation of Perimeter:

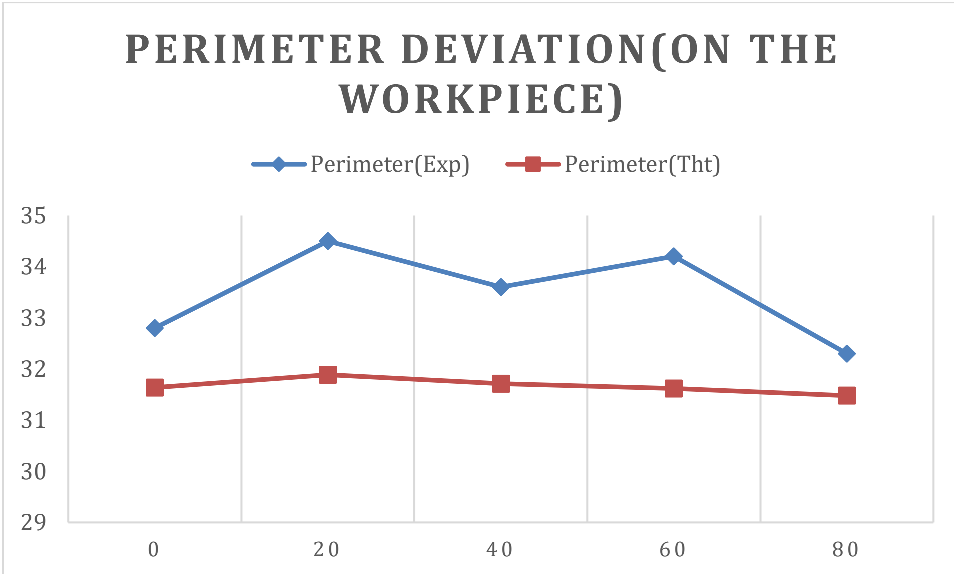


Figure 20: Deviation of Perimeter when frequency is applied on the plate

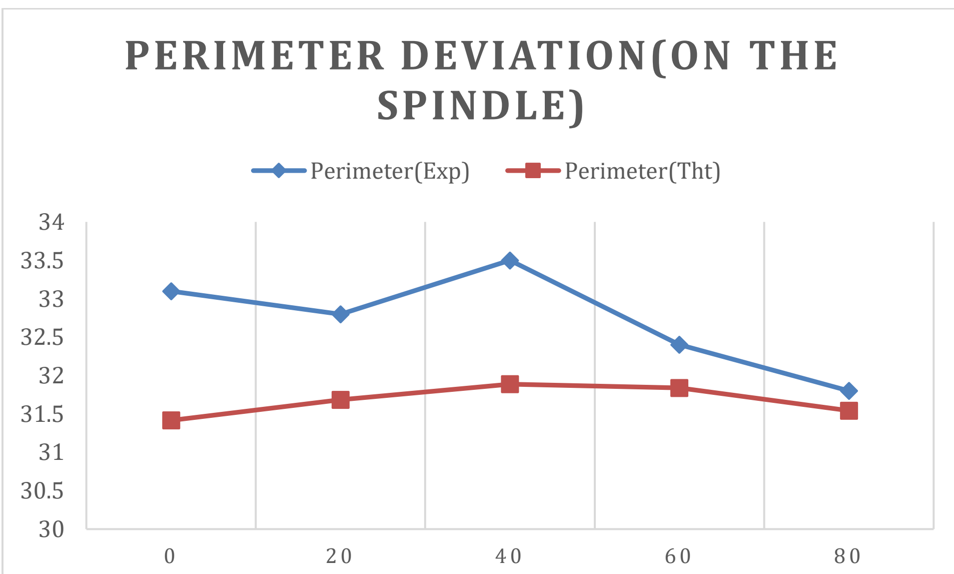


Figure 21: Deviation of Perimeter when frequency is applied on the spindle

For comparing the surface roughness of an aluminum body machined in presence of ultrasonic vibration, 5 different frequencies were applied in two orientations in this experiment. In the first orientation vibration frequencies were applied on the workpiece and secondly on the spindle of the drilling machine. Both cases, the frequencies were same. To analyze the surface roughness of the Aluminum plate all the drill holes were seen. Calculating the circularity index and surface roughness for different frequencies in both orientation it is found that for the increasing ultrasonic frequencies applied in this experiment, the surface roughness was decreasing gradually and for the highest frequency applied 80kHz, the circularity index was highest and the surface roughness was lowest. This means that for higher ultrasonic vibration frequency, surface roughness could be improved efficiently. Over conventional drilling ultrasonic assisted drilling results in much better drill performance. The hole