

University of Miskolc



FACULTY OF MECHANICAL ENGINEERING AND INFORMATICS
INSTITUTE OF MANUFACTURING SCIENCE

SCIENTIFIC STUDENT CONFERENCE THESIS

**INVESTIGATION OF MACHINING PARAMETERS EFFECTS ON CUTTING
FORCE AND VIBRATION IN CNC TURNING**

**A MEGMUNKÁLÁSI PARAMÉTEREK FORGÁCSOLÓERŐRE ÉS REZGÉSRE
GYAKOROLT HATÁSÁNAK VIZSGÁLATA CNC ESZTERGÁLÁSNÁL**

WRITTEN BY:

Tanuj Namboodri

student of the Mechanical Engineering study program at MSc level

SUPERVISOR (S):

Dr. Csaba Felhő

Director of Institute, associate professor
Institute of Manufacturing Science

Dr. Raghawendra Pratap Singh Sisodia

associate professor
Institute of Materials Science and Technology

Miskolc, 2024

Declaration of authenticity

I, the undersigned Tanuj Namboodri, student at the Faculty of Mechanical Engineering and Informatics of the University of Miskolc, declare and certify with my signature that I have prepared this thesis myself, we have carried out the examinations described therein, unless we indicate otherwise, and I have achieved the results described ourselves. I used data and information only from the sources listed in the bibliography. Any part that I have taken from another source, either verbatim or in the same sense, but reworded, is clearly marked with the source.

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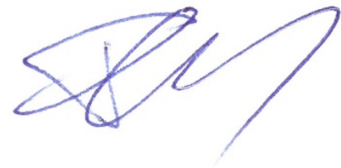
A handwritten signature in black ink, appearing to be 'Tanuj' followed by a stylized surname.

Tanuj Namboodri
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Statement of the supervisor

I, the undersigned, **Dr. Csaba Felhő** the lecturer in the Institute of Manufacturing Science at the University of Miskolc, I consider the Scientific Student thesis (TDK thesis) entitled *Investigation of Machining Parameters Effects on Cutting Force and Vibration in CNC turning* to be suitable for submission.

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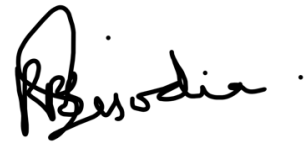


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I, the undersigned, **Dr. Raghawendra Pratap Singh Sisodia** the lecturer in the Institute of Materials Science and Technology at the University of Miskolc, I consider the Scientific Student thesis (TDK thesis) entitled *Investigation of Machining Parameters Effects on Cutting Force and Vibration in CNC turning* to be suitable for submission.

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Nomenclature

V_c – Cutting Speed

f – Feed or Feed Rate (f)

rpm - Rotation Per Minute

DOC – Depth of Cut (a_p)

DOF or df – Degrees of Freedom

MRR – Material removal rate.

$AccX$ – Acceleration in X direction

$AccY$ – Acceleration in Y direction

$AccZ$ – Acceleration in Z direction

$F(X)$ or F_x – Cutting force in X direction

$F(Y)$ or F_y – Cutting force in Y direction

$F(Z)$ or F_z – Cutting force in Z direction

AV_b – Active Vibration

F_a or AF – Active Force or Active Cutting Force

F_c – Cutting Force or Tangential Force

F_f – Feed Force or Axial Force

F_r – Passive Force or Radial Force

r – Coefficient of correlation

p - Probability of significance

$ANOVA$ – Analysis of variance

R_z – Mean Surface Roughness Depth.

R_a - Arithmetic Average (AA) Surface Roughness

$AV_b RMS$ – Root Mean Square of Active Vibration Magnitude

$AF RMS$ – Root Mean Square of Active Cutting Force Magnitude

1. Abstract

Machinability remains an important and relevant problem in Automotive and Marine Industry as well as a topic of research in the academic. Machinability is affected by several well-known as well some unknown machining parameters. Machinability is affected by several well-known as well some unknown machining parameters. X5CrNi18-10 has become very popular in automotive and marine industries due to its excellent corrosion resistance, mechanical properties and versatility but it is necessary to pay attention to the correct cutting data during the machining operation. Machining parameters like feed, depth of cut, cutting speed, cutting forces & vibrations induced from the interaction of workpiece and tool, because they directly influence the quality of product, production time, tool wear, which overall determines financial aspect of the manufacturing industries and has an impact on the environment. It is necessary to understand the effects of machining parameters and their influence on cutting forces and vibration for avoiding failures during manufacturing processes. This report highlights the correlation between machining parameters and their influence on cutting forces and vibration induced in turning of X5CrNi18-10 steel grade using dynamometer and MPU6050 sensor and highlights the parameters which has effect on the surface quality of machined surface.

2. Introduction

The computerization in manufacturing industries is rapidly growing increasing the efficiency, lowering labour costs. As industries recognise the benefits of predictive maintenance and operational efficiency the implementation of artificial intelligence is on the rise helping industries in economic growth and providing low costs solutions in the marketplace. In addition, the companies are prioritizing the sustainable practices by focusing on use of material. Material selection one of the key variable in manufacturing industry, which frequently causes uncertainties regarding its machinability. Machinability remains an important and relevant problem in Automotive and Marine Industry as well as a topic of research in the academic. Machinability is affected by several well-known as well some unknown machining parameters. Over the last decade the manufacturing industries has spent much in understanding and identifying the unknown parameters, which often effects the quality indicators of the machined part or finished product. Quality indicators such as surface integrity and material integrity. Eraslan. D. et al. [1] mentioned that selecting the proper engineering material with desired mechanical properties and easy-to-cut characteristics is essential for increasing productivity and decreasing production costs in machining operations. The selection of proper engineering materials not only allows industry to be economically profitable, but it is also beneficial to the environment. Recent research work of Labuda W. [2], [3], [4], [5] shows that X5CrNi18-10 has become very popular in automotive and marine industries due to its excellent corrosion resistance, mechanical properties and versatility. E. Kantorikova [6] mentioned that X5CrNi18-10 is an austenitic corrosion resistant steel that forms an important group of material, their high fracture toughness and corrosion resistant properties are irreplaceable part of engineering industry, due to its high fracture toughness, it is necessary to pay attention to the correct cutting data during the machining operation. E. Kantorikova [6], Wojciech Labuda [2], [3], [4], [6] mentioned that this steel is used in automotive industry to produce various parts such as exhaust systems, grilles, trim strips and shafts and in marine industries for sea water pumps shaft and other marine machinery parts. Sharma V. et al. [7] mentioned that the turning operation is more economical and widely used machining process used in the manufacturing industries to produce shaft from hard material, for turning operation to be efficient selection of cutting parameters is highly recommended by the researchers. Machining parameters like feed, cutting forces & vibrations induced from the interaction of workpiece and tool, because they directly influence the quality of product, production time, tool wear, which overall determines financial aspect of the manufacturing industries and has an impact on the environment. For successful implementation of turning study of cutting forces is critically important because cutting forces correlate strongly with cutting performance such as surface accuracy, tool wear, tool breakage, cutting temperature. The cutting force is one of the most significant characteristic variable to monitor in cutting operations since its variation is directly proportional to the cutting conditions. Lalwani. D. et al. [8], explained that cutting forces are a result of extreme conditions at the tool- workpiece interface. R. Pawade et al. [9], studied larger cutting forces generate poor surface finish and extensive surface damage in high-speed turning of Inconel 718 using PCBN tools. Yong W. et al. [10], showed the distributed cutting force model significantly influences the stability of turning processes, especially at low spindle speeds, by incorporating both discrete and continuous time delays. Kim and Ehmann [11] suggested that knowledge of cutting forces is one of the most important criteria. This knowledge is also very useful for cutter design, machine tool design, and monitoring tool wear and breakage. Sreejith et al. [12] observed that the cutting force and cutting temperature influence the performance of cutting tools while machining carbon/carbon composites.

The cutting forces can be divided into three components, commonly referred to as the three-axis cutting force components. The active force, (F_a) or AF , is the result of the

combination of the cutting force (F_c), and the feed force, (F_f), in the direction of the cutting action. The passive or radial force, denoted by the symbol (F_r), does not contribute to the power conversion, since the tool and the workpiece do not move relative to one another in the direction of movement. Muhammad Rizal et al. [13]. The resultant force (R_f) on the turning process can be expressed by the following Eq. 1.

$$R_f = \sqrt{F_a^2 + F_r^2} = \sqrt{F_c^2 + F_r^2 + F_f^2} \quad (1)$$

$$F_a = \sqrt{F_c^2 + F_f^2}$$

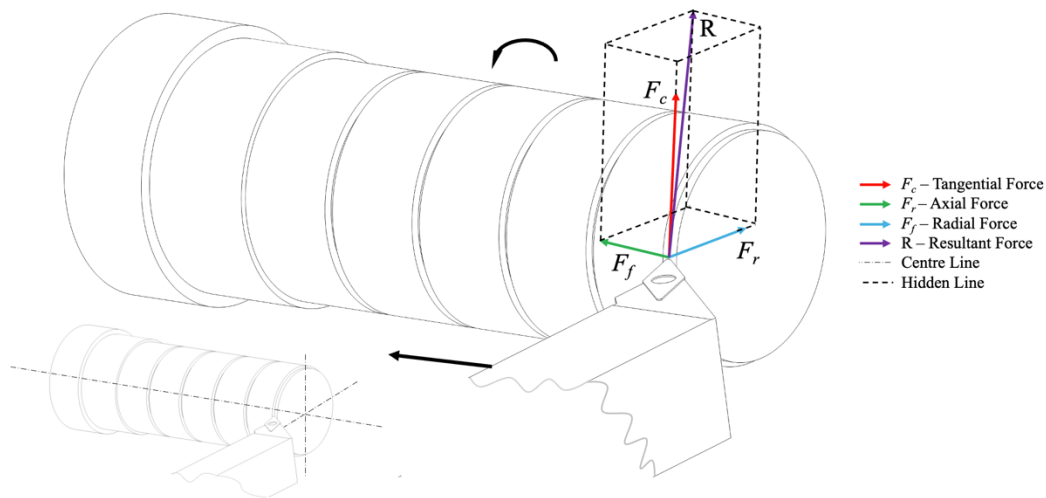


Figure 1. Direction of forces in turning operation.

