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Smart Monitoring of Vibration in CNC Turning Tool Holders: Arduino-Based Sensor Interface

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Abstract

Vibrations are a common problem in CNC turning operations, affecting the machine tool's overall performance and productivity. The geometrical accuracy and surface quality are reduced as a result of repeated vibrations, reducing tool life. Vibrations can now be sensed and responded, thanks to new advancements in electronic technology. The goal of this research work is to use a 3D accelerometer(sensor) to measure vibrations and determine the value of vibration and its causes by analyzing data on specific axes to take corrective action. Collecting vibration data while doing turning operation was needed to understand the impact of vibrations on Tool life & surface roughness. To capture vibration on the tool holder while turning, a 3D accelerometer (sensor) was attached or mounted on tool holder. The sensor attached to tool holder is connected to Arduino UNO, Arduino is connected to laptop. With the help of software and the Programme we can get the live reading of vibration while doing turning operation. Thus, real-time data on vibrations while turning will be available for analysis, with the use of electronic technology. After determining the vibration data the causes of vibrations, will be known to us. Then by variation in machining process parameters and reducing the causes of vibrations, we can improve the tool performance and quality of machining.

Keywords: CNC Turning, Vibrations, Surface quality, 3D Accelerometers, Machining parameters, Sensors.

INTRODUCTION

Cutting force is critical due to many cutting force features in turning processes that can help predict and detect tool conditions like tool wear, tool cutting mechanism, and vibrations [1]. A lot of commercial devices are designed to accurately measure cutting forces, but their cost and some installation practicalities might restrict their usability in actual applications. The cutting force should be assessed using a straightforward, small, user-friendly, and affordable technical technique suitable for small and medium-sized businesses. The current investigation measures the cutting force generated by a CNC turning machine during a turning operation by adjusting the rake angle of the tool holding device and installing a tool the owner sensor.. Sensors are directly attached to the tool holder shank, one on the top and one on the bottom of the rectangular shank, to measure vibrations and gauge cutting force [2]. The suggested tool holder sensor attachment accurately and successfully detects cutting forces under various turning situations, according to several machining experiments performed on a CNC turning machine [2].

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Surface finish, cutting forces, tool life, chip morphology, and vibration in Ti6Al4Vmachining are influenced by machining factors such as cutting speed, feed, depth of cut, tool type, cooling techniques, and cutting approach angle [3, 4].

The forces and vibrations produced during metal cutting are closely related to the cutting conditions and have an effect on heat generation, tool wear, the quality of the machined surface, and the accuracy of the workpiece dimensions [5]. The goal of measuring and calculating these cutting forces is to gain a better understanding of the mechanism of cutting, including how cutting variables affect cutting force; workpiece machinability; chip generation; chatter; and tool wear [6]. In contrast to the experimental readings with the data received from the smart instrument, the values obtained from the data collected through some inaccuracies can be found in engineering calculations [7]. A cutting force is produced during the turning process as a result of the tangential force, feed force, and radial force [2]. About 70% of the resultant is caused by the tangential force, 25% by the feed force, and just 5% by the radial force. These ratios are described in [8].

An object's anatomical state during cycling or oscillating motion in its status during starts up, shut-down, and standard posture is known as vibration, as well as when the system is deported from its normal state. The number of repeating cycles per unit of time is how it is defined. The Hertz (Hz) is the SI unit of measurement for frequency. The number 'f' represents frequency. The symbol "T" represents a period, which is the exact opposite of frequency and is the length of a single cycle. The change in velocity over time is expressed mathematically as speed. Due to the presence of both magnitude and directions, in this case, the SI unit for measuring acceleration is (m/s^2), which is a vector quantity [9].

Sensors will be used in machining to measure tangential force and feed forces. This technique uses a tool holder a specially designed tool with various rake angles. The product's upper and lower sections are linked through these two sensors. The sensor is embedded in the cutting tool shank between the upper and lower parts. The cutting force in the machining is measured by this sensor. Another sensor is embedded in the cutting tool shank's lower portion. The feed force will be measured with this sensor. The sensors are held in place with insulators. The metal shim that acts as the sensor's electrode extension and generates the voltage output has a connection wire connected to it. When force is applied to the sensor, it can generate electric charge signals. The Arduino receives the generated signals. Making a very accurate sensor that can measure cutting forces is the aim of this research work. (Such as main tangential force Fc, feed force Ff, and thrust force Fp) during high-speed turning [1].

FORCE MEASUREMENT AN OVERVIEW

Cutting force is a crucial sign of how well the metal cutting process is working, Including the quality of the workpiece, the cutting power, and tool wear [10–12]. Real-time cutting force measurements allow for the observation of cutting conditions and the timely adjustment of cutting parameters, all of which will increase cutting effectiveness, prolong insert life also save machining costs. The need for extremely accurate cutting force measurement during the high-speed metal cutting process is growing as machining processes become more complex in terms of both speed and precision. As a result, there is a considerable need for a cutting force sensor with high natural frequency and accuracy Since the middle of the 20th century, cutting force measuring research has been ongoing [13]; and numerous types of cutting force sensors, including current, vibrant, fiber-optic, strain gauge, and piezoelectric sensors, have been developed [14–16]. Some of them meanwhile, can meet the demands of high precision and high natural frequency. Owing to their outstanding stability and efficiency strain gauge and piezoelectric sensors have received much more attention to date. For instance, Ergun Ates and Kadir Aztekin created a uni-piece strain gauge-based cutting force sensor for a lathe with two axes [17]. The sensor has a good measuring error (3.75%), however, it can only detect the three, or two components of the cutting force, and the author did not explain how detected cutting forces interact with one another. Tulio Hallak Panzera created a three-dimensional cutting force sensor using the same theory, and its consistency was below 8.4% percent. [18] The natural cycle though, is ignored in this study.

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Additionally, as a lathe tool post needs to be taken out to attach the sensor, the developed sensor was incompatible with utilizing a lathe system. The original lathe system might be impacted by this. A cutting force sensor for turning that uses a strain gauge was also developed by Süleyman Yaldiz [19]. However, he sacrificed its natural frequency in favor of low output errors and cross-sensitivity (0.17 percent to 0.92 percent) (0.12 percent -0.8 percent) (159.2 Hz). A piezoelectric modular sensor for measuring three-dimensional cutting forces in turning was proposed by G. Totis et al [20]. The finite element method (FEM) calculation shows that this work performs well, with relative static errors under 5.91 percent and an average natural frequency of 1 kHz. Strong linearity and low cross-sensitivity are characteristics of the piezoelectric film embedded smart cutting tool developed by Chao Wang et al. for monitoring cutting force [21], however, it is limited to measuring one aspect of the cutting force and is unable to detect signs of consistent force. To measure cutting forces under high precision and high-speed metal cutting conditions, only a small number of cutting force sensors generally possess the favorable accuracy and high natural frequency needed.

Realistically, Uquillas, Daniel Alberto, and Syh-Shiuh Yeh A cutting force is produced during the turning process as a function of the tangential force (Ft), feed force (Ff), and radial force (Fr). About 70% of the resultant is caused by the tangential force, 25% by the feed force, and just 5% by the radial force. These ratios are described in [8]. The sensor is built with four chambers, one for the strain gauges and three on either side of the tool holder shank. The cables for the strain gauges can also pass via a hole in the shank. Four to quantify the strain produced by the tangential force and the feed force during cutting, strain gauges are positioned on each face of the tool holder.

Given the percentage relationship between the three force components mentioned above, we can approximate the resultant value by measuring only the tangential force and the feed force. The Wheatstone bridge circuit's half-bridge arrangement is used for the test. The feed force is measured using the second pair (right and left), whereas the tangential force is measured using the first pair (top and bottom). By doing so, we may examine the cross-sensitivity and estimate the cutting force's component.

A high-precision sensor that can measure the three triaxial cutting forces—the main cutting force (Fc), the feeding force (Ff), and the propulsion force (Fp)—during a high-speed turning operation is the goal of the study by You Zhao, Yulong Zhao, Songbo Liang, and Guanwu Zhou. A unique design for measuring tri-axial cutting forces was proposed, consisting of two mutually perpendicular octagonal rings. Because of the effect of the circular ring theory the sensitive element of the created sensor is determined to be an octagonal ring [1].

For a circular ring, It is possible to compute the ring's outer surface tension when force Fp or Fc is applied to it; Where r, t, and b are the average radius, thickness, and width of the circular ring, respectively; stands for the ring's surface tension; k as constants with according to certain standards. The forces Fp and Fc are applied vertically and tangentially to the top of the ring, respectively. The angle of inclination between the cross section of the ring and the vertical plane is indicated by the circumference ratio.