oversize was much more improved for the higher frequency applied here. Displacement of the hole center becomes less because of ultrasonic frequency. Roundness of the drill hole also improves because of higher circularity index found applying higher ultrasonic frequency. Ultrasonic assisted drilling reduces cutting temperature and tool wear with formation of small chip with faster evacuation.

The second set of experiment was done taking variable feeds, rpm and frequencies. The parameters were taken in two ways i.e., code form which is the mathematical model which was made in correlation to our experiments and the other one is the parameter which was represented in our experiment. The data set is given below:

Code Form			Actual Form				
Frequency	RPM	Feed	RPM	Feed(mm/min)	Frequency	CI	Ra(µm)
1	1	-1	850	60	60	0.988728599	2.865
-1	1	1	850	130	15	0.979603894	2.809
1	-1	1	360	130	60	0.950249866	4.681
-1	-1	-1	360	60	15	0.99937664	2.925
0	0	0	550	90	30	0.968848175	3.805
0	0	0	550	90	30	0.968848175	3.756
0	-1.41421	0	300	90	30	0.988710063	2.533
0	1.41421	0	1000	90	30	0.974931144	2.751
-1.41421	0	0	550	90	10	0.942058516	3.113
1.41421	0	0	550	90	80	0.953181865	3.391
0	0	-1.41421	550	50	30	0.991668617	2.529
0	0	1.41421	550	150	30	0.997384858	5.044