The cutting force is the force required to accomplish the cutting process, which involves cutting the workpiece and deforming the materials to produce chips. Cutting forces have been shown to be the most effective measure for understanding metal machining processes. I.N. Tansel et al. [14], Laghari R. et al. [15] Ulvi Şeker et al. [16] mentioned that a significant amount of this research has been focused on measuring and predicting cutting forces during milling. That is because understanding the cutting forces is critical because they have a direct impact on heat generation, and hence tool wear, machined surface quality, and workpiece precision. They are also used to design machine tools, cutting tools, and fixtures. The forces which help in performing machining operation also affects the cutting tool, in terms of deformation, bend, wear, which leads to the vibration in the machining system [17]. Vibration is defined as the periodic displacement of a product at a high frequency. Machining vibrations, often known as chatter, indicate the relative movement of the workpiece and the cutting tool. There are three types of mechanical vibrations produced during the turning process. They are natural, forceful, and self-excited vibrations [18]. The resultant vibration can be calculated by taking magnitude of vibrations in x, y and z axis as expressed in Eq. 2.

$$R_{V_b} = \sqrt{V_x^2 + V_y^2 + V_z^2} \quad (2)$$

Where R_{V_b} is Resultant vibration, V_x is vibration in x direction or Radial direction, V_y is vibration in y direction or Axial, V_z is vibration in z direction or Tangential. No studies were found which states the active vibration which has real impact on the machining process

however understanding the point of contact the summation of Radial and Tangential direction is considered due to movement of tool in axial direction as shown in Fig. 8(b). These vibrations have an impact on common machining processes including turning, milling, and drilling. Nayak. A. et al. [19] studied that the frequencies of force and vibration responses are significantly connected, and observed vibrations can be used to predict forces generated. Prasad. B. et al. [20] concluded, vibration is a common concern in turning processes, affecting machining results, particularly tool wear. Abdullah Aslan [21] investigated variations in cutting forces and vibration have a direct impact on flank wear. Yong Wu [10] mentioned one of the most frequently accepted reasons for machine tool chatter is surface regeneration theory, the machined surface becomes wavy as a result of relative vibrations between the tool and the workpiece as a result, delay effects emerge in metal cutting operation models because the cutting force is controlled by the chip thickness, which is dependent on both the present tool position and the delayed position from the preceding cut, in result, the delay-differential equations are employed to describe machine tool vibrations, and regenerative machine tool chatter can be viewed as the manifestation of self-excited oscillations in a time-delay system. One of the main effects of chatter is to reduce the quality of surface roughness [22], [23], since the cutting tool is in direct contact with the workpiece during machining, self-excited vibration takes place as shown in Fig. 2(a) [24], where (k) is the spring constant and (c) is damping coefficient which represents the level of damping. Zhang Xiang-hui et al. [25] reported the chatter in machining has an effect on surface roughness and machining precision, but also cutter life. Shahabi and Ratnam et al. [26] showed a decrease in average roughness (R_a) during the early stages of machining, followed by an increase in R_a as the machining was prolonged. Vibration has been proven to be a major element influencing surface roughness in all turning processes [27]. Ozbek and Saruhan [28] examined cutting tool vibration amplitude, temperature, tool wear, and surface roughness during dry and minimum quantity lubrication (MQL) turning of AISI D2 cold work tool steel. The average roughness decreased by 82%, demonstrating that vibration and tool wear have a considerable impact on surface roughness, with roughness increasing as vibration amplitude rose. García Plaza and Núñez López [29] used singular spectrum analysis (SSA) on vibration data from workpiece-cutting tool interaction to assess surface roughness (R_a). The vibration signals were monitored with triaxial accelerometers positioned near the workpiece-tool interface. The signal along the tool feed direction was discovered to be the key data source for monitoring surface roughness. The authors demonstrated that the frequency ranges in the vibration signal can be used to accurately estimate surface roughness. Surface roughness is caused by the repetitive movement of the cutting tool tip along the workpiece at the proper feed rate during the machining process as shown in Fig. 2(c). This relative motion interacts in a complex manner, based on workpiece parameters, cutting circumstances, tool vibration, and metal shearing during chip production [30]. Surface roughness is a widely used measure of a machined product quality and, in most cases, is a technical requirement for mechanical products because, along with dimensional precision, it affects the functional behavior of the parts during their useful life, especially when they have to come into contact with other materials [31].

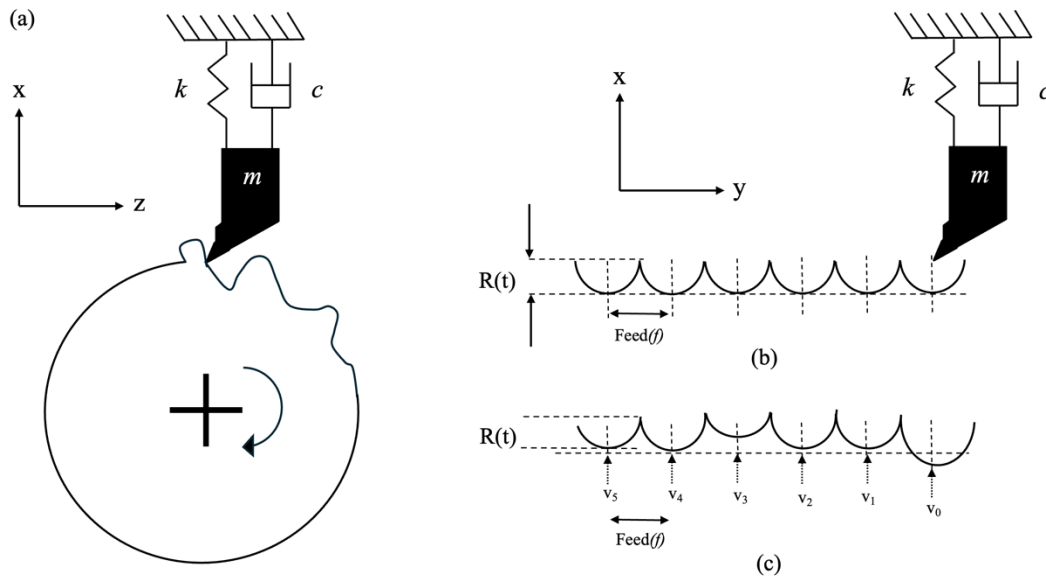


Figure 2. (a) Chatter Diagram (b) Ideal surface profile without vibration (c) Surface profile with vibration.

Surface Roughness have effects on several factors that effects the machine, like stress concentration, frictional wear, corrosivity etc. reason why in process surface roughness prediction is important. D. Arola [32] reported, Surface roughness increases fatigue strength, and the fatigue stress concentration factor (K_f) of machined surfaces ranges from 1.01 to 1.08. K. Kubiak et al [33] reported rough surfaces have a lower coefficient of friction and increase wear rate, while smooth surfaces have a decrease in wear rate and wear activation energy. Li et al. [34] mentioned that surface roughness increases corrosion rate and decreases surface electron work function, contributing to corrosive wear, likewise many researchers has focused the effects of surface roughness on the functionality of the machine. The machining parameters like feed (f), depth of cut (DOC) (a_p) and cutting speed (V_c) influences the unknown parameters like cutting forces and tool vibration and quality indicators surface roughness and surface hardness [35].

As a result, understanding the effects of machining parameters and their influence on cutting forces and vibration is important for avoiding failures in manufacturing processes, particularly those involving machining. This report aims to study the correlation between machining parameters, cutting forces and vibration in turning of X5CrNi18-10 steel grade using dynamometer and MPU6050 sensor. In addition, to highlights the correlation of machining parameters which has effect on the surface quality of machined surface. To check the validity of the regression model, analysis of variance (ANOVA) was used. Besides correlation analysis, this report also presents Vickers microhardness measurement and Light optical microscopic microstructure of the turned surfaces to better understand the effects of the hardness variation due to different cutting parameters on turned surface and to observe the microstructural variation on the turned surface.

3. Materials and Methods

3.1 Workpiece Preparation

The test material for this study is steel X5CrNi18-10, it is an austenitic chrome nickel steels. Nickel is an austenitic forming element that expands the austenite region in Fe alloys. Although chromium belongs to the ferrite-forming elements, with a suitable concentration of Cr and Ni, these steels have an austenitic structure at room temperature [36].

Table 1

Chemical composition % of steel X5CrNi18-10 (1.4301): EN10088-2[37]

C	Si	Mn	Ni	P	S	Cr	N
max 0.07	max 1	max 2	8 10.5	- max 0.045	max 0.015	17.5 19.5	- max 0.11

Chemical composition of X5CrNi18-10 (1.4301) according to EN10088-2 is provided in Table 1. The mechanical properties of specimen used in the experiment are mentioned in Table 2 .

Table 2

Mechanical properties of steel X5CrNi18-10 (1.4301)

Rm - Tensile strength (MPa)	R _{p0.2} 0.2% proof strength (MPa)	KV - energy transverse	Impact (J)	A - Min. elongation at fracture (%)	Vickers hardness (HV)
500-750	190-235	+20°	60	35-45	220 - 450

Fig. 3. highlights the diameter of the workpiece the specimen was divided in 5 equal surfaces of 30mm length each with a gap of 4 mm between the surfaces, and 5 mm depth creating a groove parting the surfaces. These surfaces were divided to perform the experiment with the different machining parameters where feed, depth of cut and cutting speed was varied according to the design of experiments mentioned. Vibration and cutting forces data was recorded on each surface.

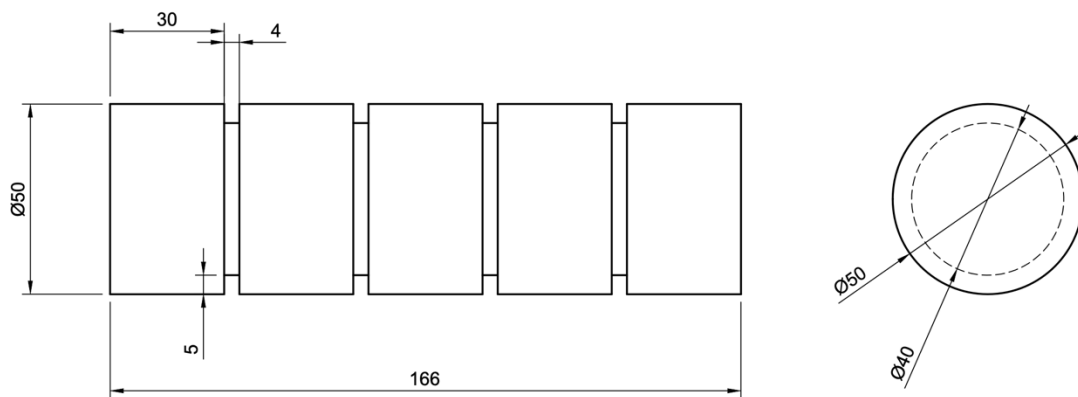


Figure 3. Drawing of workpiece specimen.

Initially the specimen was 50 mm cylinder with each surface length of 30 mm, Total no. of specimen used in this experiment were four, giving the total of twenty surfaces, however only

eighteen surfaces were used in the first part of the experiment as per design of experiment as mentioned in the Table 5.

3.2 Tool Specification

The tool used in the experiment was the DDJNL2525M15 from Seco tools [37], shown in Figure 4. The tool's shank is 25.00 mm in height (H) and breadth (B), providing stability while turning. The rotary holder version given is R for right-handed operation. The turning inserts have a basic shape known as D which relates to a 55° insert angle. The tool's overall length (L1) is 150.00 mm, ensuring sufficient reach during operations, and the clamping system is labelled as D indicating the method used to secure the insert. The angle of attack of the holder is defined as J at 93°, which influences the tool's alignment during the cut. In addition, the cutting edge of the cutting insert is 15mm. The specification of tool is highlighted in Table 3.

Table 3.

DDJNL2525M15 Tool description[38].

Shank Height (H)	Shank Width (B)	Rotary Holder Version	Turning Inserts Basic Shape	Total Length (L1)	F	Clamping System	Angle of Attack Holder	Edge Length
25.00 mm	25.00 mm	R (right)	D (55°)	M (150.00 mm)	32.00 mm	D	J (93°)	15

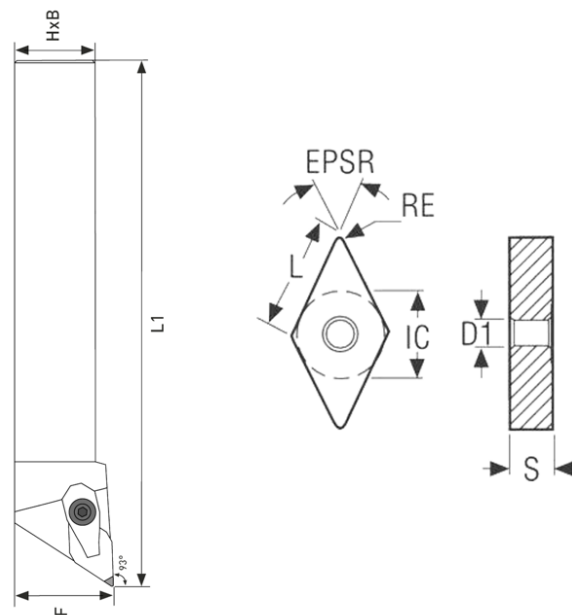


Figure 4. (a) Tool description, (b) Insert specification [38].