The equations above demonstrate the connection between the forces Fp and Fc and the ring's surface stress. An octagonal ring is frequently used to replace a circular one since it is easier to fix and looks similar [22–24].

The purpose of this Research by, Viral K. Patel & Maitri N. Patel is set up as follows A brief description of the created smart sensor is given. The suggested programming and interface for Arduino and Lab-VIEW are described, and some final observations are offered. An innovative smart sensing device for tracking the status of machines and measuring vibration. With this Arduino microcontroller board, an accelerometer is incorporated. A smart sensor powered by a microprocessor will be used to

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gather 3-D vibrations, and the microcontroller will store the data so it can be transferred to other devices (such as a laptop or PC) for additional signal processing. Vibration monitoring provides a great deal of promise for finding localized machine problems, according to analytical methods [25].

Jorge Cubas, Josuet Leoro, Daniel Reyes, and Syh-Shiuh Yeh designed the tool holder in this study utilizing the same fundamental technique described [2]. There were various steps in the procedure to determine where the strain gauges should be placed. The strain gauges were set within tiny chambers after investigating the tool holder and determining the ideal location for the sensor to minimize vibrations and obtain accurate data. These were created specifically to meet all the requirements, including protection from the working environment and sensor shape. Placing the strain gauges improved the chance of obtaining greater strain values. Compared to the experiment where they were attached directly to the tool holder surface.

Additionally, an interior hole was constructed to accommodate the sensors' cables. To maintain the tool holder stiff and achieve optimal performance, the strain response of several designs was simulated using CAD/CAE software.

Sensors are affixed to the tool's top, and a vibration exciter is positioned at its base to reduce vibration. When a tool vibrates, the sensors will detect it, and the vibration exciter will produce an opposing vibration force to make the tool stop vibrating. By doing this, we can get components with nice surface polish. This methodology offers the simple and flexible control of vibration over conventional complex methods, and the system adapts itself for variation in process parameters on top of being economically feasible. Online movement decreased leads to better surface finishes and longer tool life.

R. Kaaliarasan has developed Design, A clever cutting device inbuilt micro-cooling that shows how it can reduce machining costs while also taking environmental considerations into account [26]. The use of less cooling fluid and more energy- and resource-efficient machining techniques can both reduce manufacturing costs [27]. By limiting contamination of created swarf and reducing the cutting temperature, environmentally friendly internal micro cooling can decrease tool wear, increase machining accuracy, and enhance machining economics [28, 29].

APPLICATION OF SENSORS & ARDUINO

The smart sensor instrument assembly is a microprocessor-based sensing unit that can gather 3-dimensional vibrations. To accurately capture low amplitude signals and prevent any loading effects, signal measurement and amplification are conducted in the ADXL335 Triple axis accelerometer circuit, which is depicted in Figure 1. The amplified signal is collected by the Arduino UNO microcontroller and delivered to any third-party device on a desktop or laptop computer via a serial communication protocol [25]. Software for computers can be used to view the collected data (Tables 1 and 2).

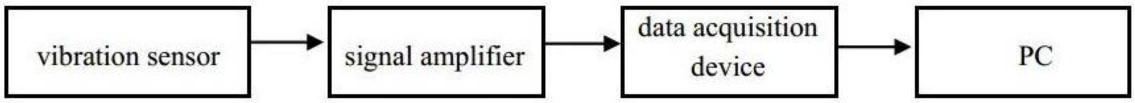

Figure 1. The Components of the System.

Vibration sensing and amplification by ADXL335 Triple axis

The ADXL335 Triple Axis Sensor, as depicted in Figure. 2, is a small, thin, low-power 3-axis accelerometer sensor with signal-conditioned voltage outputs. The gravitational constant, g, has a full-scale range of approximately 3 g (1 g = 9.8 m/s2). In tilt-sensing applications, it can detect both the static acceleration of gravity and the dynamic acceleration brought on by motion, shock, or vibration.

The Xout, Yout, and Zout pin capacitors Cx, Cy, and Cz are used to control the bandwidth of the accelerometer.

Table 1. Specification of Arduino UNO.

Microcontroller	AT-mega 328P
Operating Voltage	5V
Input Voltage (recommended)	7 to12V
In-out Voltage (limit)	6 to20V
Digital I/O Pins	14 (of which 6 provide PWM output)
PWM Digital I/O Pins	06
Analog Input Pins	06
Analog Input Pins	20mA
DC current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328P) of which 0.5 KB is used by the boot loader
SRAM	2 KB (AT-mega 328P)
EEPROM	1 KB (AT mega-328P)
Clock Speed	16 MHz
LED_BUILTIN	13
Length	68.6
Width	58.4
Weight	25 g

Table 2. Specification ADXL335 Triple axis module.

The ADXL335 Triple axis	Three-axis acceleration measurement
Module measures acceleration within the range	±3 g in the x, y, and z-axis
Module produces analog voltages	Proportional to acceleration as output signals.
Highest voltage level	0 g is 1.65V
Operating Voltage	1.8V to 3.6V.
Operating Current	350µA.
Temperature Range	−40 to +85°C.
Sensitivity	270 to 330mV/g
Shock Resistance	Up to 10,000g.
Dimension	4mm x 4mm x 1.45mm

The bandwidths for the X, Y, and Z axes can range from 0.5 to 550 Hz and from 0.5 to 1600 Hz, respectively. The ADXL335 Triple axis sensor comprises a poly-silicon surface micro-machined sensor and signals conditioning circuitry to perform open-loop acceleration measurement architecture. An analog voltage proportionate to the acceleration serves as the output signal. In tilt sensing applications, the accelerometer can measure the dynamic acceleration caused by motion, shock, or vibration in addition to the static acceleration of gravity. Acquisition of vibration sensor, signal amplifier, and data [25].

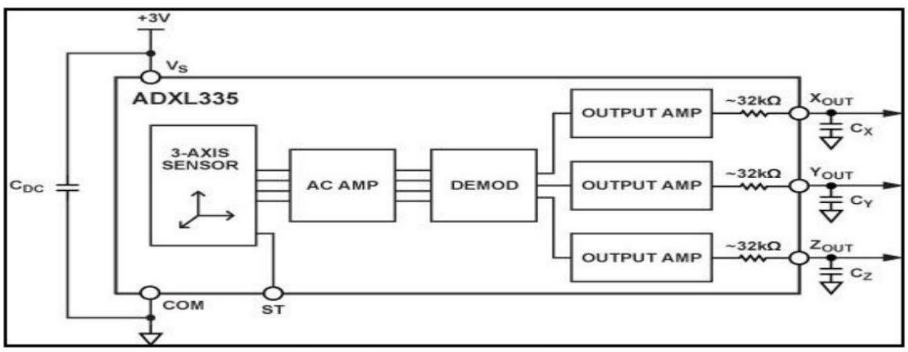

Figure 2. Vibration measurement and amplification.

The sensor is a micro-machined poly-silicon surface structure built atop a silicon wafer. In addition to resisting acceleration forces, polysilicon springs anchor the structure to the wafer's surface. Using a kind of differential an capacitor with distinct fixed plates and plates connected to the moving mass, the

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deflection of the structure is measured. The centered plates are moved by 180° out of phase square waves. Acceleration deflects the moving mass, throwing off the differential capacitor's equilibrium and resulting in an amplitude of the sensor output that is inversely connected to acceleration. Phase-sensitive demodulation algorithms are then used to determine the direction and amplitude of the speed.

Three Dimensional Measurements

The X, Y, and Z axes are sensed by the single-structure ADXL335 Triple Axis. As a result, there is minimal cross-axis sensitivity and the three axes' sensing directions are highly orthogonal. The most common cause of cross-axis sensitivity is mechanical misalignment of the sensor die with the package. Of course, system-level correction is possible for mechanical misalignment.Performance: Instead of adding additional temperature adjustment circuitry, cutting-edge design techniques ensure that the ADXL335 Triple Axis has a high-performance built-in. Temperature hysteresis is negligible (usually less than 3 mg throughout a temperature range of 25°C to +70°C), and there is no quantization error or non-monotonic behavior as a result [10].

Setting the Bandwidth

With the use of the letters Cx, Cy, and CzThe ADXL335 Triple Axis' X-out, Yout, and Zout pins can To achieve low-pass filtering for anti-aliasing and noise reduction, capacitors are similar require being added to each of these pins. be band limitedThese pins need capacitors are similar added in order to provide low-pass filtering for noise elimination and aliasing... The 3 dB bandwidth is calculated using the formula F3 dB = 1 / (2(32 k) C(X, Y, Z). The bandwidth fluctuates as a result of the internal resistor's tolerance, which can vary by up to 15% of its nominal value (32k). It is suggested that Cx, Cy, and Cz have a minimum capacitance of 0.0047F in all circumstances [25].