Table 12: Second Set of Parameters

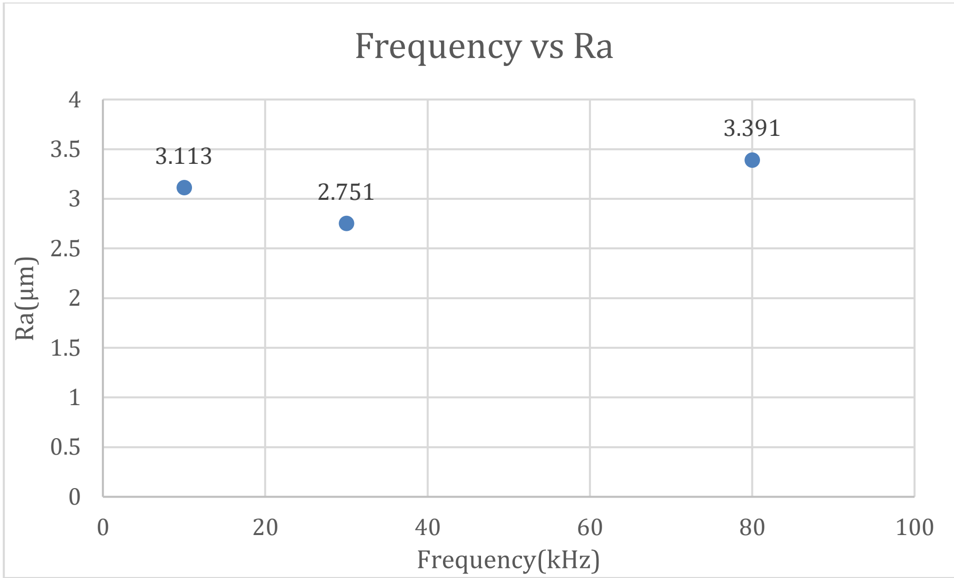


Figure 22: Frequency vs Surface Roughness

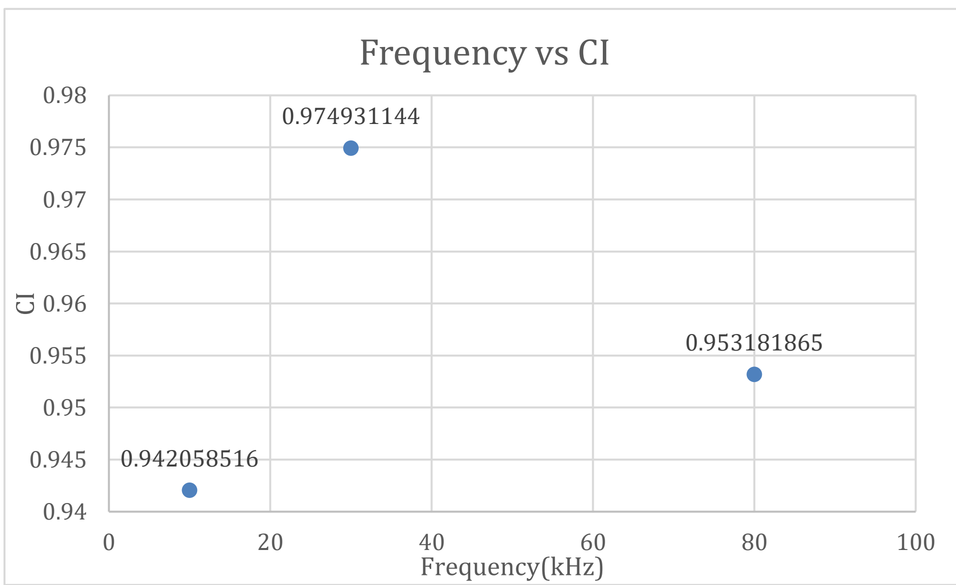


Figure 23: Frequency vs Circularity Index

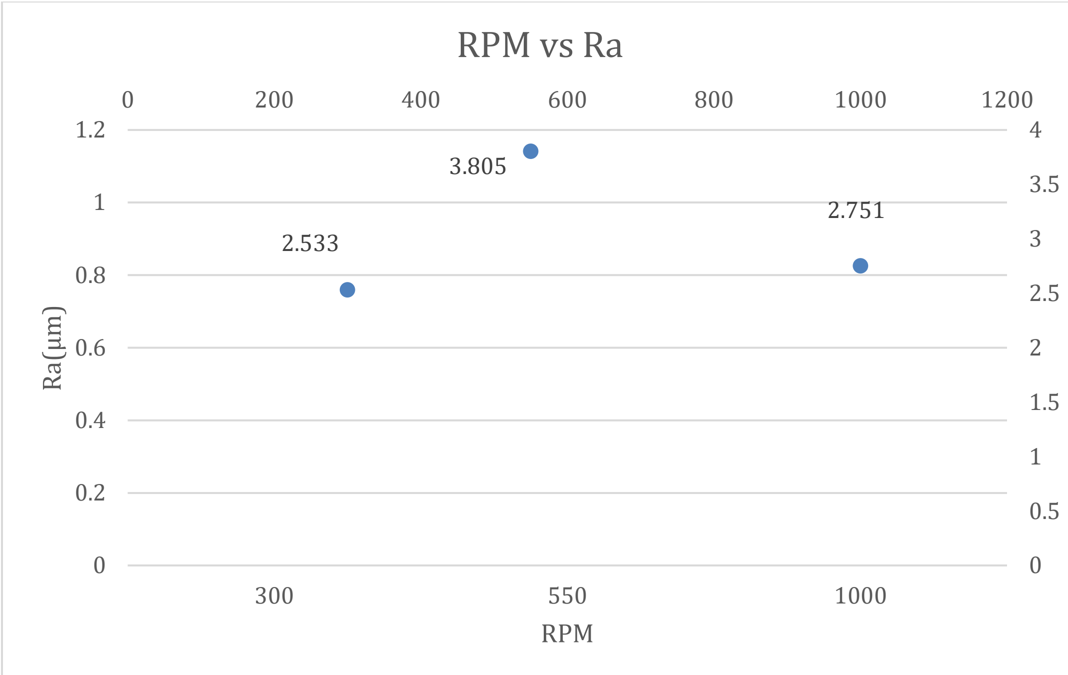