3.2.1 Insert Specification

Seco Tool's DNMG150604-MF1 Insert was used during all the experiments, insert specifications are provided in Figure 4 and Table 4. The insert size and form are denoted by DN 1506, which denotes a specific geometric arrangement suited for a variety of turning operations. It is made of carbide with a PVD coating, which improves wear resistance and cutting performance. The insert is labelled neutral in terms of hand orientation, which means it can be used in both left- and right-handed applications. The cutting-edge length is 15.5 mm, provides a large cutting surface for material removal. The insert's thickness is 6.35 mm, ensures

endurance and strength during cutting operations. The corner radius is 0.4 mm, affects finishing quality and lowers cutting forces.

Table 4.
DNMG150604-MF1 Insert Specification[38].

Insert size and shape	Grade type	Insert hand (IH)	Cutting edge length (L) (mm)	Insert thickness (mm)	Corner Radius (RE) (mm)
DN1506	Carbide PVD	Neutral	15.5	6.35	0.4

The tool and insert were selected based on industry expert's recommendations.

3.3 Electronic Setup

Electronic setup is development of a device to monitor the vibration signals, Vibrational signal was measured in each of the machining passes using MPU6050 sensor & ESP32 Microcontroller [39], the microcontroller was used for the code to run, the data was collected using SD card module attached to the microcontroller. The wire connection for the electronic setup is shown in Fig. 5.

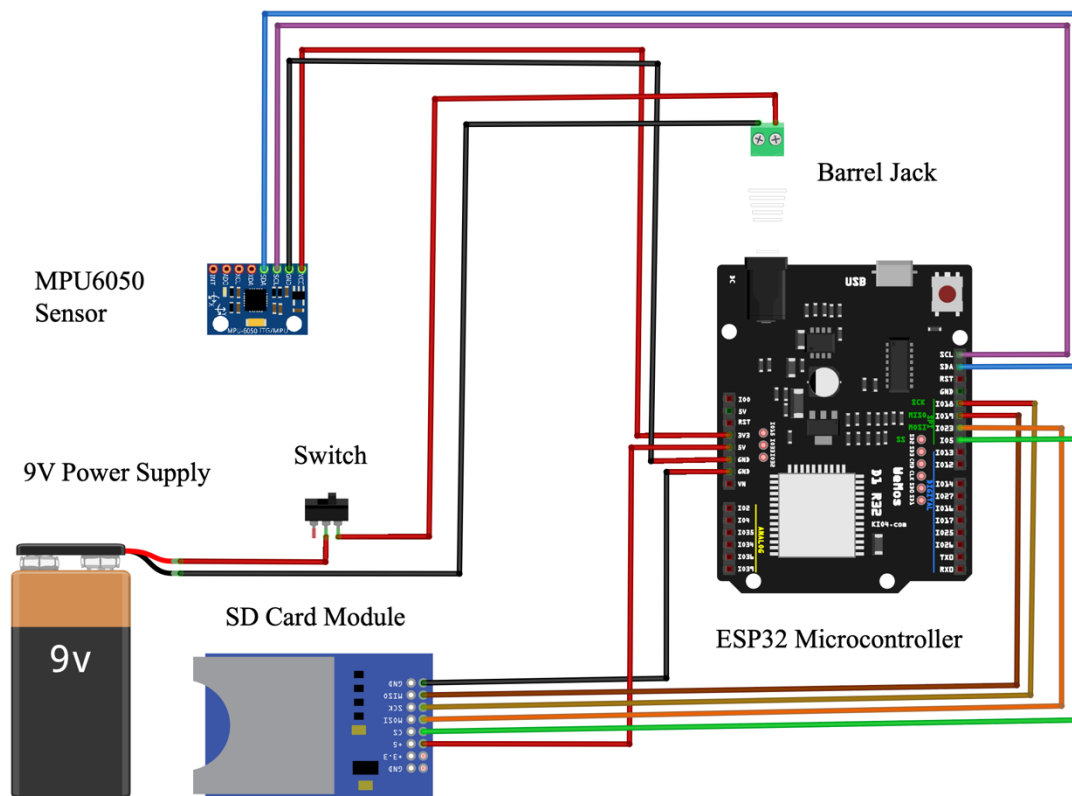


Figure 5. Connection diagram used for collecting vibrational signal.

The MPU6050 sensor module used is a comprehensive 6-axis motion Tracking Device. It combines 3-axis Gyroscope, 3-axis Accelerometer and Digital Motion Processor, The MPU-6050 pins connected to microcontroller ESP32 are, SCL: Serial Clock pin. this pin connects to microcontrollers SCL pin. SDA: Serial Data pin this pin connects to microcontrollers SDA pin. GND: Ground pin this pin connects to ground connection. VCC: Power supply pin this pin to +5V DC supply. The ESP32 microcontroller includes two 240MHz cores, each with a Tensilica

Xtensa 32-bit LX6 microprocessor. SD card Module is connected to microcontroller for the purpose to store the data, it is a breakout board used for SD card processes reading and writing the data. The other sensors like ADXL35 can be used however based on literature [40]. It was found that that MPU6050 is more reliable than other in terms of sensitivity, precision. A 9V power supply was used to provide power to the sensor and the microcontroller. The selected range of accelerometer has a full-scale $\pm 2g$, a sensitivity of 16384 LSB/g, and a sampling data rate of 1 kHz.

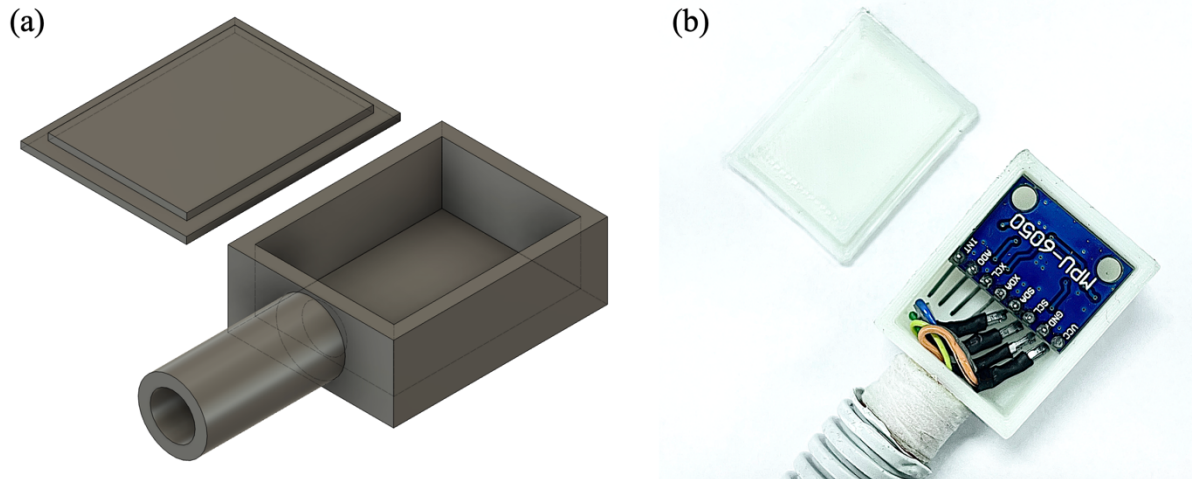


Figure 6. (a) 3D model of developed sensor case. (b) Printed Sensor case for experiment.

Qidi X- CF Pro 3D printer was used to fabricate the sensor case to protect sensor from chips and the lubrication during the machining process, Material used for printing was ABS plastic, the top and bottom layers have a lines pattern, which prints parallel lines to provide a solid surface finish, line width of 0.4 mm and layer height of 0.2mm was used during printing. The infill density is set to 100%, which means the print's interior structure is totally solid, resulting in maximum strength and longevity. The infill is designed in a Zigzag pattern, with diagonal lines alternating directions to improve the part's internal stability. The infill speed is 60 mm/s and wall speed was 30 mm/s, which balances precision and efficiency throughout the printing process. The printing temperature is kept at 270°C to provide optimal material extrusion, while the build plate is heated to 110°C to ensure appropriate print adhesion and reduce the possibility of warping.

3.4 Experimental Setup

The finish turn OD turning operation was carried out to obtain experimental data in the wet condition, HAAS ST-20 Y series machine was used to conduct all the experiments as shown in the Fig. 7(a), this machine is Y axis CNC turning centre, has a max capacity of 298×572 mm, 63.5 mm bar, 533 mm swing, ± 50.8 mm Y-axis travel, 20 hp vector drive, 4000 rpm, A2-6 spindle, 210 mm chuck, and a 12-station BMT 65 turret. This machine is suitable for the larger workpieces and for complex operation [41]. The coolant used during the experiment is 5% emulsion of CIKS HKF 420 type oil. It is necessary to understand the coolant type to achieve the best results.

Fig. 7(b), represents the developed device for measuring vibration signals during the turning operation, two monitors were used in the experiment one for monitoring the vibration signals and another for monitoring the cutting forces. Vibration signal measurement device was fabricated using 3D printer and milling on the plastic box, sensor case was printed in order to prevent it for chips and coolant lubricant used during the machining operation. A wire casing was provided so that the chips falling during operation doesn't interrupt the measurement. A

switch and Led was included in the developed device so that after all the initialization and checkup when the LED switch turns on and emits the green light, it shows that the everything is working according to planned and the vibration signals are being saved in the SD card attached.



Figure 7. (a) HAAS ST-20 Y CNC Machine (b) Electronic setup (c) Real time monitoring vibration and cutting forces

The sensor was attached to the tool with the clip to collect the vibrational data as shown in Fig. 8(a) and Fig 8(b), electronic setup box was screwed on the tool holder, the setup allowed electronic box to be stationary with respect to movement of tool which provided the uninterrupted connection to the experiment. The direction of sensor with respected to tool direction is same as the Dynamometer direction, Where Y is radial, X is tangential, and Z is axial.

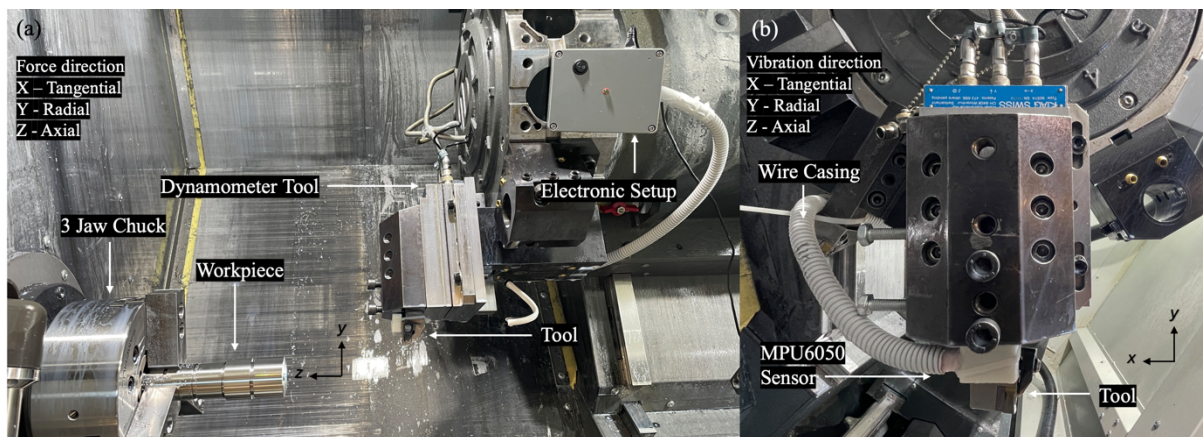


Figure 8. (a) Experimental setup. (b) Vibration sensor and dynamometer setup.