Noise Consideration

The scale factor, or output sensitivity, of the ratiometric ADXL335 Triple Axis is directly proportional to the supply voltage. The output sensitivity is usually 360 mV/g at Vs = 3.6 V (Vs = Supply voltage). Typically, the output sensitivity is 195 mV/g when Vs = 2 V. Although the noise density drops as the source voltage increases, this is because the output noise is absolute in volts as opposed to the ratio metric. This is true since the noise voltage does not change but the scale factor (mV/g) does. For Vs = 3.6 V, the X-axis and Y-axis noise density typically range from 120 g/Hz to 270 g/Hz, while at Vs = 2 V, the opposite is true. As a result, noise signal interference can be reduced by employing a high supply [25].

Vibratory Signal Acquisition Using Arduino

Here, two objectives are accomplished by using the ARDUINO-DAQ, a microcontroller-based data acquisition board:

An independent data gathering system with data buffering capabilities should be utilized to lessen the computational load on the primary central fault diagnostic system.

Specialized hardware that is durable enough to resist the tough industrial environment and may be fitted near the motor.

The ATmega328-based Arduino Uno microcontroller board is named after the Italian word for one, uno. It features a 16 MHz ceramic resonator, a USB port, a power jack, an ICSP header, a reset button, six analog inputs, and fourteen digital input/output pins, six of which can be used as PWM outputs. All the components required to get started are included with the the Arduino; all you need to do is power it by connecting a USB cable to a computer, using a battery, or by using an AC-to-DC adapter. Using the Uno also has the advantage of relatively inexpensive chip replacement. Although there are other more sophisticated boards available, the UNO board—the very first Arduino board will work for this project (Figure 3).

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Figure 3. Arduino board with In-circuit Serial Programming (ICSP).

Interfacing an ADXL335 Triple axis accelerometer with an Arduino is simple in this case. The Arduino board, ADXL335 Triple axis accelerometer, connecting wires, and USB cable to connect the Arduino board to a computer are all required for this process [25].

Process for Circuit Building

The Arduino board is wired to the five pins of the accelerometer. Connect the Arduino's GND pin to the GND pin of the ADXL335 Triple axis. Then, attach the ADXL335 Triple Axis VCC (supply voltage) to the Arduino's 5V, followed by the analog pins for X, Y, and Z on the Arduino: A5. Following the foregoing wiring, the finished product is depicted in Figure 4. The reference voltage for analog to digital conversion would be 5V. Each of the six analog inputs on the Arduino Uno has a resolution of 10 bits and is designated A0 through A5 (i.e. 1024 different values). By default, they measure between zero and five volts, but the Aref pin and the analog Reference () function allow you to adjust the upper limit of their measurement range [25].

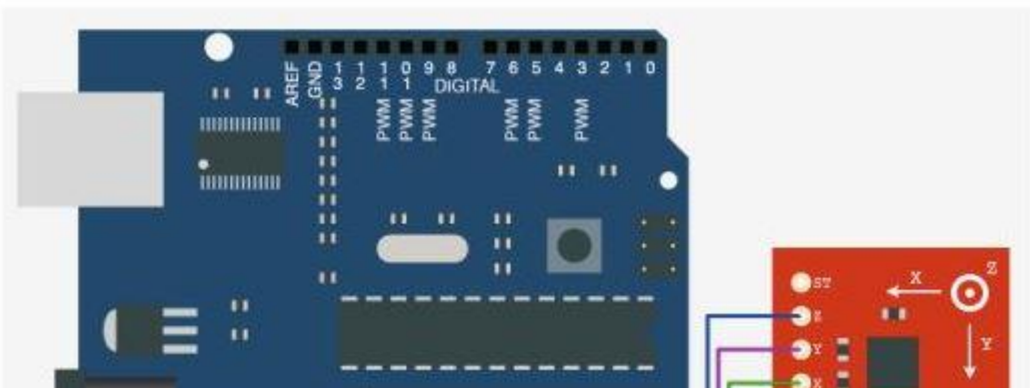

Figure 4. Interfaced Arduino with ADXL335.

Arduino Programming

The ATmega328 controller is then programmed using a USB to serial programmer after the Arduino has been connected to the accelerometer. The Arduino Uno's ATmega328 is pre-burned with a boot loader that enables code updates without the use of an external hardware programmer. The following example software demonstrates how to retrieve sensor data and send it to a PC, laptop, or other devices. The following capabilities are part of the Arduino software: a serial monitor that enables monitoring of simple text data delivered to and received from the Arduino board. The Arduino Uno may connect to a computer, another Arduino, or other microcontrollers to communicate. The ATmega328 enables serial communication via TTL (transistor transistor logic) and UART (universal asynchronous receiver transmitter) on digital pins 0 (RX) and 1 (TX) (TX). The ATmega16U2 controller on the board, which the computer's software sees as a virtual com port, channels this serial connection through USB (Tables 3 and 4). The last step is to provide these data to external software for vibration analysis, like Lab VIEW (Laboratory Virtual Instrument Engineering Workbench) [2].

Table 3. Experimental details considered for the present study.

Work piece material and dimensions	Titanium Alloy (Ti6Al4V) Dia:- 40mm, Length:-80mm.
Cutting inserts	DNMG110408 MP3
Working insert tool geometry	Diamond shape with PVD coated
Coolants used	CIMCOOL 360
CNC	MTAB (Two axis Turning)

Table 4. Process Parameters.

S.N.	**Cutting Speed (Rpm)**	**Feed Rate (mm/rev)**	**Depth of Cut(mm)**
1	80	0.12	0.6
2	100	0.18	0.12
3	120	0.24	0.18
4	140	0.30	0.24
5	160	0.32	0.30
Symbol	*V*	*f*	*d*

Material

The material used for the experiment is Titanium alloy (Ti6Al4V) of 40mm diameter & 80 mm long round bar. In all, there were four pieces of the same dimension & material for the trial. The details properties of Titanium alloy (Ti6Al4V) are given in Table 5.

Table 5. Properties of Titanium Alloy Grade 5 (Ti6Al4V).

ASTM Grade UNS No	5 R56400
Chemical Composition Content Wt %	C Fe N O Al V H TI 0.08 0.25 0.05 0.20 5.50-6.75 3.5-4.5 0.01 Balance
Tensile Properties Ultimate Strength Yield Strength	 896 Mpa 827 Mpa
Physical Properties	
Hardness	33 HRC (Normal), Brinel Hardness 220-280
Nominal β transform	996°C
Melting Point (approx)	1650°C
Modulus of elasticity	114 Gpa (tension), 42 Gpa (torsion)
Thermal Conductivity	6.6 W/m °C
Machinability rating	0.2

Tool Details

WALTER *Tiger* tec inserts set a completely new standard in the field of cast iron machining. Due to the high cutting speeds and feed rates, productivity is markedly increased in terms of cast iron machining. Now, you can pro fit from these advantages also when it comes to the machining of steel. *Tiger* tec Steel is available in three grades: WPP 10, WPP 20, WPP 30. The three cutting tool material

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grades cover the complete range of steel workpiece materials from unalloyed structural steel through to low alloyed steel, and case hardened steel to the high-alloyed and tempered steels with a tensile strength within the range of 1300 N/mm^2. The cutting tool grades are selected according to the hardness/toughness ratio of the cutting tool material and the machining conditions:

- WPP 20 Universal grade covering about 80% of all applications
- WPP 10 Ideally suitable for maximum cutting speeds at favorable machining conditions WPP 30 Solves every problem when it comes to difficult cutting conditions and interrupted cuts whether for finishing, medium cutting, or roughing:

The new grades are available for all steel geometries of the negative basic shape

The new multi-layer coating structure excels in ultimate wear resistance combined with optimal toughness.

Walter Insert DNMG110408 MP3 coated with PVD (TIALN) was used for the experiment as per the holder specification of the CNC MTAB MAXTURN machine. A total of 08 number inserts were used for 25 trials as per DOE. The detailed specification of Insert is given in Table 6.

Table 6. Cutting Insert Details.