Figure 24: RPM vs Surface Roughness

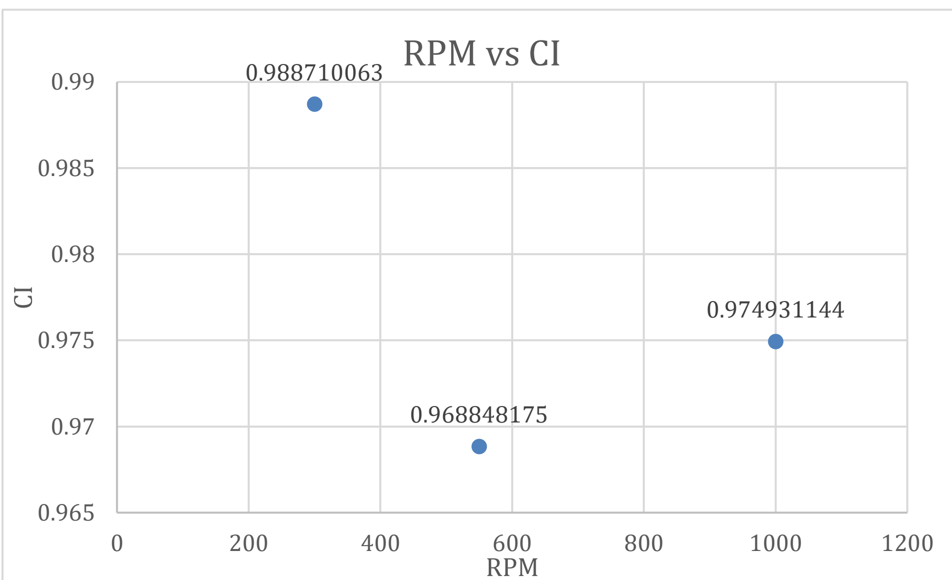


Figure 25: RPM vs Circularity Index

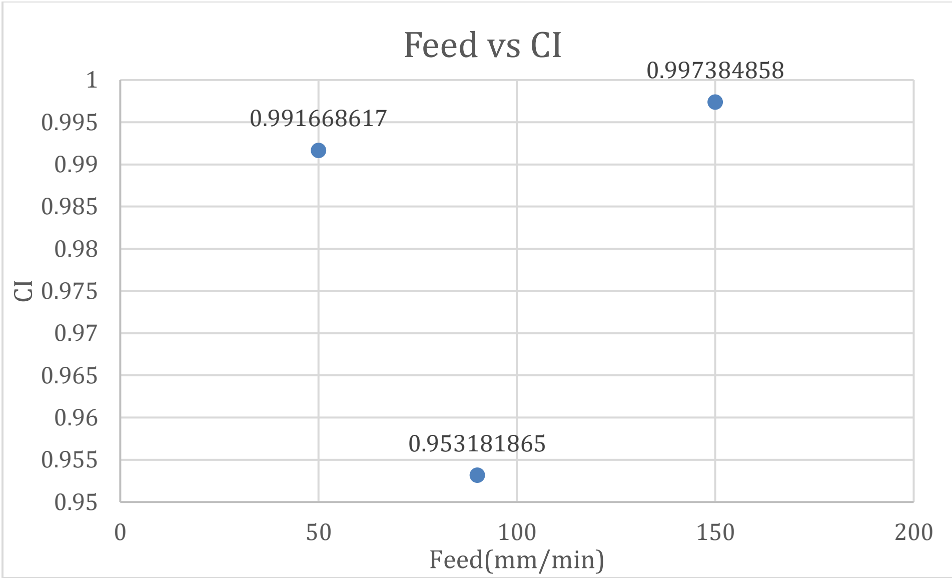


Figure 26: Feed vs Circularity Index

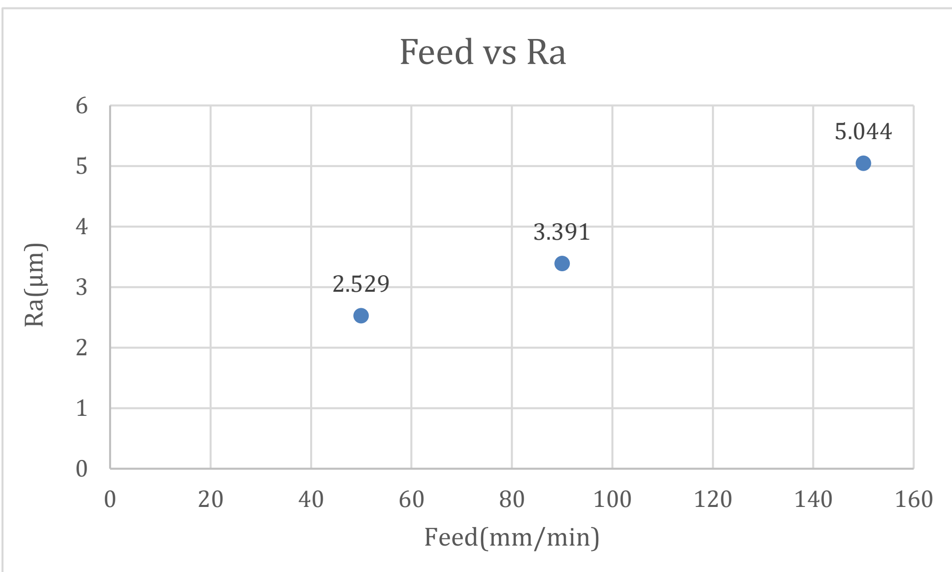


Figure 27: Feed vs Surface Roughness