The cutting force components were measured using a three-component piezoelectric dynamometer, from Kistler Corporation 9257-A, Fig. 8(a) and 8(b). The dynamometer's output was amplified using a charge meter Kistler Corporation Model 5015A for three force

components i.e., F_x , F_y , F_z , has been connected to National Instruments CompactDAQ-9171 four-channel data acquisition unit (USB). The amplified signals from the charge amplifier are supplied into the data acquisition system, where they are transformed to digital output, which is then transferred to the computer. The setup allowed for the installation of a dynamometer between the tool holder of the CNC lathe and the tool without interacting with other parts. The three cutting force components were measured, as seen in Fig. 8(a). Tool, dynamometer and sensor position is defined in Fig. 8(a) and 8(b) respectively, monitor allows to validate the data during the process to avoid any error it is recommended to visualise the real time data. This configuration allowed the experiment to be conducted cleanly and without errors. Fig. 9, represents the schematic diagram of experiment setup used in this study.

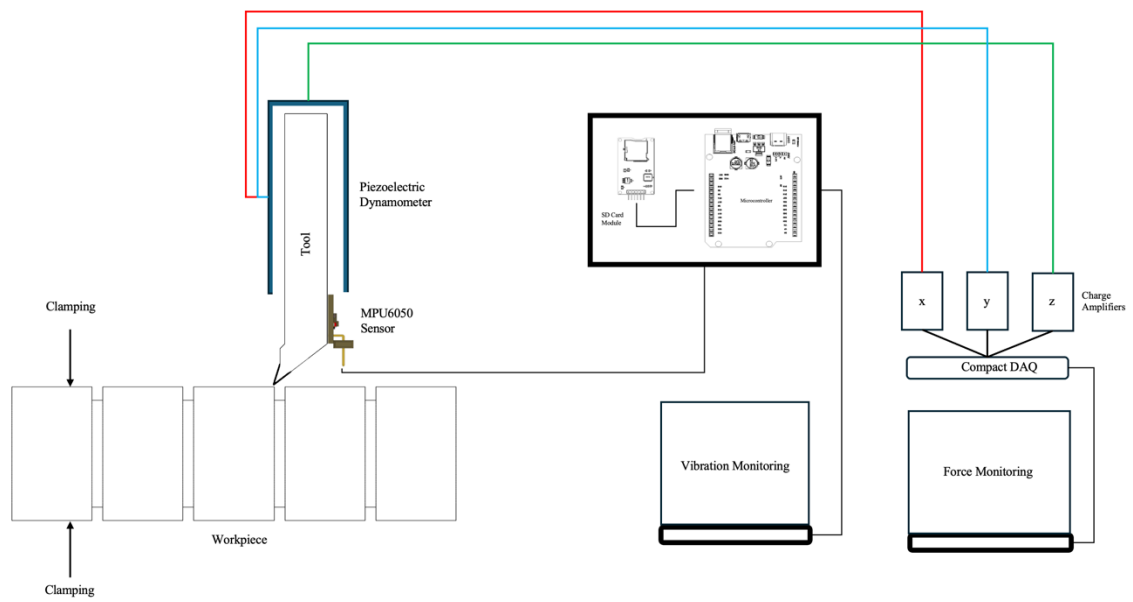


Figure 9. Schematic of experimental setup.

3.5 Design of Experiments

The experiments were designed based on Taguchi's orthogonal array (OA), the depth of cut with 2 levels, cutting speed with 3 levels and feed rate with 3 levels. According to Taguchi's rules, the selection of a suitable orthogonal array depends on the total number of degrees of freedom (DOF) of the processing parameters, the total DOF for the experiment is 5, the selected OA should consist of at least as many degree of freedom, the L_{18} array provide sufficient variation to analyse these factors.

In this setup, depth of cut is examined at two levels, 0.5 mm and 1 mm, cutting speed is examined at three levels, at 150, 200, and 300 m/min and the feed rate are also varied at three levels, 0.08, 0.16, and 0.24 mm/r. Table 5, represents Taguchi's Orthogonal Array, designed systematically to investigate the influence of various machining parameters on the performance outcomes.

Vibration and Cutting forces were measured in each experiment number to understand the relationship and behaviour of machining parameters on each other to improve the overall quality of the final machined product.

Table 5.
Taguchi's Orthogonal Array L_{18}

No.	Depth of Cut (a_p) mm	Cutting Speed (V_c) m/min	Feed Rate (f) mm/rev
1	0.5	150	0.08
2	0.5	150	0.16
3	0.5	150	0.24
4	0.5	200	0.08
5	0.5	200	0.16
6	0.5	200	0.24
7	0.5	300	0.08
8	0.5	300	0.16
9	0.5	300	0.24
10	1	150	0.08
11	1	150	0.16
12	1	150	0.24
13	1	200	0.08
14	1	200	0.16
15	1	200	0.24
16	1	300	0.08
17	1	300	0.16
18	1	300	0.24

4. Results and Discussion

4.1 Vibration Analysis

The vibrational data was collected through electronic setup as mentioned in experimental setup, the data was saved in “[dot] csv” format with order Time (ms) with sampling frequency 1000Hz, acceleration in X direction (AccX) (m/s^2) is tangential acceleration, acceleration in Y direction (AccY) (m/s^2) is radial acceleration, the acceleration in Z direction is axial and it was kept zero intentionally because of the movement of tool in the Z direction. The active vibration consists of X and Y component. After the collection of data, Origin Pro academic licenced software was used to process the data, analyse the signals during the machining process. The raw or unfiltered data from the sensor, where the vibrational signals in terms of acceleration in X direction and acceleration in Y direction was computed and the magnitude was taken. Fig. 10, represents the magnitude of tangential and radial acceleration.

$$A_{V_b} = \sqrt{V_x^2 + V_y^2} \quad (3)$$

A_{V_b} refers to active vibration, which is the sum of tangential and radial acceleration. When a tool moves in the axial direction, a force acts on it, and the vibration values are fairly low in comparison to tangential and radial.

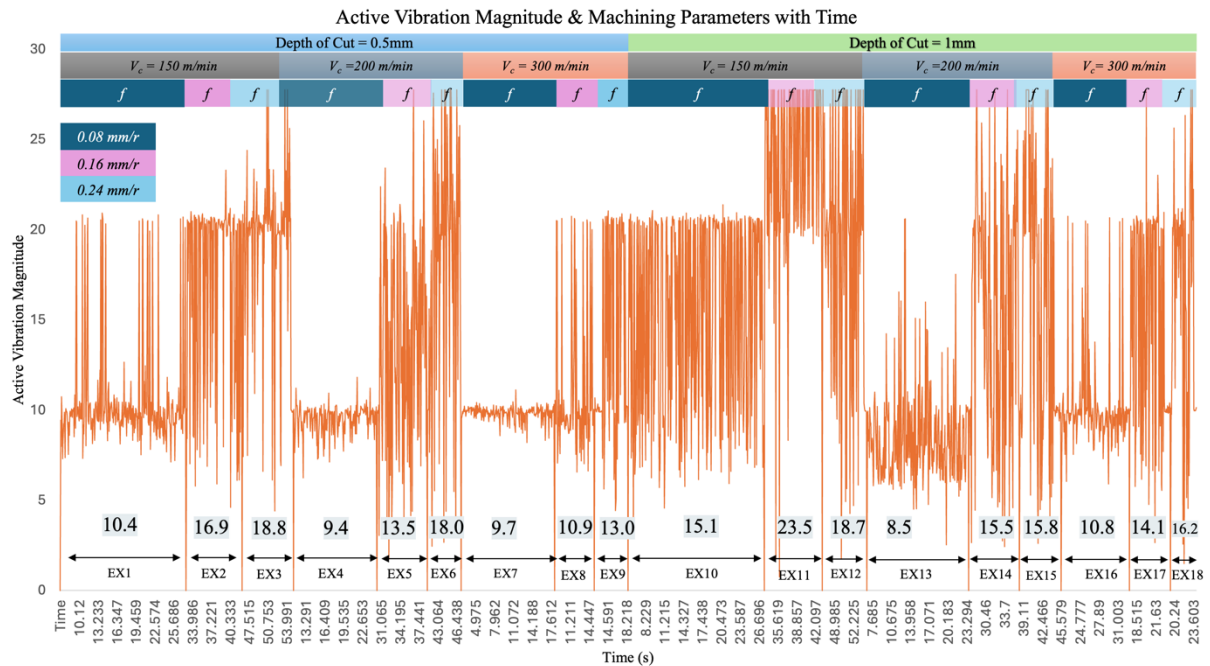


Figure 10. Magnitude of active vibration with time for each experiment.

The data was separated according to surface in order to calculate the relation between each surface roughness and amplitude of vibration. To understand the characteristics of vibration EX means, experiment no., It can be visualized from the Fig. 10 the total no. of experiments were eighteen and active vibration RMS is computed for each experiment, the horizontal axis represents the time in seconds. Fig. 10, displays the depth of cut on the top, cutting speed below it and feed rate used for each experiment.

It can be analysed from the Fig. 10, that during which machining parameters the value of active vibration RMS is low, high or medium. The vibration analysis represents that with increase of

feed rate vibration during the machining process also increases, the least value of active vibration RMS was found in EX13 with DOC (ap) 1mm, V_c –200m/min and f – 0.08 but the signal peaks are high during that period. The highest value of AV_b RMS was found during EX11 with DOC (ap) 1mm, V_c – 150 m/min and f – 0.16.

4.2 Force Analysis

The Force data was collected through three-component piezoelectric dynamometer, from Kistler Corporation electronic setup as mentioned in experimental setup, the data was saved in “[dot] txt” format with order Time (s), Force in X direction F(x) (N) is tangential force, Force in Y direction F(y) (N) is radial acceleration, the acceleration in Z direction is axial F(z) in N, The active cutting force is sum of tangential and axial force, so force in Y direction was kept zero intentionally because the tool is stationary in Y and the force value is very less in compared to other forces which is inconsiderable in compare to other force, this force is also called passive force.

Fig. 11, represents active force magnitude with machining parameters for each experiments and it can be visualised from the Fig. 11, that active cutting force value is smaller in EX7 with DOC (ap) 0.5 mm, V_c –200m/min and f – 0.08 and it can be concluded from vibration analysis that EX7 also has one of the least active vibration magnitude value. The highest value of active cutting force is found during EX12 with DOC (ap) 1mm, V_c – 150 m/min and f – 0.24 , similarly the vibration value is high in EX12. It can also be analysed from the Fig. 11. that with increase of feed rate the active cutting force value also increases.