ISO Designation	**Coating**	**Grade**	**Manufacturer**
DNMG110408 MP3	PVD-TIAIN	WPP10	WALTER *Tiger* tec

Coolant

For optimal performance, water-based metalworking fluids need to be mixed correctly and kept within the correct concentration range. To make sure the starting concentration is accurate, the fluid concentration needs to be tested before mixing it with water to charge the machine's fluid reservoir or central system. A chemical titration method, CIMCHEKTM test strips, or a CIMCOOL Refractometer can be used to measure the concentration [31]. The percentage or ratio of the amount of emphasize fabrication fluid to the total volume of the mix can be used to express concentration. The concentration used to initially fill a devoid sump is known as the "charge" combine it with ratio. The "makeup" mix ratio, which is also which is usually less than the the midst ratio, is the concentration used to make up for fluid losses from evaporates and carry-off. For experiment purposes, we have used CIMCOOL 360 as a coolant for all 25 trials with a 15% concentration [4].

Coolants remove heat and metal cutting (chips) from the cutting zone. A coolant can break up chips and avoid damage to the cutting tool. Coolants also provide a lubrication role. The removal of heat and available oxygen has two-fold benefits: to reduce chemical reactions between titanium and cutting tools, and mitigate the risk of titanium fires [32]. The temperature drops at the cutting interface as a result of better coolant access nearer the cutting edge of the tool. Because of the decreased tool degradation rates, this demonstrated a notable improvement in tool life [33].

Table 7. Coolant Details [4].

Coolant	**Concentration**	**Pressure**
CIMCOOL 360	15%	10 Bar

The three functions of cutting fluid are chip transportation, cooling, and lubrication. Cutting fluid also protects machine parts from corrosion and oxidation (Table 7). Cutting fluid has a considerable impact on the durability of tools, the productivity of processes, and the quality of output [30]. As a lubricant to reduce tool wear, cutting force, the formation of built-up edges, and friction between the tool and the workpiece. As a result, energy consumption, tool wear, and workpiece surface roughness can all be decreased. Production is also increased by using higher feeds and speeds. Redirecting the heat from the cutting region and bringing the tool's and the piece being cut's temperature down, acting as a coolant. As a result, tool wear is reduced and the work piece's dimensional tolerance is raised. The

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cutting fluid also flashes the chips away from the tool and workpiece, reducing the risk of early tool failure and workpiece quality degradation due to chip embedding [30].

Experimental Setup

The MTAB MAXTURN is a small industrial slant bed lathe with an 8-station a programmable turret that is utilized to turn Ti6Al4V alloy. The FANUC MTAB industrial controls are included with the machine being used. Cast iron bed, high-quality pinned ball screws, LM directions, servo motors, a cooling agent system, AC panel cooler for control box, complete machine guard, and other features are just a few of its small design elements (Figures 5 and 6). MAXTURN can be integrated with automation components such as a robot, and gantry for automating production. It is suitable for prototyping and batch production of light machining operations (Tables 8 and 9).

Table 8. Product Specification.

Model Name/Number	**MAXTURN**
Max Spindle Speed	4000 rpm
Spindle Motor Power Siemens Continuous	3.7 KW
Standard Chuck Size	135 mm
X-Axis Stroke	230 mm
Maximum Turning Diameter	80 mm
Maximum Turning Length	190 mm
Spindle Size	A2-4

Figure 5. CNC Machine.

Acceleration Data Plot (Arduino)

Real-time data for analysis is required or feedback is needed to control and monitor the operation in processes. The real-time information helps to control the sudden breakdown or damage by controlling the machining parameters in Figure 7. The graph shows the Acceleration data received is plotted on X-axis against time(Sec) in the range of (-15.79 to 9.44m/s^2).

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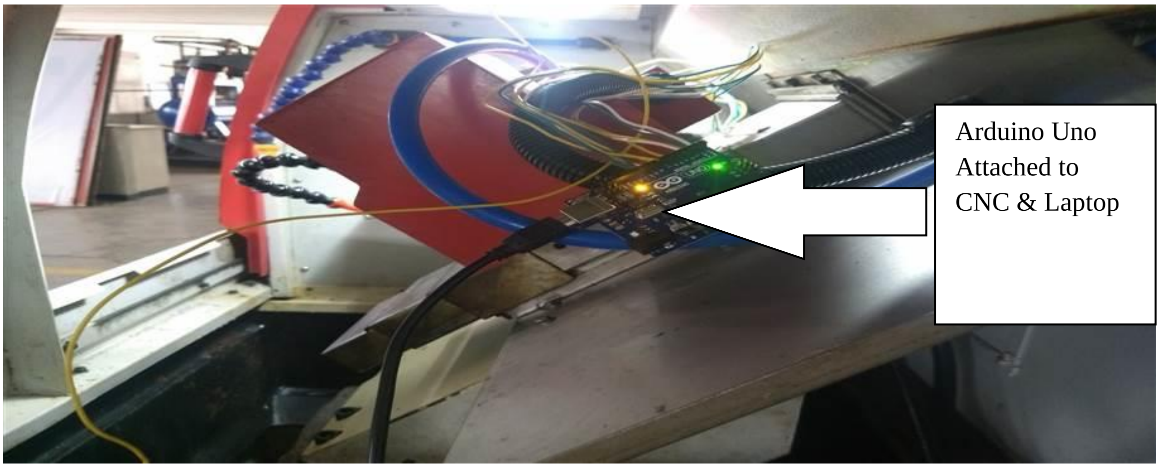

Figure 6. CNC Machine with arduino.

Table 9. Data of Acceleration and Force(Arduino).

Acceleration on X axis (m/s^2)	Acceleration on Y axis (m/s^2)	Acceleration on Z axis (m/s^2)	Force in X (N)	Force in Z (N)
8.71	-4.05	-3.78	6.28	-2.57
-11.59	0.45	1.89	-8.36	0.98
9	-4.48	-3.90	6.49	-2.78
-6.8	0.3	-4.12	-4.90	-3.20
7.99	-4.34	-2.67	5.76	-1.74
-9.12	0.88	3.39	-6.58	2.24
6.1	-2.16	-3.78	4.40	-2.47
-11.44	0.16	14.90	-8.25	10.70
8.13	-3.47	-2.38	5.86	-2.16
-11.15	-0.86	11.56	-8.04	7.98
9.44	-4.92	-3.12	6.81	-2.47
-6.8	0.3	-11.45	-4.90	-8.01
9	-5.06	-3.23	6.49	-2.68
-1.73	0.59	9.12	-1.25	6.94
7.12	-2.6	-2.87	5.13	-1.74
-4.05	1.75	1.78	-2.92	1.08
9.15	-4.19	-2.26	6.60	-2.16
-3.03	0.45	-0.78	-2.18	-0.38
9	-4.63	-3.12	6.49	-2.57
-8.4	-0.13	0.67	-6.06	0.25
8.71	-4.77	-3.89	6.28	-2.36
-9.56	0.3	7.11	-6.89	5.37
9.15	-4.92	-3.17	6.60	-2.78
-6.51	0.45	5.56	-4.69	3.80
5.96	-2.02	-3.12	4.30	-2.78
-15.79	-0.42	0.28	-11.38	0.04
8.86	-4.34	-3.89	6.39	-2.68
-4.19	0.88	1.78	-3.02	1.08
7.84	-3.76	-3.89	5.65	-2.36
-5.06	1.46	-3.67	-3.65	-2.57
9.15	-3.61	-3.89	6.60	-2.36
-4.63	0.74	-6.11	-3.34	-4.56
8.57	-5.21	-3.12	6.18	-2.47
-6.37	0.74	-0.11	-4.59	-0.48
7.41	-2.02	-3.67	5.34	-2.26
-3.47	1.03	0.56	-2.50	0.66
9.29	-4.92	-3.23	6.70	-2.68
-6.37	0.59	-10.28	-4.59	-7.91
8.71	-4.34	-3.28	6.28	-2.57
-1	0.74	-14.17	-0.72	-10.52

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9.44	-5.06	-3.59	6.81	-2.26
-4.19	0.74	1.89	-3.02	0.98
8.28	-4.19	-3.11	5.97	-2.78
-9.27	0.88	4.24	-6.68	3.38
8.86	-3.18	-3.21	6.39	-2.68
-8.83	0.59	-2.15	-6.37	-1.74
9.15	-4.77	-3.89	6.60	-2.36
-4.77	1.17	-9.11	-3.44	-6.65
9.44	-4.77	-3.15	6.81	-2.68
-6.37	0.59	6.78	-4.59	4.64
9.44	-4.77	-3.13	6.81	-2.57
-6.37	0.59	1.89	-4.59	1.08
9.44	-4.77	-3.14	6.81	-2.68
-6.37	0.59	-1.12	-4.59	-1.22
9.29	-4.92	-3.14	6.70	-2.68
-6.51	0.59	2.28	-4.69	2.13

The real-time data is acquired with the help of a sensor attached to the tool holder during turning operation. During turning operation the sensor senses the real-time data and sends it to Arduino UNO which transfers it with help of software to the PC (Figure 8). The graph of the Acceleration data received is plotted on Y-axis against time(Sec) in the range of (-5.26 to 1.75m/s^2).