Deviation of Diameter with respect to Drill Bit (in terms of Frequency)

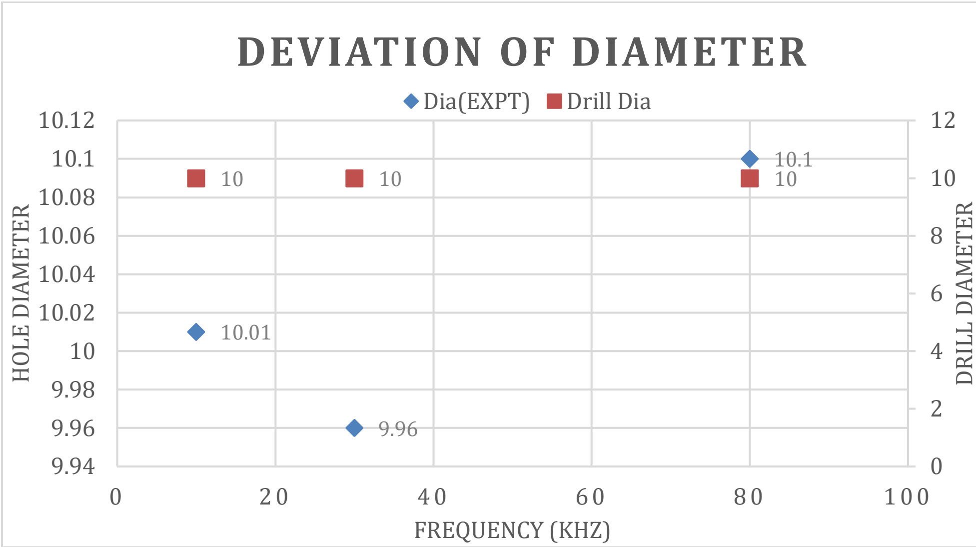


Figure 28: Deviation of Diameter with respect to Drill bit

Deviation of Diameter using Software (in terms of Frequency)