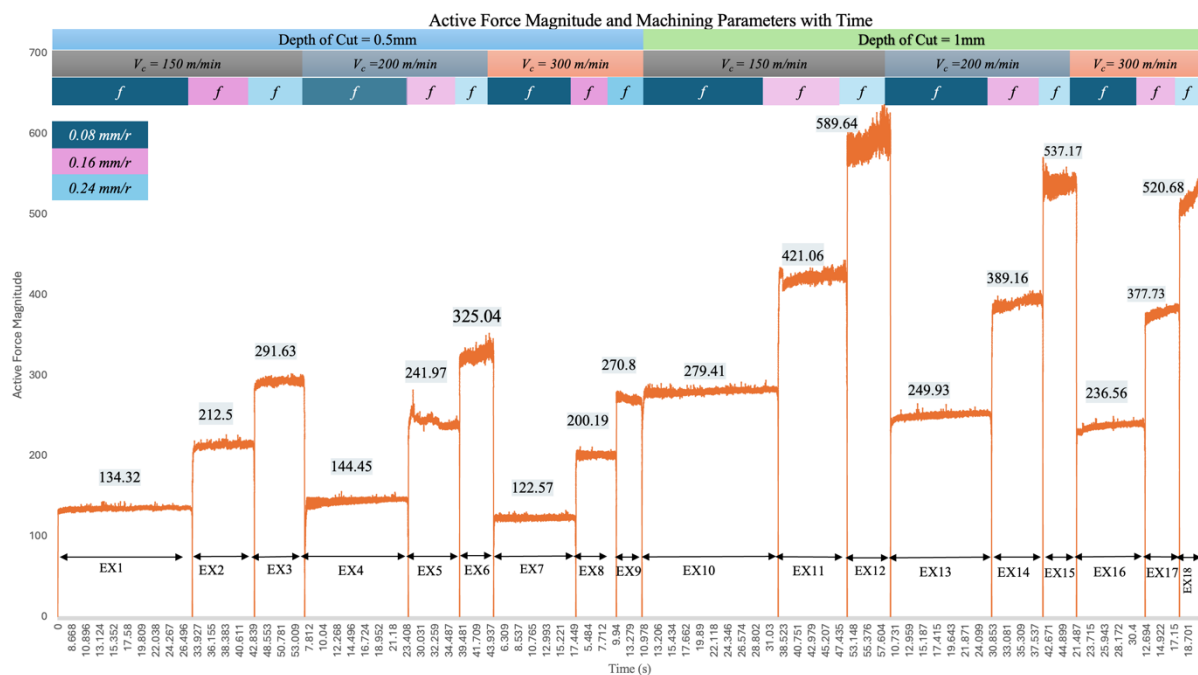


Figure 11 . Magnitude of active force with time for each experiment.

Fig. 10, and Fig. 11, can be compared and the best machining parameters can be optimized with the comparison, where the vibration is low and the cutting force value is low, which will reduce chatter during the turning operation and a good quality product can produced. Table 6, represents the calculated values of AV_b RMS and AF RMS for the correlation analysis, active vibration RMS is in m/s^2 and active cutting force RMS is in N.

Table 6.

AV_b RMS and AF RMS Value for Experiments.

Experiment No.	Active Vibration RMS	Active Force RMS
1	10.96	134.32
2	17.83	212.53
3	19.56	291.63
4	9.56	144.45
5	14.87	241.97
6	19.61	325.04
7	9.84	122.57
8	11.82	200.19
9	14.53	270.8
10	16.11	279.41
11	24.24	421.06
12	20.22	589.64
13	8.95	249.93
14	17.1	389.16
15	17.68	537.17
16	10.51	236.56
17	15.66	377.73
18	17.46	520.68

4.3 Standard Deviation Results

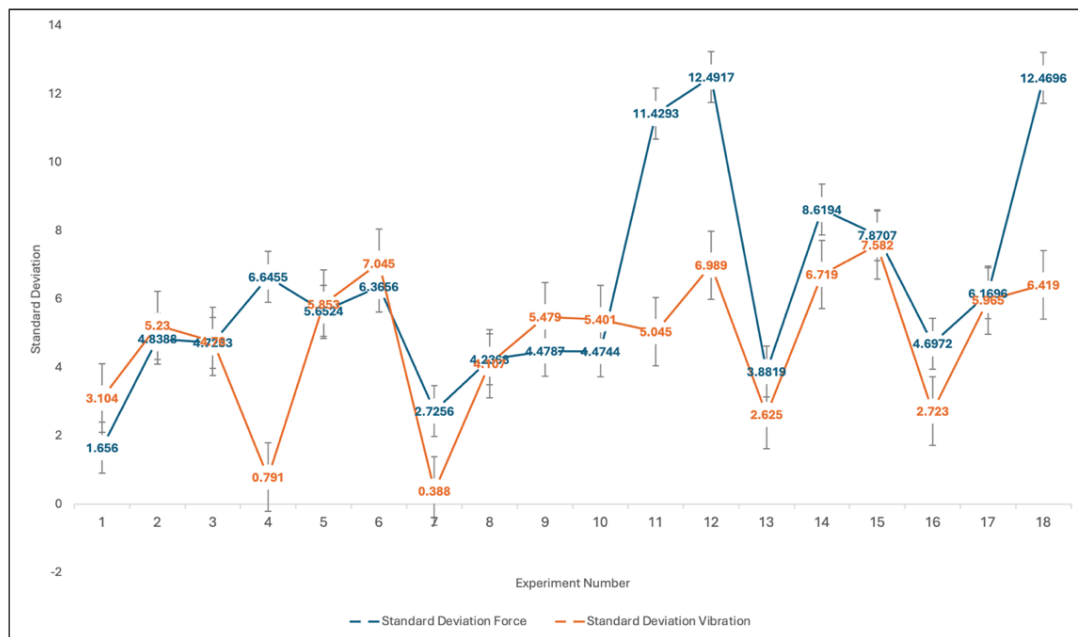


Figure 12. Standard deviation of active cutting force magnitude and active vibration magnitude.

The standard deviation was calculated for magnitude of cutting forces data and the vibration data using MATLAB academic licence, the two datasets have nearly close standard deviation values which suggests that the amount of variability or spread in each datasets is the same, even the data sets are different in terms of their values or distributions. Experiment 1 for both force and vibrations have low standard deviation indicating more consistent reading and with the less fluctuation. In experiment 12 the force has high standard deviation compared to vibration suggests greater variability. In experiment no. 3, 5, 8, 17 the values are closer for both force and vibration suggest that the variability is similar for both cutting force and vibration. This is important for analysing to assess the consistency and variability during each test.

4.4 Surface Profile Analysis

In this work, surface values of the machined workpiece were measured by Alti Surf 520 as shown in Fig. 13, the surface profile was measured for all 18 machined surfaces or 18 Experiments, the sampling length of 10mm at the scale of 100 μm using CL2 confocal chromatic sensor. The examined surface roughness parameters are R_a - Average Surface Roughness and R_z - Average Roughness Depth.

Surface roughness is measured using the Arithmetic roughness average (R_a) or Arithmetic Average roughness (R_a). This metric is often referred to as the arithmetic mean roughness value, arithmetic average (AA), or centreline average (CLA). The arithmetical average roughness is defined as the area between the roughness profile and its centre line, or the integral of the absolute value of the roughness profile height over the evaluation length [42]. Thus, R_a is given by the following Eq. 4.

$$R_a = \frac{1}{L} \int_0^L |Y(x)| dx \quad (4)$$

when evaluated from digital data, the integral is normally approximated by a trapezoidal rule.

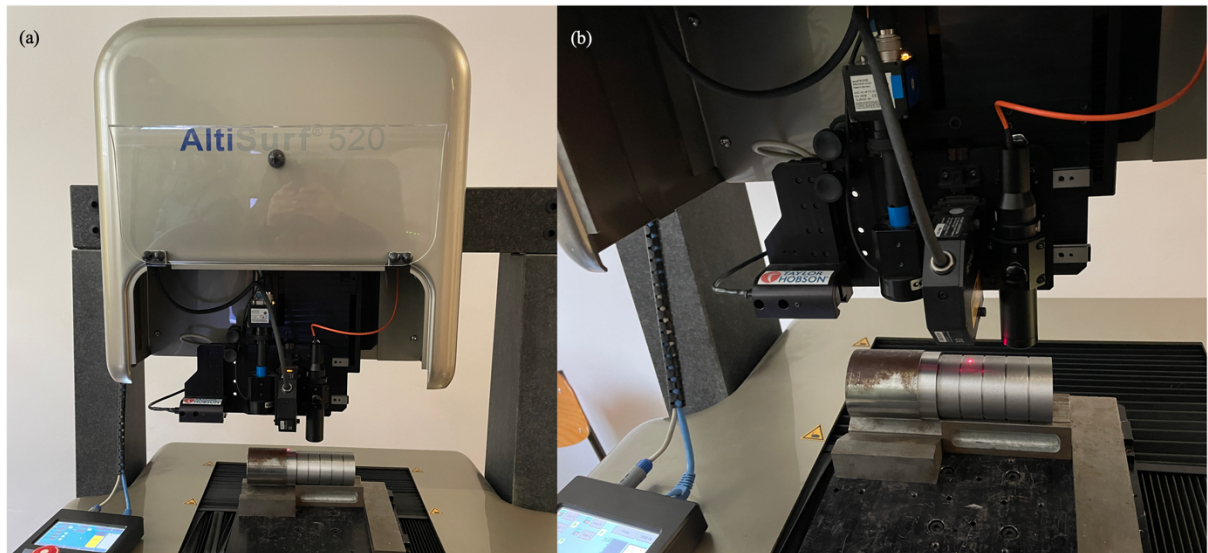


Figure 13. (a) Setup for surface profile measurement, (b) Working area of the Alti Surf 520.

$$R_a = \frac{1}{n} \sum_{i=1}^n |Y_i|, \quad (5)$$

where R_a is the arithmetic average deviation from the mean line (μm), L is the sampling length, and Y is the ordinate of the profile curve. R_z is average absolute value of the five highest peaks and the five lowest valley is defined on the sampling length, this parameter is frequently used to check whether the profile has protruding peaks that might affect static or sliding contact function. R_z is evaluated using Eq. 6 [43].

$$\frac{\sum y_{p_i} + \sum y_{v_i}}{5} \quad (6)$$

Table 7. represents the value of AA Surface Roughness and Mean surface roughness depth, the value was calculated for the correlation analysis. The surface 2D profile was measured according to ISO 4287, Gaussian filter (λ_c) was applied in accordance with the Table ISO 4288 to reduce the noise.

Table 7.

<i>2D Surface profile confocal microscopy results.</i>		
Experiment No.	AA – Surface Roughness (Ra)	Mean Surface Roughness Depth (Rz)
1	0.138	0.953
2	0.164	1.173
3	0.193	1.221
4	0.119	0.719
5	0.145	1.032
6	0.211	1.187
7	1.011	4.495
8	1.763	7.629
9	2.816	13.665
10	0.122	0.881
11	0.148	0.936
12	0.236	1.39
13	0.123	0.75
14	0.129	0.929
15	0.217	1.249
16	1.045	4.378
17	1.74	7.228
18	2.831	13.699

4.5 Vickers Microhardness Analysis

Microhardness tests were conducted in accordance with EN ISO – 6507-1 standard procedures using Mitutoyo MVK-H1 microhardness tester. Vickers microhardness analysis is important for examining and understanding the mechanical properties by analysing the variation on the turned of the turned surfaces due to different cutting parameters. S. Song et al. [44] studied that vickers micro hardness is correlated with contact hardness and relative contact pressure which are dependent on surface roughness parameters. This study also used coolant during the turning operation, cooling effect have several advantages on the turned surface, Radoslaw W. Maruda

et al. [45] studied cooling effects on microhardness and mentioned that the minimum quantity lubricant (MQCL) reduces the depth of hardened layer compared to dry cutting, indicating less structural change, G. Krolczyk et al. [46] also studied surface integrity in different cutting conditions and it has been shown that the wet cutting decreased the hardened depth of surface integrity. Microhardness was performed on the machined surface section with load of 200 g for a 10s dwell time. Hardness was measured at three points on each surfaces and average hardness was calculated to understand the behaviour between machining parameters and hardness of machined surface.