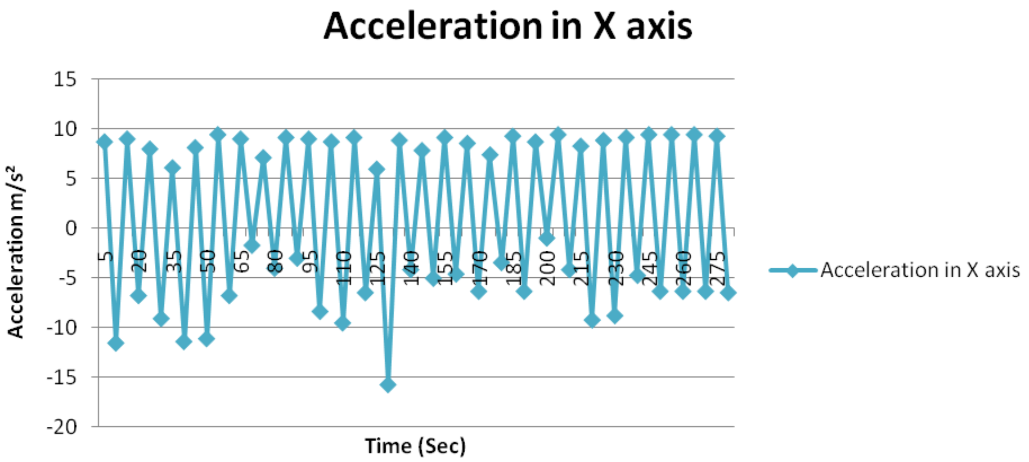

Figure 7. Acceleration in X-axis of Tool.

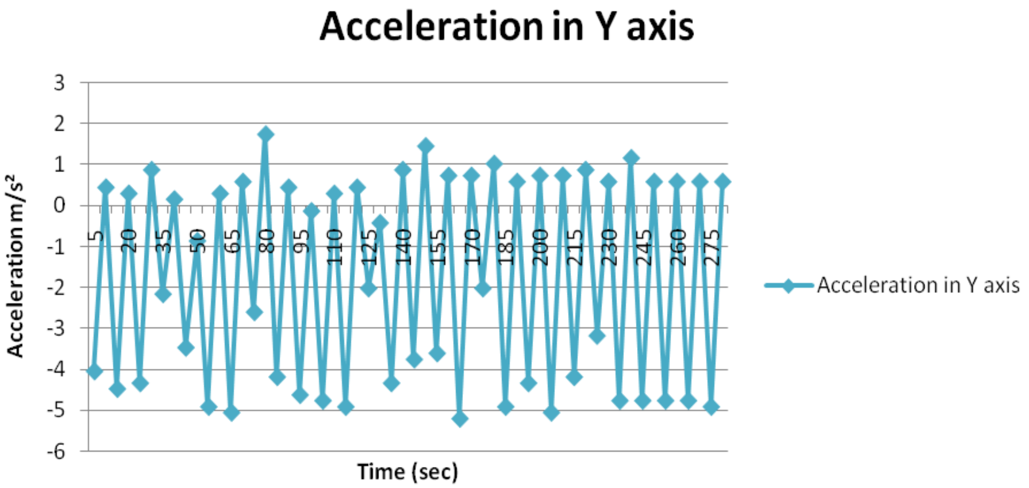

Figure 8. Acceleration in Y-axis of Tool.

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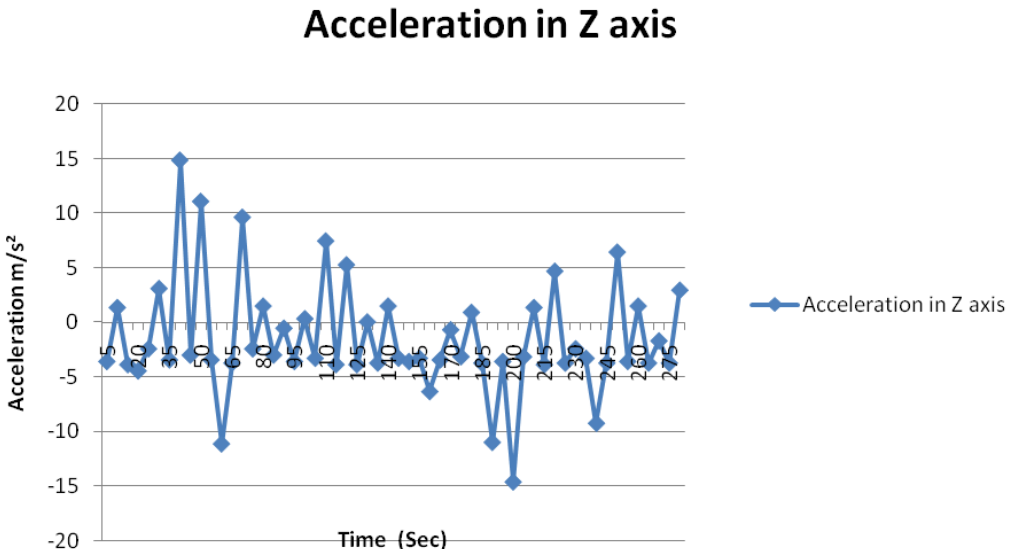

Figure 9. Acceleration in Z-axis of Tool.

The real-time data regarding acceleration is important to know so, that we can control or change the operating parameter which causes acceleration or force while performing the turning operation. The graph of the Acceleration data received is plotted on the Z-axis against time(Sec) in the range of (-14.59 to 14.84m/s^2). Maximum acceleration is observed on Z-axis due to the high speed and feed given in the Z direction (Figure 9).

The real-time data about Acceleration & Force gives us information about vibration in the tool and tool holder. By reducing the vibration during turning operations we can achieve better results. Thus knowing the forces acting, then controlling them, with analysis and taking corrective action. The graph shows Force data received is plotted on X-axis against time(Sec) in the range of (-11.38 to 6.81N) (Figure 10).

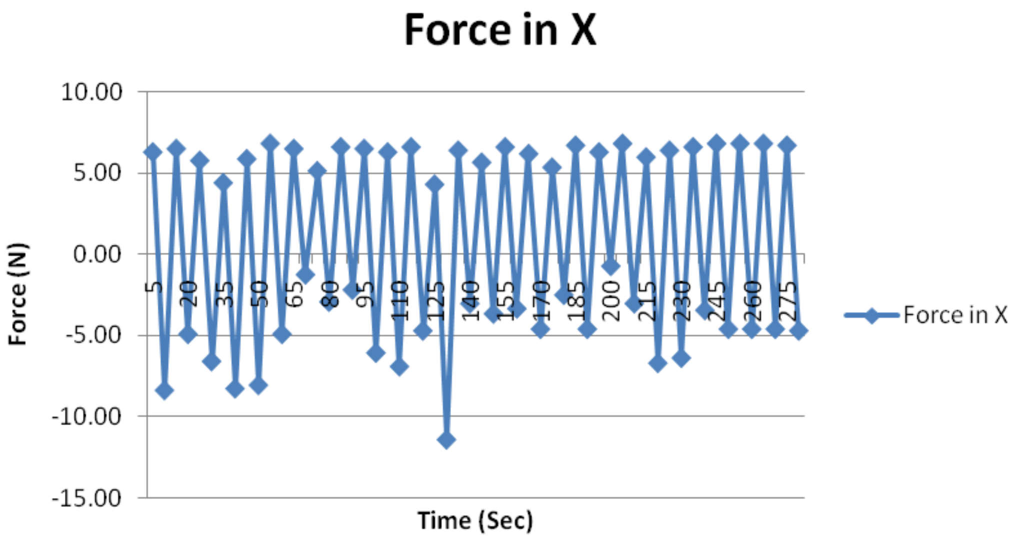

Figure 10. Force in X-axis of Tool.

Vibration in tool & tool holder reduces the life of the tool due to tool wear, chip formation, built-up edge, etc. By having real-time information about force we can reduce the source of vibration during turning operation hence can improve the surface roughness and better tool life. The graph shows Force

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data received is plotted on Z-axis against time(Sec) in the range of (-10.52 to 10.70N). Maximum Force is observed on Z-axis due to the high speed and feed given in the Z direction (Figure 11).