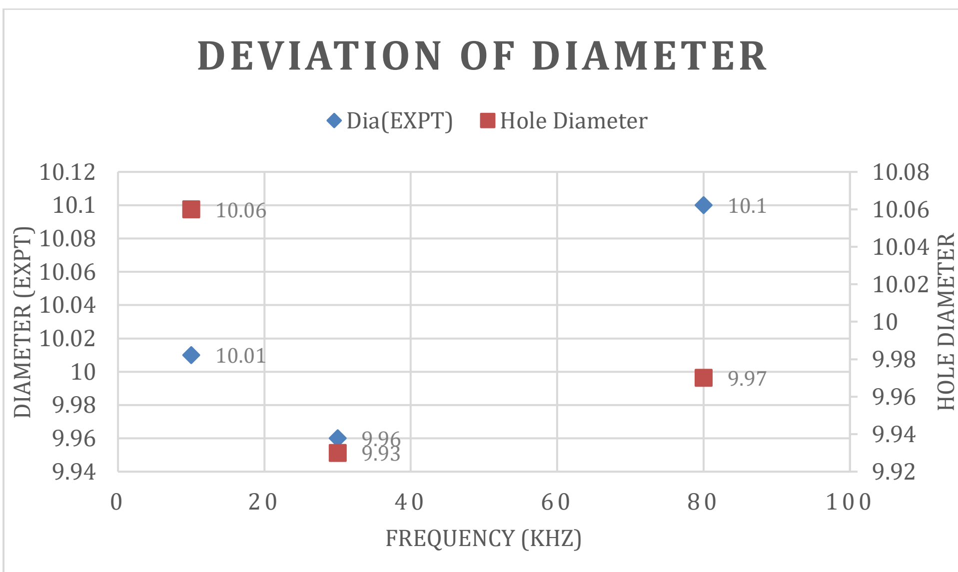


Figure 29: Deviation of Diameter with respect to Diameter taken by using Solidworks

Deviation of Diameter with respect to Drill Bit (in terms of RPM)

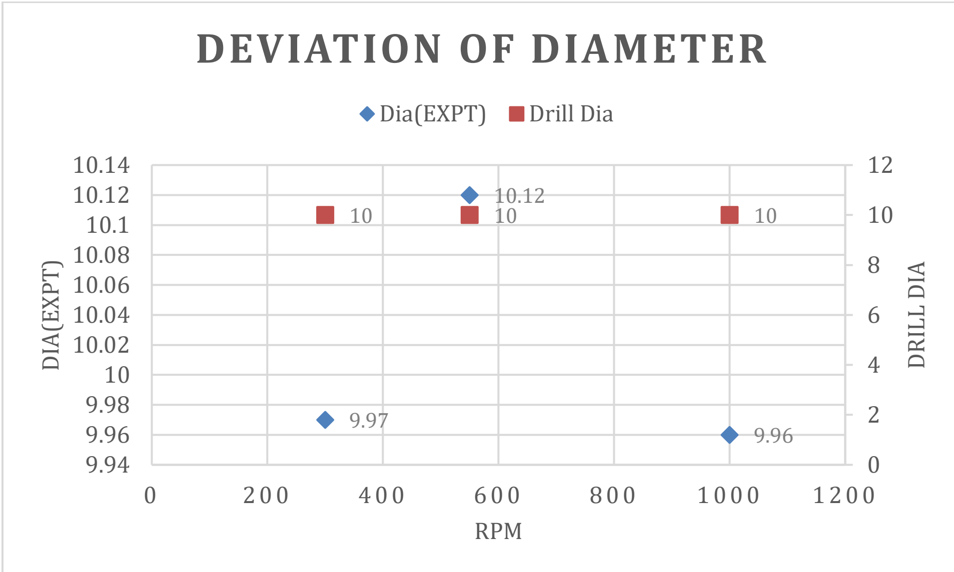


Figure 30: Deviation of Diameter with respect to Drill bit

Deviation of Diameter using Software (in terms of RPM)