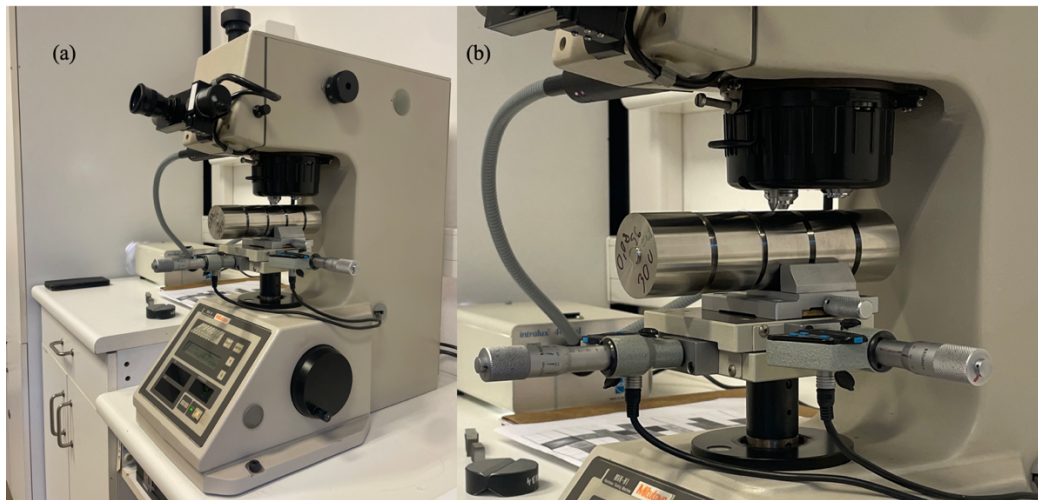


Figure 14. (a) Setup for hardness measurement, (b) Working area of the MVK-H1.

Table 8.
Vickers Microhardness results.

Experiment No.	HV0.2 – 10s
1	336
2	369
3	379
4	336
5	361
6	340
7	374
8	378
9	338
10	338
11	372
12	351
13	365
14	381
15	361
16	357
17	330
18	366

The analysis provides non-linear relation, however by looking at data from Table 9. and machining parameters it can be concluded that at low cutting speed 150 m/min, feed rate increases micro hardness increases for both depth of cut (0.5 mm and 1.0 mm). For moderate cutting speed 200 m/min the value of hardness is less consistent, but hardness is increased with feed rate increase until 0.16 mm/rev. The effect of high cutting speed on microhardness is more varied and inconsistent. From experiment number 1, 2 and 3 it can be observed that with the increase of feed rate, hardness is also increasing, which can be visible in experiment number 4 and 5 but it drops at moderate cutting speed and high feed.

4.6 Microscopic Analysis

Microscopic analysis using optical micrograph is important for detailed examination of turned surfaces, as it provides insights into surface topography and ensure precision in manufacturing processes, Liang-Chia Chen et al. [47] mentioned that microscopic surface profiles are important for ensuring strict geometric compliances in precision manufacturing. To understand the topography of turned surface, light optical microscope (Carl Zeiss microscopy, Axio Observer 5) has been used. Fig. 15 represent the optical microscopy set-up connected to the computer and the scaling was set from the setting to make the image more precise.

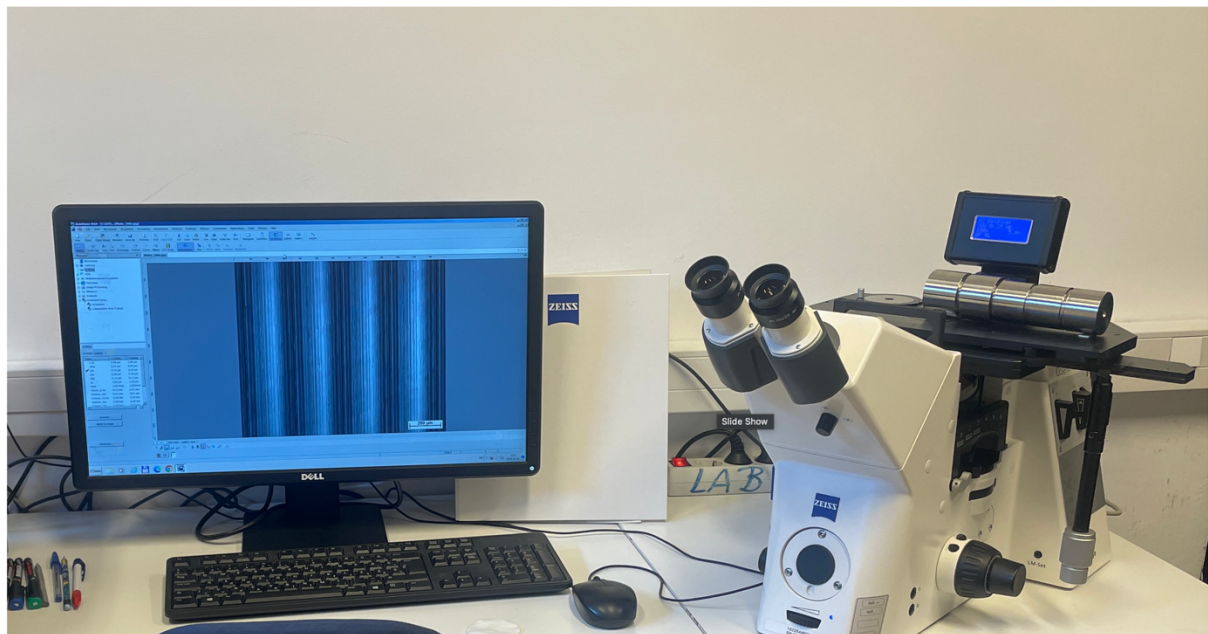


Figure 15. (a) Setup for optical micrograph, (b) Working area of the Axio Observer 5.

Fig. 16 present the optical micrograph of machined surface for experiment no. 4, 5 and 6 with different feed, 0.5 mm DOC and 200 m/min cutting speed. The results of the study showed that spacing of machined surface with varying feed rate and the feed mark can be seen on the Fig 16 (a), (b), (c), surface tearing at several points is also highlighted in the picture which represents the defects in the surface. When the feed rate is decreased the strip spacing on the machined surface become narrower, during the low and high feed rate the surface tearing can be seen in the Fig.16(a) and Fig. 16(c), with lower feed 0.08 mm/rev the surface tearing is high. This analysis was only performed for 3 experiments with same cutting speed and same depth of cut, to analyse variation of feed on the surface defect.

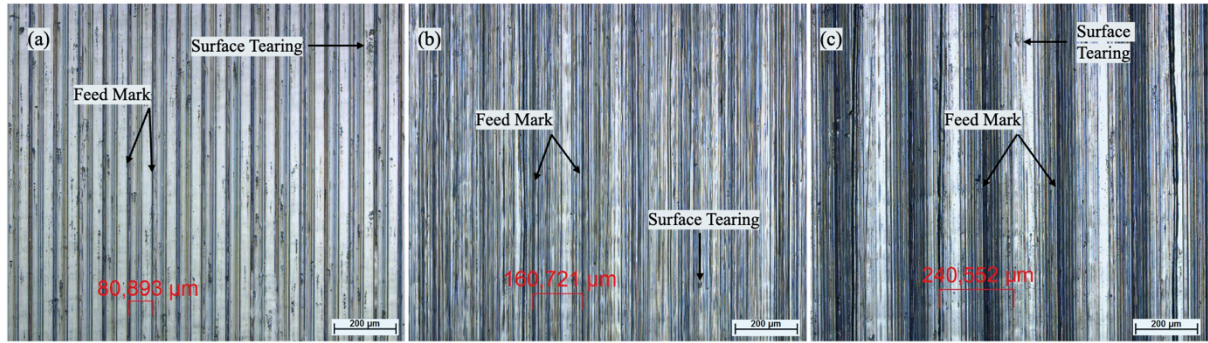


Figure 16 . Optical micrograph 100× of surfaces in turning of X5CrNi18-10, (a) $f = 0.08$ mm/rev, (b) $f = 0.16$ mm/rev, (c) $f = 0.24$ mm/rev.

4.7 Statistical Analysis

Table 9. represents the calculated data of active cutting force RMS & active vibration RMS data for correlation with machining parameters like Feed Rate(f), Depth of Cut (a_p), Cutting Speed (V_c) and calculated results of AA Surface Roughness (R_a) Mean Surface Roughness Depth (R_z) Vickers Micro Hardness HV0.2 for the correlation analysis. The highlighted correlation analysis is noted in results section.

Table 9.
Machining Parameters and results for correlation analysis.

Exp No.	DOC (a_p) mm	V_c m/min	f mm/rev	AVb RMS m/s^2	AF N	RMS	R_a μm	R_z μm	HV
1	0.5	150	0.08	10.96	134.32		0.138	0.953	336
2	0.5	150	0.16	17.83	212.53		0.164	1.173	369
3	0.5	150	0.24	19.56	291.63		0.193	1.221	379
4	0.5	200	0.08	9.56	144.45		0.119	0.719	336
5	0.5	200	0.16	14.87	241.97		0.145	1.032	361
6	0.5	200	0.24	19.61	325.04		0.211	1.187	340
7	0.5	300	0.08	9.84	122.57		1.011	4.495	374
8	0.5	300	0.16	11.82	200.19		1.763	7.629	378
9	0.5	300	0.24	14.53	270.8		2.816	13.665	338
10	1	150	0.08	16.11	279.41		0.122	0.881	338
11	1	150	0.16	24.24	421.06		0.148	0.936	372
12	1	150	0.24	20.22	589.64		0.236	1.39	351
13	1	200	0.08	8.95	249.93		0.123	0.75	365
14	1	200	0.16	17.1	389.16		0.129	0.929	381
15	1	200	0.24	17.68	537.17		0.217	1.249	361
16	1	300	0.08	10.51	236.56		1.045	4.378	357
17	1	300	0.16	15.66	377.73		1.74	7.228	330
18	1	300	0.24	17.46	520.68		2.831	13.699	366

To understand the relationship between variables, Pearson correlation analysis was studied, where correlation coefficient lies between -1 and 1. In case of coefficient of relation $r > 0$ shows a positive correlation between the two variables, the value of r is near to +1 means the

correlation is strong positive correlation, when the value is near to 0 it shows the correlation is weak. If $r < 0$ there a negative correlation between the variables which shows that by changing the value of the variable will not have the direct effect on the other.

4.7.1 Correlation analysis between Feed Rate, AVb RMS, AF RMS.

Table 10. represents the correlation between 3 main key variables of the study, feed, active force RMS and active vibration RMS, correlation coefficient between feed rate and active force RMS is 0.688, indicating very strong positive linear relationship which suggests that and increase in feed rate is strongly influences increase in active force, and there is less than 1% probability that this observed correlation is due to random variation.

Table 10.

Correlation Analysis Feed, Active Force RMS & Active Vibration RMS.

Correlations Variables	Feed Rate (f) mm/rev	Active Vibration RMS (AVb RMS)	Active Force RMS (AF RMS)
Feed Rate (f) mm/rev	1	.697**	.688**
Active Vibration RMS (AVb RMS) m/s ²	.697**	1	.699**
Active Force RMS (AF RMS)	.688**	.699**	1

** Correlation is significant at the 0.01 level (2-tailed).

Correlation between feed and active vibration RMS also suggests strong positive linear relationship with correlation coefficient of 0.697 as feed rate increases the active vibration RMS also increases. Correlation coefficient between active force RMS and active vibration RMS is 0.699 with statically significant at 0.01 level, suggests that higher active force influences higher active vibration.

4.7.2 ANOVA Results between Feed Rate and AF RMS.

According to experimental results in Table 10. first order regression model of active Force RMS as a function of feed was developed at a 95% of confidence level as shown in Fig. 17. The Eq. 7, is given by

$$y = 80.09 + 1.42E3 x \quad (7)$$

Table 11.

ANOVA of Feed and Active Force RMS.