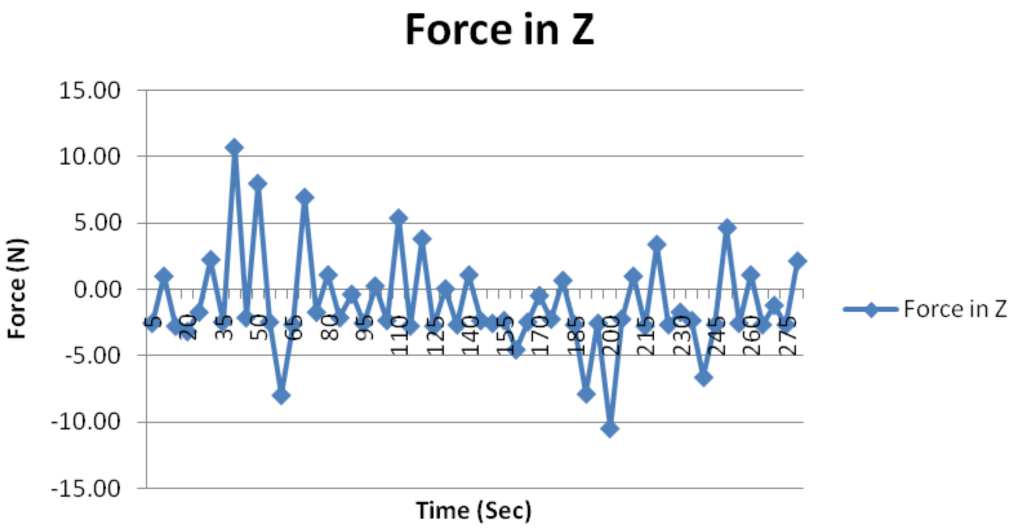

Figure 11. Force in Z-axis of Tool.

Verification of Arduino Results using FFT

In Figure 12 show the CNC Machine with FFT and Table 10 Data of Acceleration and Force with FFT.

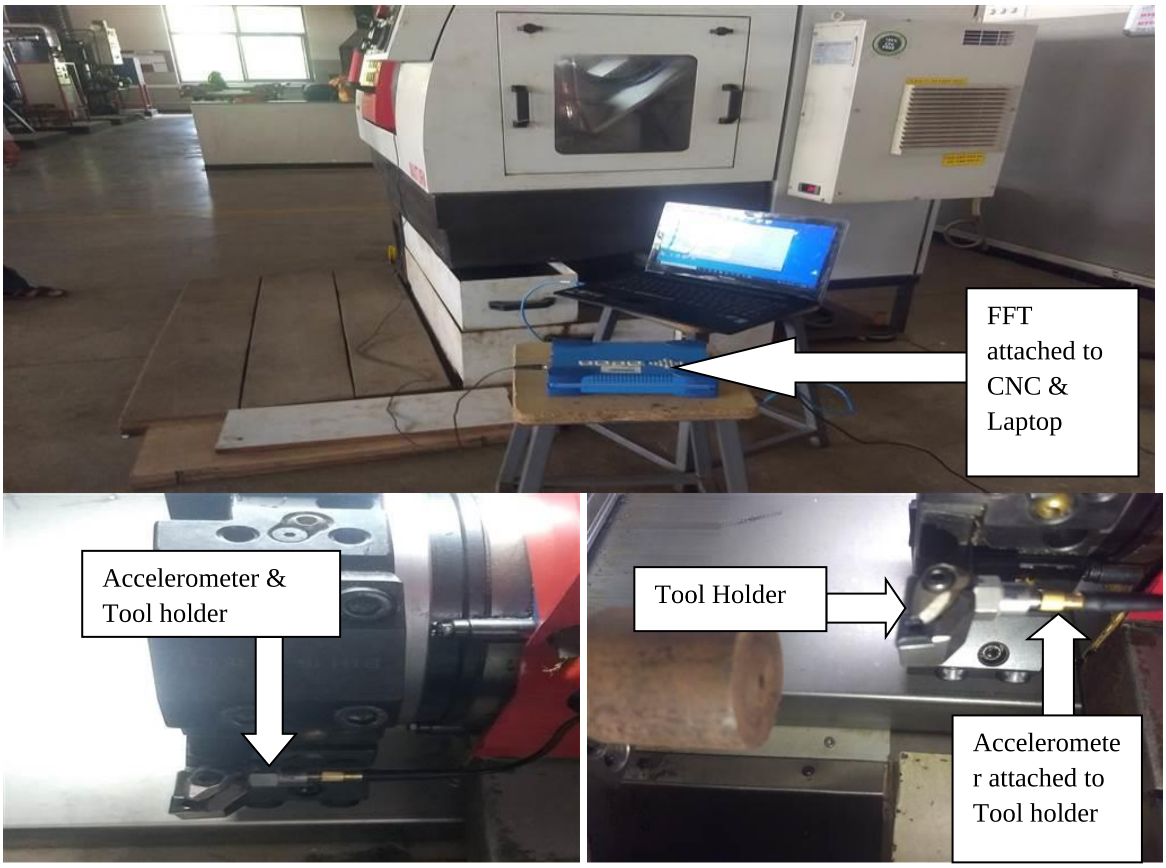

Figure 12. CNC Machine with FFT.

Table 10. Data of Acceleration and Force with FFT.

Acceleration in X axis (m/s^2)	Acceleration in Y axis (m/s^2)	Acceleration in Z axis (m/s^2)	Force in X (N)	Force in Z (N)
8.21	-4.30	-3.57	5.92	-0.75
-11.09	0.20	1.36	-8.00	0.98
8.3	-4.60	-3.86	5.98	-0.81
-6.2	0.7	-4.44	-4.47	-3.20
7.19	-4.67	-2.41	5.18	-0.51
-9.0	0.98	3.1	-6.49	2.24
6.18	-2.46	-3.43	4.46	-0.72
-11.60	0.34	14.84	-8.36	10.70
8.0	-3.1	-2.99	5.77	-0.63
-11.25	-0.9	11.07	-8.11	7.98
9.44	-4.12	-3.43	6.81	-0.72
-6.2	0.8	-11.11	-4.47	-8.01
8.6	-5.27	-3.72	6.20	-0.78
-1.53	0.78	9.62	-1.10	6.94
7.0	-2.89	-2.41	5.05	-0.51
-4.20	1.98	1.5	-3.03	1.08
9.00	-4.37	-2.99	6.49	-0.63
-3.0	0.78	-0.53	-2.16	-0.38
8.5	-4.89	-3.57	6.13	-0.75
-8.1	-0.34	0.34	-5.84	0.25
8.25	-4.90	-3.28	5.95	-0.69
-9.2	0.78	7.45	-6.63	5.37
9.24	-4.34	-3.86	6.66	-0.81
-6.2	0.12	5.27	-4.47	3.80
5.56	-1.8	-3.86	4.01	-0.81
-15.29	-0.68	0.05	-11.02	0.04
8.16	-4.68	-3.72	5.88	-0.78
-4.10	0.78	1.5	-2.96	1.08
7.14	-3.16	-3.28	5.15	-0.69
-5.28	1.12	-3.57	-3.81	-2.57
9.30	-3.89	-3.28	6.71	-0.69
-4.26	0.90	-6.33	-3.07	-4.56
8.12	-5.67	-3.43	5.85	-0.72
-6.1	0.98	-0.67	-4.40	-0.48
7.0	-2.21	-3.14	5.05	-0.66
-3.0	1.78	0.92	-2.16	0.66
9.1	-4.14	-3.72	6.56	-0.78
-6.1	0.12	-10.97	-4.40	-7.91
8.21	-4.89	-3.57	5.92	-0.75
-0.72	0.90	-14.59	-0.52	-10.52
9.14	-5.45	-3.14	6.59	-0.66
-4.44	0.98	1.36	-3.20	0.98
8.56	-4.34	-3.86	6.17	-0.81
-9.87	1.4	4.69	-7.12	3.38
8.16	-3.90	-3.72	5.88	-0.78
-8.13	0.90	-2.41	-5.86	-1.74
9.67	-4.1	-3.28	6.97	-0.69
-4.12	1.67	-9.23	-2.97	-6.65
9.1	-4.1	-3.72	6.56	-0.78
-6.1	0.90	6.43	-4.40	4.64
9.1	-4.1	-3.57	6.56	-0.75
-6.1	0.89	1.5	-4.40	1.08
9.1	-4.89	-3.72	6.56	-0.78
-6.1	0.89	-1.69	-4.40	-1.22
9.1	-4.12	-3.72	6.56	-0.78
-6.1	0.89	2.95	-4.40	2.13

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Acceleration Data Plot (FFT)

The FFT analyzer is used to acquire real-time data during turning operation. The accelerometer is attached to the tool holder, and the data sensed by the accelerometer is received by FFT and transferred to the PC with help of software. The graph shows the Acceleration data received is plotted on X-axis against time(Sec) in the range of (-15.29 to 9.67m/s^2) (Figure 13).