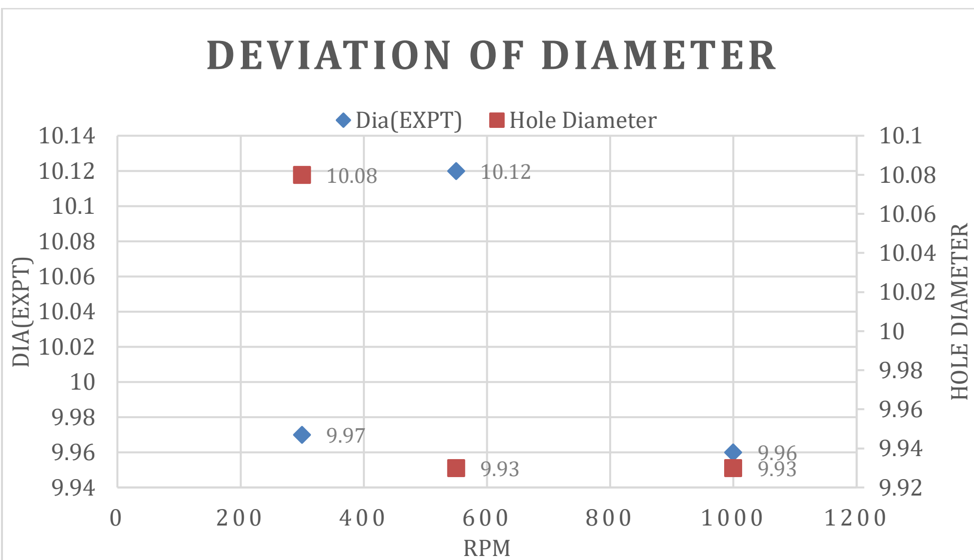


Figure 31: Deviation of Diameter with respect to Diameter taken by using Solidworks

Deviation of Diameter with respect to Drill Bit (in terms of Feed)

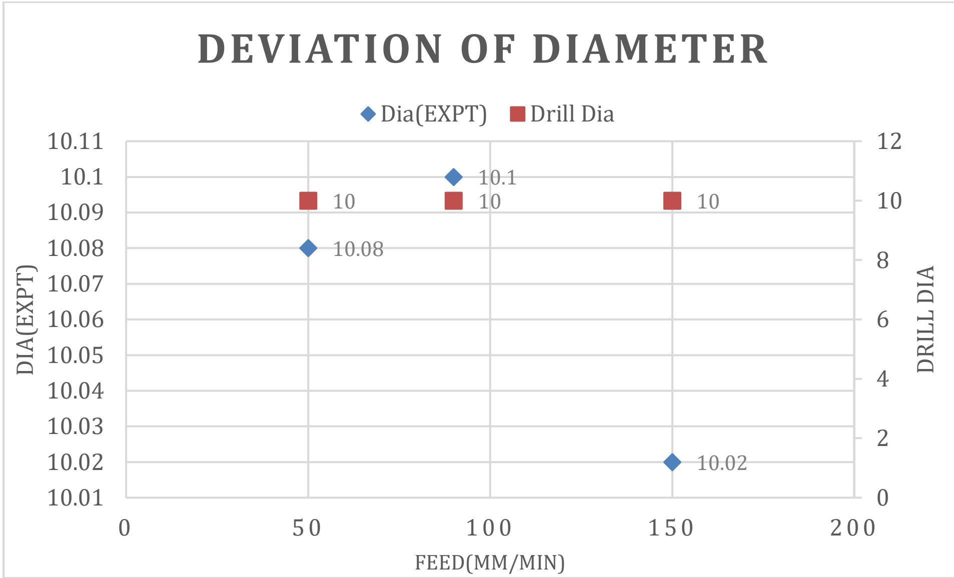


Figure 32: Deviation of Diameter with respect to Drill bit

Deviation of Diameter using Software (in terms of Feed)