ANOVAa					
Model		Sum of Squares	df	Mean Square	F Sig.
1	Regression	155888.17	1	155888.167	14.41 .002b
	Residual	173046.81	16	10815.426	
	Total	328934.98	17		

a Dependent Variable: Active Force RMS (AF RMS)

b Predictors: (Constant), Feed Rate (f) mm/rev

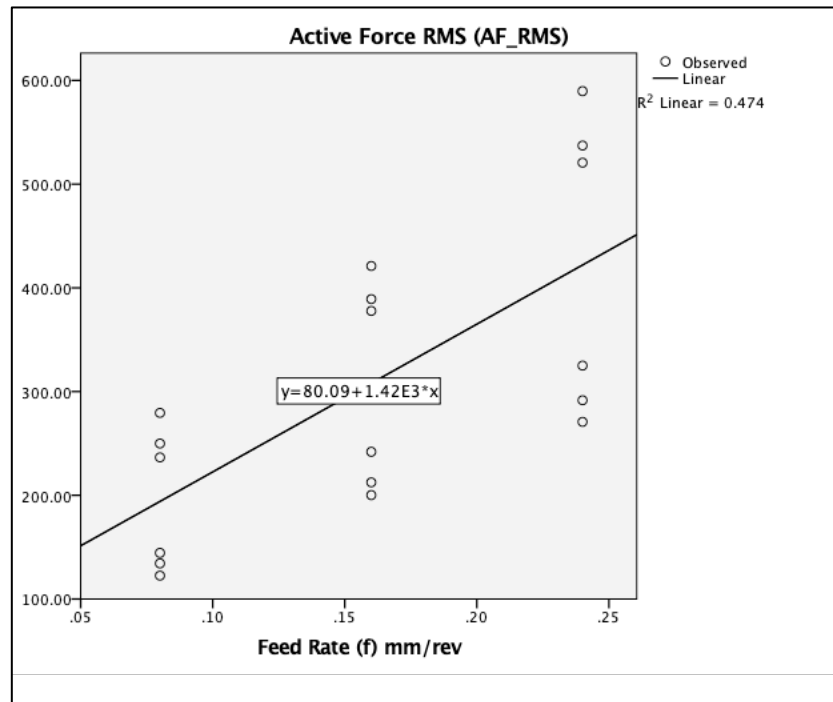


Figure 17. Linear regression line graph feed rate & active force RMS.

In the Eq. (7), y represents one variable and x represents the other variable, the Equation, $y = ax + b$ where a is the slope and b is the y intercept, which can be used to predict y based on the on the observed level of x , which highlights the impact of one variable on another. In Eq. 7, x is feed and y is active force RMS with $R^2 = 48.6\%$, y is active force RMS is in [N] and feed is in [mm/r], The analysis of variance (ANOVA) is represented in Table 11, model is found statically significant with p - value (probability of significance) less than 0.05, In this case 0.002, since the exact significance is 0.000 so the effects will be statically significant, means high significance. ^a Dependent Variable – active force RMS, ^b Predictors - (Constant), feed rate, “df” is degrees of freedom which shows the number of independent variables in the model. The analysis of variance (ANOVA) of regression was evaluated. using SPSSStatistics academic licence software.

4.7.3 ANOVA Results between Feed Rate and AVb RMS

The first order regression model for active vibration RMS as a function of feed rate as shown in Fig. 18, is given by Eq. 8.

$$y = 8.17 + 44.93 x \quad (8)$$

Table 12.
ANOVA of Feed and Active Vibration RMS.

ANOVA ^a					
Model		Sum of Squares	df	Mean Square	F
1	Regression	155.016	1	155.016	15.1
	Residual	164.275	16	10.267	
	Total	319.291	17		

^a Dependent Variable: Active Vibration RMS (AVb RMS) m/s²

^b Predictors: (Constant), Feed Rate (f) mm/rev

With $R^2 = 47.4$, the statical significance of model is studied by ANOVA as shown in Table 12. The probability of significance is less than 0.05, the exact p – value is 0.001 which is statically significant or high significance. ^a Dependent Variable – active vibration RMS, ^b Predictors - (Constant), feed rate. The value of R^2 is acceptable in both cases.

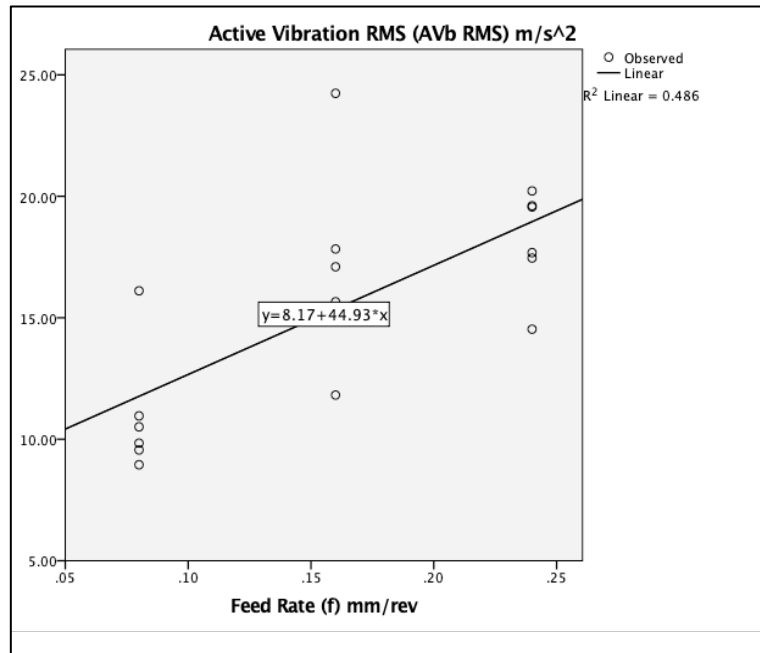


Figure 18. Linear regression line graph feed rate and active vibration RMS

4.7.4 Correlation analysis between Depth of Cut (DOC), AF RMS

The depth of cut is one of the important machining parameter which can influence the cutting forces, correlation between Depth of Cut (DOC) and AF RMS was calculated is highlighted in Table 13. Pearson correlation was studied, and it was found that correlation coefficient between feed and R_Force RMS vibration is 0.681 which represents the 68.1% of correlation between both variables. “***” Suggests correlation is significant at the 0.01 level (2-tailed). This is a stronger correlation, there is a 99% chance that a real relationship exists between the variables. There are 99% chances a real relationship exists between the above variables.

Table 13.
Correlation Analysis DOC and Active Force RMS.

Correlations Variables	Depth of Cut (ap)	Active Force RMS (AF RMS)
Depth of Cut (ap) mm	1	.681**
Active Force RMS (AF RMS)	.681**	1

** Correlation is significant at the 0.01 level (2-tailed).

To check the adequacy of the model further ANOVA analysis is performed.

4.7.5 ANOVA Results between Depth of Cut (DOC), AF RMS

First order regression model of active Force RMS as a function Depth of Cut (DOC), was developed at a 95% of confidence level as shown in Fig. 19. The Eq. 9, is given by:

$$y = 31.74 + 3.68E2 x \quad (9)$$

Table 14.
ANOVA of DOC and AF RMS.

ANOVAa						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	152690.75	1	152691	13.862	.002b
	Residual	176244.23	16	11015		
	Total	328934.98	17			

a Dependent Variable: Active Force RMS (AF RMS)

b Predictors: (Constant), Depth of Cut (ap) mm

With $R^2 = 46.4$, the value of R^2 is satisfactory, the statistical significance of model is studied by ANOVA as shown in Table .14 The probability of significance is less than 0.05, the exact p – value is 0.002 which is statistically significant or high significance. ^a Dependent Variable – active force RMS, ^b Predictors - (Constant), Depth of cut.

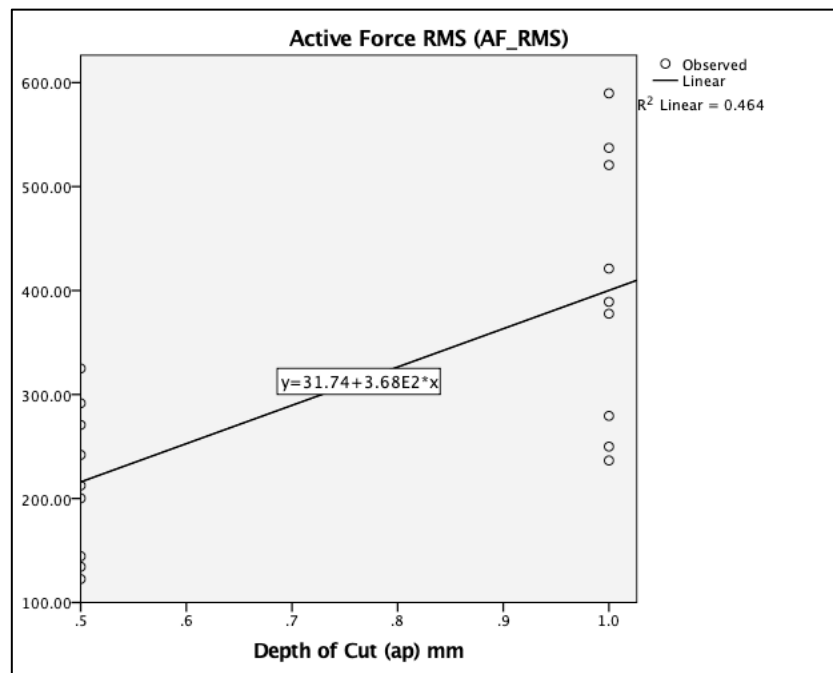


Figure 19. Linear regression line graph DOC and AF RMS.

Fig. 20, represents the main effect plots the analyse the effect of 3 parameters, feed rate, active vibration and active force Fig. 20(a). represents the plot between feed and active vibration RMS highlights the higher feed rate increases the vibration from 0.08 mm/rev to 0.16 mm/rev and moderate increase by increasing feed from 0.16 mm/rev to 0.24 mm/rev. The effect of depth of cut also shows a significant increase in influencing vibration. The cutting speed shows a decrease which implies that by increasing the cutting speed the vibration in the machining can be reduced which can be seen in Fig. 20(c). Active force RMS and machining parameters also highlights the significant results, with increase in feed rate the magnitude of cutting forces also increases, which is expected due to material removal, The AF RMS also increases with the depth of cut which can be seen in Fig. 20(e), with increase in cutting speed the AF RMS

decreases which suggests that by increasing the cutting speed the cutting forces will have low effect on the quality indicators of the final product.

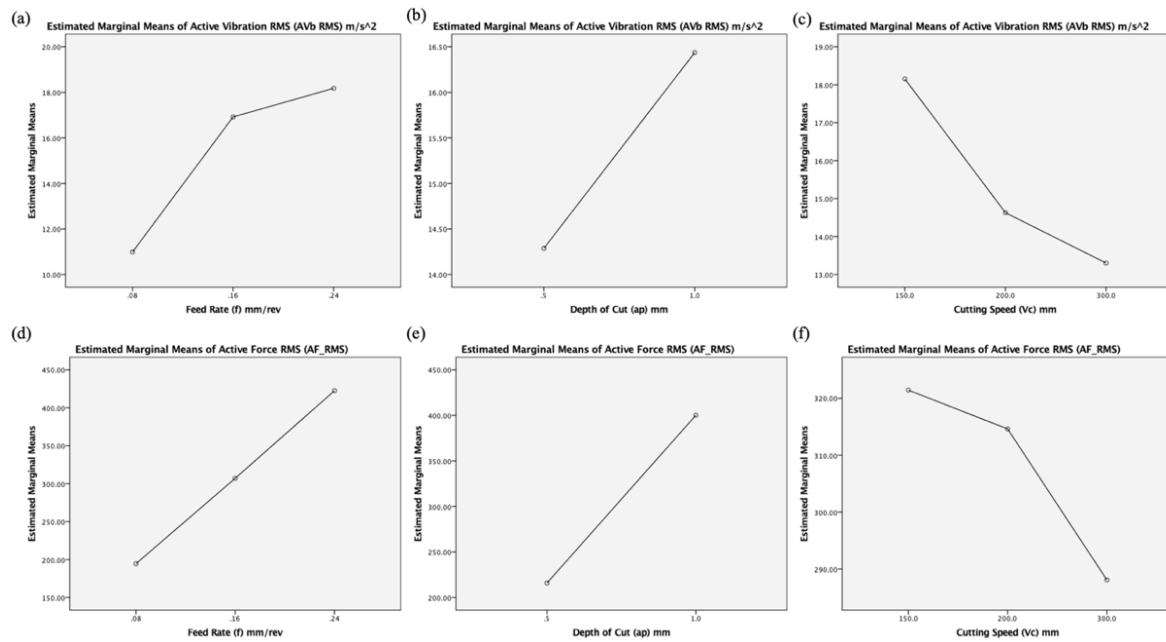


Figure 20. Main effect plot between AVb RMS, AF RMS and machining parameters.