Getting real-time data is a challenge. FFT is very useful in getting real-time data regarding vibrations, sound, etc. The data gives us feedback which helps in taking corrective action when needed. Also in analysis and forecasting, data can be used. The graph shows the Acceleration data received is plotted on Y-axis against time(Sec) in the range of (-5.67 to 1.98m/s^2) (Figure 14).

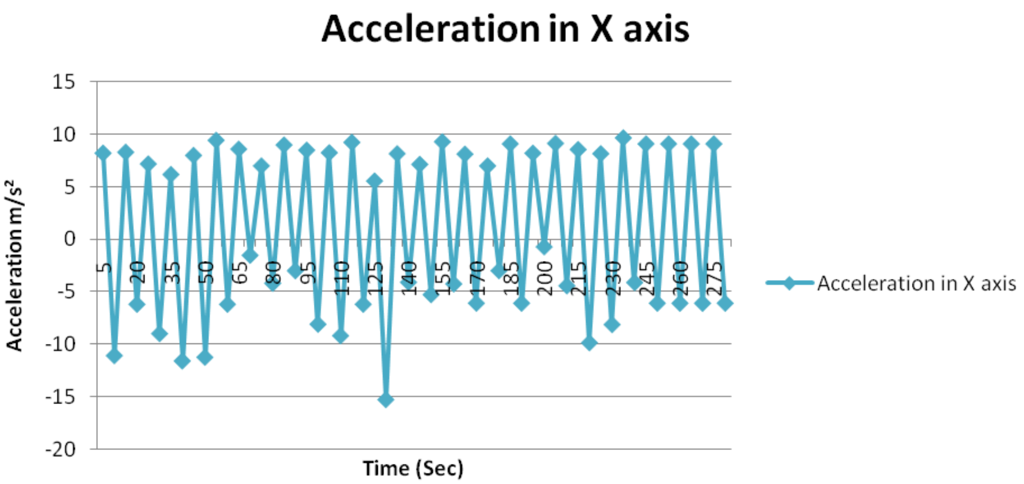

Figure 13. Acceleration in X-axis of Tool.

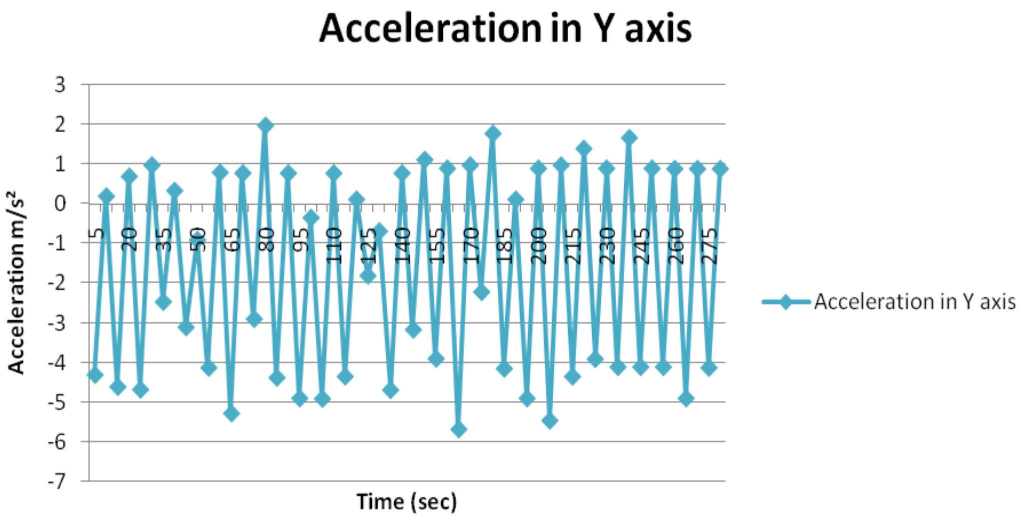

Figure 14. Acceleration in Y-axis of Tool.

Data and information are required for analysis. Hence a feedback system is needed to avoid sudden breakdowns or accidents. The real-time data makes the system more efficient and effective. FFT is very useful in getting real-time data during the turning operation. The graph shows the Acceleration data received is plotted on Z-axis against time(Sec) in the range of (-14.84 to 14.59mm/s^2). Maximum acceleration is observed on Z-axis due to the high speed and feed is given in the Z-direction (Figure 15).

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Forces acting during turning operations are the major causes of vibration and tool failure. Hence to know the source of vibration real-time data is needed. FFT gives good real-time information This information is useful to understand the causes of vibration. Thus changing the operating parameters based on analysis done on data received helps to improve the performance. The graph shows Force data received, is plotted on X-axis against time(Sec) in the range of (-11.02 to 6.97N) (Figure 16).

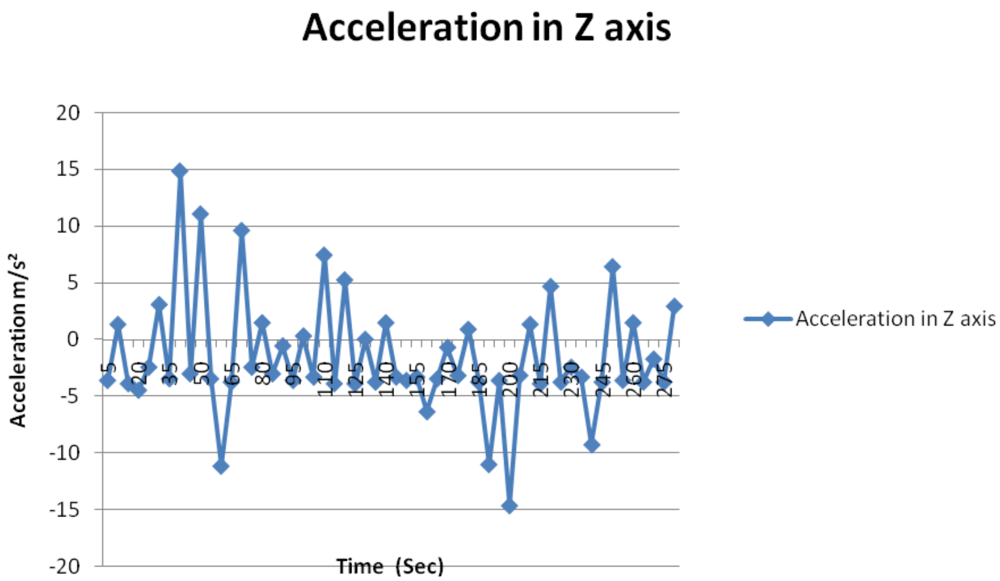

Figure 15. Acceleration in Z-axis of Tool.

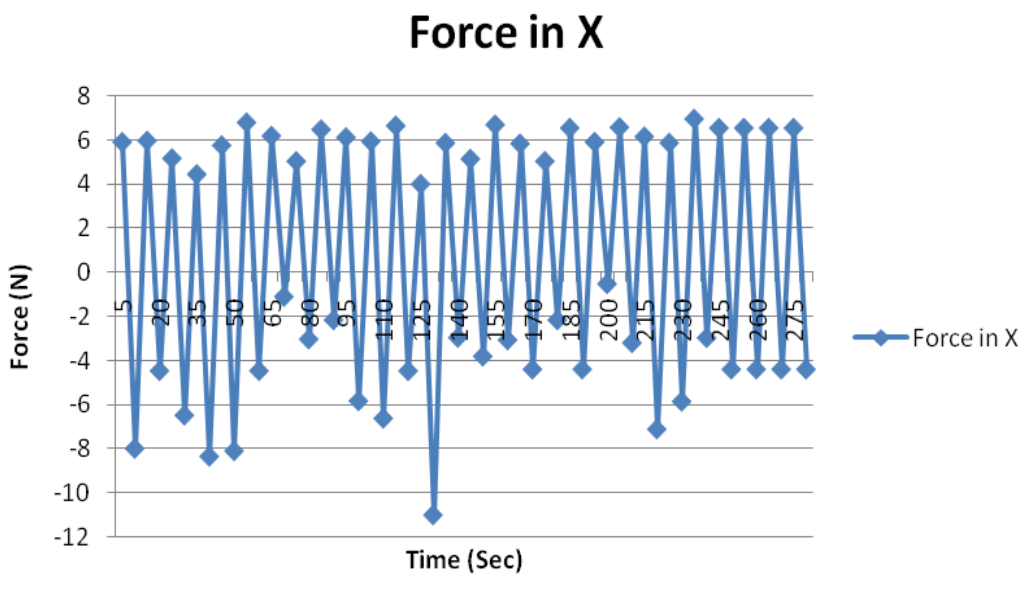

Figure 16. Force in X-axis of Tool.