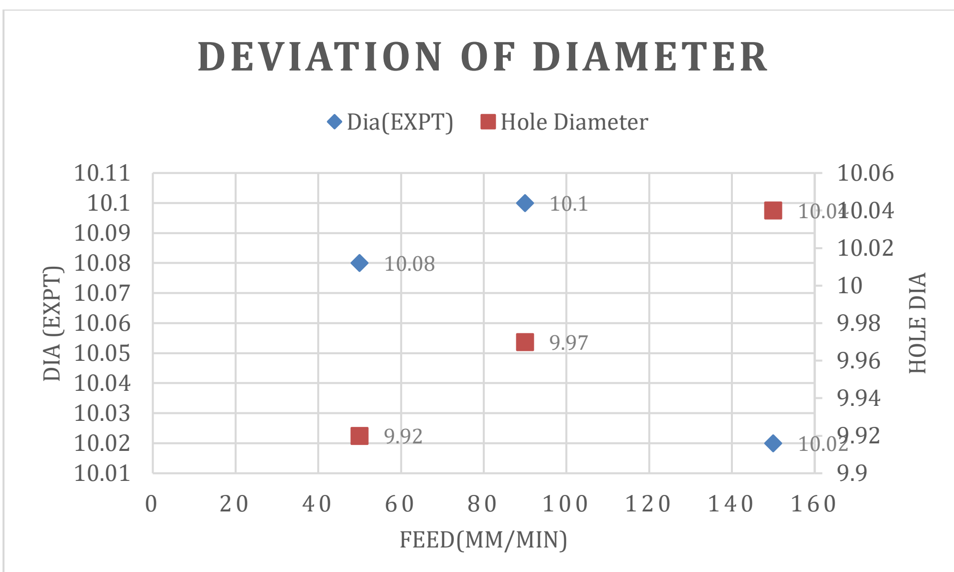


Figure 33: Deviation of Diameter with respect to Diameter taken by using Solidworks

Chapter V

Conclusion and Future Works

After conducting the experiments by applying frequencies ranging from 0 kHz to 80 kHz, keeping the feed 120 mm/rev, spindle speed 600 rpm in both the cases we found out that there is a huge improvement in the outcome of drilling. Our findings are

- There is an improvement in the surface roughness, circularity of the drilled holes
- Shorter chips, shorter build up edge,
- Less generation of heat,
- Decrease tool wear which in turn increases the tool life.
- With increasing frequencies, the chatter generated while machining is reduced.
- The drilled holes become more circular and pronounced and require less effort.

For the second half of the experiments, we found that both the outcomes circularity index and surface roughness vary significantly with respect to spindle speed, feed rate and frequency altogether. All the parameters were taken reviewing the literature. From the second set of experiments, when considering with respect to frequency the circularity was found to be best for 30khz, the surface roughness was best for 30khz. For RPM 300 at 30khz and 90 mm/min both the circularity and surface roughness were found to be best. For 30 khz, 150 mm/min and 550 RPM circularity was the best and for 30 khz, 50 mm/min and 550 RPM the surface roughness was the best.

So, we can say that for the variation of the different parameters i.e., frequency, feed and rpm there is a measurable amount of change in the circularity and surface roughness on the hole. The main goal of this experiment was to find out how much of a change there is when the feed and rpm is fixed keeping the frequency variable and when we apply different feed and rpm for different frequency. It can also be seen that for the same frequency and same feed but for different rpm differences in surface roughness and circularities can be found. This was due to the different factors including the accuracy of the machine, surrounding temperature, application of coolant etc.

5.1 Future works:

- Increase the feed and spindle speed
- Now we used 2 emitters placed on both sides, we are planning to put 2 more emitters on other sides whilst keeping the frequency same as our device is trained for only 4 frequencies.
- Check the surface roughness
- Measure the cutting force required while drilling to get the perfect hole
- Check desired chip formation while drilling.
- Measure the cutting temperature generated.

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Figures

[A] https://learnmechanical.com/wp-content/uploads/2020/01/schemetic-diagram-of-ultrasonic-machining-1024x844.jpg?ezimgfmt=ng:webp/ngcb1

[B] https://themechanicalengineering.com/wp-content/uploads/2019/12/Drilling-Machine-Parts.jpg.webp

[C] https://ecoreprap.com/wp-content/uploads/2022/01/CNC-Drilling-Machine.jpg

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