4.7.6 Correlation analysis between Vc, Ra and Rz.

In the study a significant correlation was found between cutting speed (Vc), AA surface roughness (Ra) and mean surface roughness depth (Rz), Table 15, represents the correlation results between each variables. It can be noted from the Table 15, that correlation coefficient between cutting speed (Vc) and AA surface roughness is 0.833, with statically significant at 0.01 level, suggests that higher cutting speed influences the AA surface roughness.

Table 15.
Correlation Analysis Vc, Ra & Rz.

Correlations Variables	Cutting Speed (Vc) mm	AA Surface Roughness (Ra)	Mean Surface Roughness (Rz)	Surface Depth
Cutting Speed (Vc) mm	1	.833**	.795**	
AA Surface Roughness (Ra)	.833**	1	.996**	
Mean Surface Roughness Depth (Rz)	.795**	.996**	1	

** Correlation is significant at the 0.01 level (2-tailed).

4.7.7 ANOVA Results between Vc and Ra

To ensure the acceptability of the regression model, ANOVA is calculated and the first order regression model between Vc and AA surface roughness shown in Fig. 21, is given by Eq. 10.

$$y = 1.9 + 0.01 x \quad (10)$$

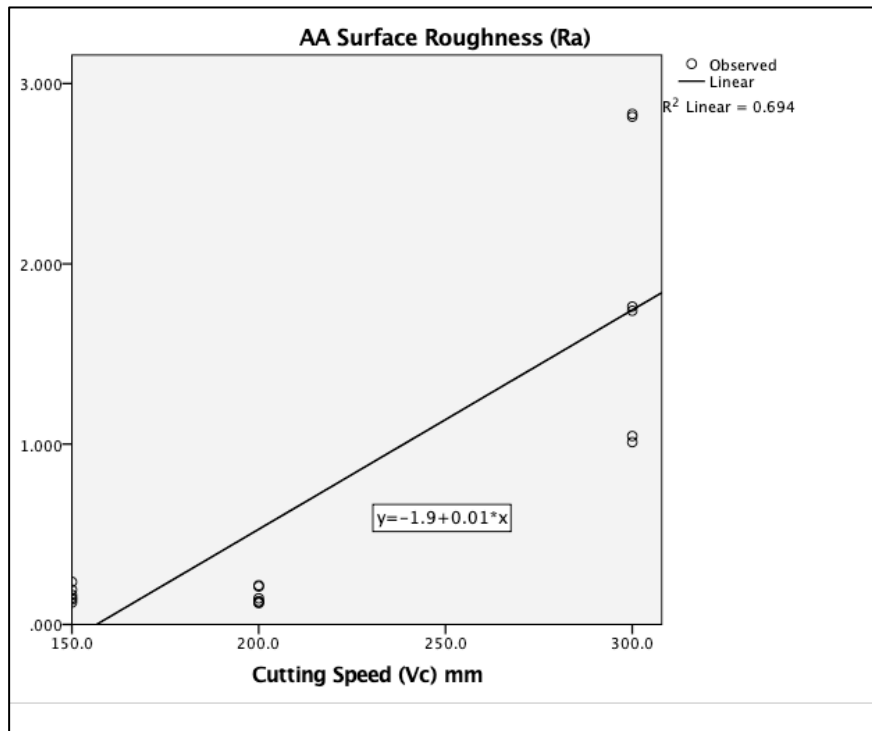


Figure 21. Linear regression line graph V_c and R_a .

Table 16.
ANOVA of V_c and R_a .

ANOVA ^a						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	10.355	1	10.355	36.287	.000b
	Residual	4.566	16	0.285		
	Total	14.92	17			

^a Dependent Variable: AA Surface Roughness (R_a)
^b Predictors: (Constant), Cutting Speed (V_c) mm

4.7.8 ANOVA Results between V_c and R_z

The correlation coefficient between cutting speed (V_c) and mean surface roughness depth (R_z) is 0.795, suggests high correlation between both variables. It implies that by changing V_c the R_z values also changes.

Table 17.
ANOVA of V_c and R_z .

ANOVA ^a						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	198.025	1	198.025	27.453	.000b
	Residual	115.411	16	7.213		
	Total	313.436	17			

^a Dependent Variable: Mean Surface Roughness Depth (R_z)
^b Predictors: (Constant), Cutting Speed (V_c) mm

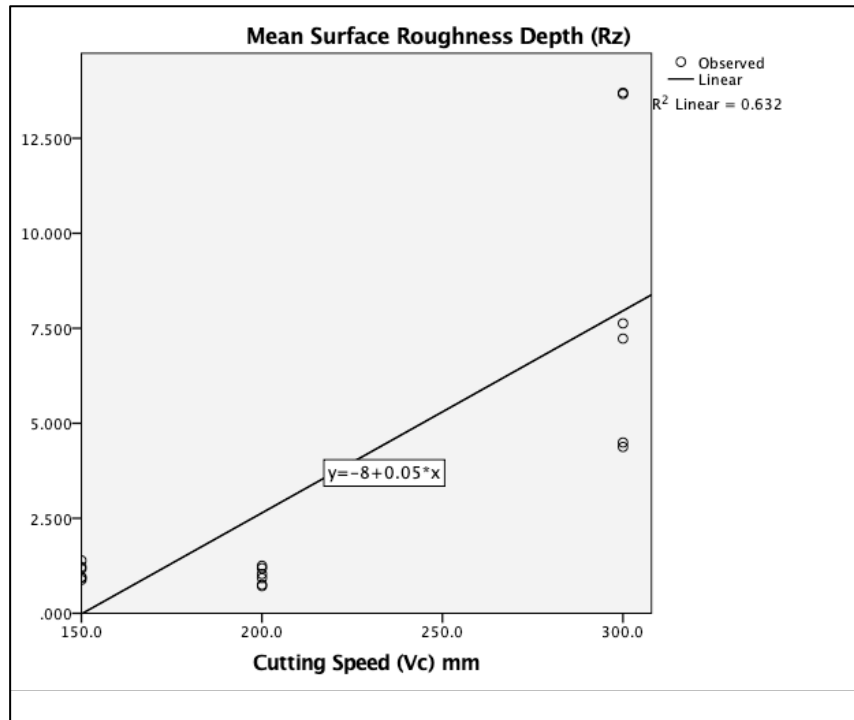


Figure 22. Linear regression line graph V_c and R_z .

Fig. 22. represents the linear regression line graph, The analysis of variance (ANOVA) is represented in Table 17, model is found statically significant with p - value (probability of significance) less than 0.05, in this case 0.000, so the effects will be statically significant, means high significance. The first order linear regression model has been developed for Cutting Speed (V_c) and Mean Surface Roughness Depth (R_z) is given by Eq. 11.

$$y = 8 + 0.05 x \quad (11)$$

With $R^2 = 63.2$, R^2 value is very satisfactory.

5. Conclusion

The present research demonstrates the machining parameters influence cutting forces and vibration. It also highlights an important machining parameter which influences surface roughness. The following conclusions can be made from the above presented research.

1. A vibration monitoring device was successfully developed using an ESP32 Microcontroller and MPU6050 Sensor.
2. From the calculation and literature it can be concluded that the direction of active forces and active vibration differs, active force is the sum of tangential and axial, whereas active vibration is the sum of tangential and radial direction.
3. Active vibration analysis suggests that with change in feed the magnitude of vibration also changes.
 - EX13 has less vibration magnitude during whole experiment, however the vibration peaks are high in comparison to EX1, EX4, EX7.
 - EX1, EX4, EX7, EX13, EX16, with feed 0.08 mm/rev gives the less vibration magnitude with different cutting speed and DOC.
 - As the feed rate is increased the magnitude of vibration can be seen increasing.
 - In order to achieve less vibration during turning of X5Cr18-10 feed should be kept low.
4. Active Cutting Force analysis also suggests similar results.
 - The low feed rate gives low magnitude of active cutting force and as the feed rate increases the magnitude of AF RMS also increases.
 - In EX12 the highest magnitude of AF RMS was observed for $V_c = 150$ m/min, $f = 0.24$ mm/rev, and DOC = 1mm, to achieve better results these value of parameters should not be taken.
5. Standard deviation results between the cutting force and vibration data suggests that the amount of variability in each dataset is same.
 - EX3, 5, 8,17 shows that the value of both force and vibration are closer, suggesting consistency during each test.
6. Surface analysis results suggests that to achieve best AA surface roughness the vibration and cutting force value should be low which is achieved in EX4.
 - It is also noticeable in all experiment that with increase of feed AA surface roughness and mean surface roughness depth is influenced.
7. Microhardness results showed that at a low cutting speed of 150 m/min, the microhardness increased for both depths of cut.
 - The effect of high cutting speed on microhardness is inconsistent.
8. Microscopic analysis results showed the spacing in machined surface at different feed rate.
 - Surface tearing can be seen for low and high feed.
 - In order to achieve less surface tearing, feed should be kept medium.
 - This point requires more research and analysis with other machining parameters.

9. Correlation and ANOVA analysis results between feed, AVb RMS and AF RMS.
 - Correlation analysis between feed and AVb RMS suggests that there is 69.7% correlation exist between the variables.
 - Correlation analysis between feed and AF RMS suggests that there is 68.8% correlation exist between the variables.
 - There is a 99% probability that a real relationship exists between each variable and it not random.
 - ANOVA results for feed and AF RMS shows significance p-value is 0.002 which is less than 0.05 suggests that model is highly significant.
 - Similarly, ANOVA results for feed and AVb RMS shows significance p-value is 0.001 which also suggests that model is highly significant and a real relationship exist between the variables.
10. Correlation analysis between DOC and AF RMS.
 - The correlation coefficient between DOC and AF RMS is 0.681 which implies that 68.1 % or relationship exist between both variable.
 - The p- value is 0.002, verifies the validity of model.
11. Main effects plots analysis between 3 machining parameters and AVb RMS and AF RMS.
 - The increase in feed rate influences the vibration also which can be observed in correlation results also.
 - With increase in DOC, the active vibration magnitude also increases.
 - However, the cutting speed has different effects to lower the vibration cutting speed must be kept high.
 - The increase in feed rate also influences the active cutting force which is noticeable in correlation results also.
 - When the depth of cut increases the AF RMS also increases which can be understood my MRR.
 - However, with increasing in cutting speed the AF RMS decreases, to achieve low AF RMS the cutting speed must be kept high.
12. Correlation and ANOVA between Vc, Ra and Rz.
 - There is 83.3% correlation between Vc and Ra and 79.5% correlation between Vc and Rz, to achieve the best good quality of surface Vc must be chosen wisely.
 - ANOVA results for both model are highly significant with p-value of 0.000.

This report made easier to understand the relationship between machining parameters and outcomes, like active vibration and cutting forces which effects the overall quality of finished product, as well as the machining parameter which has effect on the surface integrity. The parameters in the experiments were varied relatively frequently indicates that the results are good, reliable and that the relationship between variables is real. Further studies will be performed to have more accurate understanding of the effects of machining parameters on the quality of product. The research results can help improve manufacturing efficiency, predictive maintenance, and the development of more robust vibration resistance tools specific to materials and machining conditions.

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