Data acquisition is very easy with FFT. From the data, we come to know the amount of force acting during the turning operation. The graph shows Force data received, is plotted on Z-axis against time(Sec) in the range of (-10.52 to 10.70N). Maximum Force is observed on Z-axis due to the high speed and feed is given in the Z direction (Figure 17).

RESULTS AND DISCUSSION

Acceleration Data (Arduino)

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Real-time data for analysis is required or feedback is needed to control and monitor the operation in processes. The real-time information helps to control the sudden breakdown or damage by controlling the machining parameters. The Acceleration data received is in the range of (-15.79 to 9.44m/s^2).

The real-time data is acquired with the help of a sensor attached to the tool holder during turning operation. During turning operation the sensor senses the real-time data and sends it to Arduino UNO which transfers it with help of software to the PC. The Acceleration data received is in the range of (-5.26 to 1.75m/s^2).

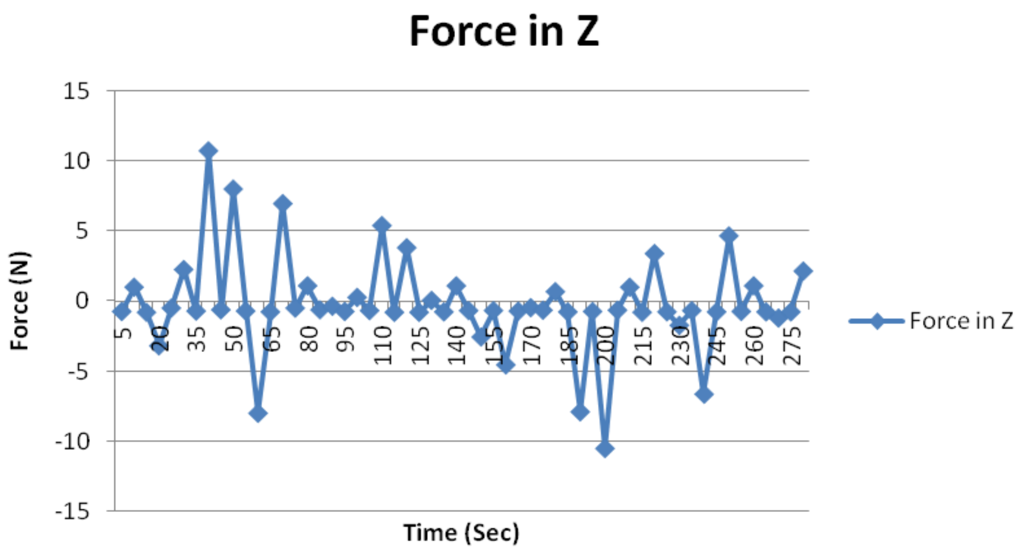

Figure 17. Force in Z-axis of Tool.

The real-time data regarding acceleration is important to know so, that we can control or change the operating parameter which causes acceleration or force while performing the turning operation. The Acceleration data received is in the range of (-14.59 to 14.84m/s^2). Maximum acceleration is observed on Z-axis due to the high speed and feed given in the Z direction.

Forces

The real-time data about Acceleration & Force gives us information about vibration in the tool and tool holder. By reducing the vibration during turning operations we can achieve better results. Thus knowing the forces acting then controlling them, with analysis and taking corrective action. The Force data received is in the range of (-11.38 to 6.81N).

Vibration in tool & tool holder reduces the life of the tool due to tool wear, chip formation, built-up edge, etc. By having real-time information about force we can reduce the source of vibration during turning operation hence can improve the surface roughness and better tool life. The Force data is in the range of (-10.52 to 10.70N). Maximum Force is observed on Z-axis due to the high speed and feed given.

Acceleration Data (FFT)

The FFT analyzer is used to acquire real-time data during turning operation. The accelerometer is attached to the tool holder, and the data sensed by the accelerometer is received by FFT and transferred to the PC with help of software. The Acceleration data received is in the range of (-15.29 to 9.67m/s^2).

Getting real-time data is a challenge. FFT is very useful in getting real-time data regarding vibrations, sound, etc. The data gives us feedback which helps in taking corrective action when needed. Also in analysis and forecasting, data can be used. The Acceleration data received is in the range of (-5.67 to 1.98m/s^2).

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Data and information are required for analysis. Hence a feedback system is needed to avoid sudden breakdowns or accidents. The real-time data makes the system more efficient and effective. FFT is very useful in getting real-time data during the turning operation. The Acceleration data received is in the range of (-14.84 to 14.59mm/s^2). Maximum acceleration is observed on Z-axis due to the high speed and feed is given.

Forces acting during turning operations are the major causes of vibration and tool failure. Hence to know the source of vibration real-time data is needed. FFT gives good real-time information This information is useful to understand the causes of vibration. Thus changing the operating parameters based on analysis done on data received helps to improve the performance. The Force data received, is in the range of (-11.02 to 6.97N).

Data acquisition is very easy with FFT. From the data, we come to know the amount of force acting during the turning operation. The Force data received, is in the range of (-10.52 to 10.70N). Maximum Force is observed on Z-axis due to the high speed and feed is given (Tables 11 and 12).

Table 11. Acceleration & Force data (Arduino).

Arduino	**X axis**	**Y axis**	**Z axis**
Acceleration data	-15.79 to 9.44m/s^2	-5.26 to 1.75m/s^2	-14.59 to 14.84m/s^2
Force data	-11.38 to 6.81N	----------	-10.52 to 10.70N
	CNC -- TWO axis X & Z		

Table 12. Acceleration & Force data (FFT).

FFT	**X axis**	**Y axis**	**Z axis**
Acceleration data	-15.29 to 9.67m/s^2	-5.67 to 1.98m/s^2	-14.84 to 14.59mm/s^2
Force data	-11.02 to 6.97N	----------	-10.52 to 10.70N
	CNC -- TWO axis X & Z		

CONCLUSION

- While turning operation vibrations are observed which affect tool life & production quality and surface roughness. Hence to sense vibration on the tool holder, the proposed approach to measure Vibrations using a Sensor attached to the tool holder was successfully implemented.
- The sensors were attached to the tool holder to sense the vibration during the turning operation. The reading was taken during the turning operation, After estimating the force components (tangential and feed), the sensor was tested in actual cutting settings and demonstrated accurate performance.
- There are many Instruments to measure vibrations, but they are costly. The combination of Arduino and Sensors is easy to assemble, and easy to use at any location, and results are displayed on the PC screen, an Arduino can be directly attached to any PC with the help of software. So it's an economical alternative to accurately measuring cutting forces and vibrations with reliability.
- Real-time data is needed for analysis, to make every system perform better. Data plays an important role in prediction, analysis, design, manufacturing, etc. The use of sensors & Arduino for real-time data acquisition in CNC Turning is very useful to get data during turning operation.
- If we compare the acceleration data from Table 11 and Table 12 the difference is negligible
- Similarly If we compare the Forc data from Table 11 and Table 12 the difference is negligible.
- We have verified the data of Arduino uno with FFT , it is very much similar.

Nomenclature

CNC	Computer numerical control
3D	Three Dimension.
SI	The International System of Units.
Hz	Hertz unit of frequency.
MS^2	Meter per second Squre.

Ft Tangential force
Ff Feeding force
Fp Thrust force
FEM Finite element method1
σ Surface Stress
β , α, k Constant
θ Inclination angle
Π Circumference ratio
PC Personal Computer
CAD Computer aided Design
CAE Computer aided Engineering
g Gravitational constant
db Band width
Vc Supply Voltage
AC Alternating current
DC Direct current
USB Universal serial bus
UART Universal asgnchronous receiver transmitter
TTL Transistor transistor logic
FFT Fast fourier transform

REFERENCES

1. Zhao Y, Zhao Y, Liang S, Zhou G. A high performance sensor for triaxial cutting force measurement in turning. Sensors (Switzerland). 2015 Apr 3;15(4):7969–84.
2. American Society of Mechanical Engineers, IEEE International Conference on Service-Oriented Computing and Applications, IEEE International Conference on Advanced Intelligent Mechatronics (Busan) ; 2015.07.07-11.
3. Qehaja N, Jakupi K, Bunjaku A, Bruçi M, Osmani H. Effect of machining parameters and machining time on surface roughness in dry turning process. Procedia Eng. 2015;100(January):135–40.
4. Patil AS, Sunnapwar VK, Bhole KS, More YS. Experimental investigation and fuzzy TOPSIS optimisation of Ti6Al4V finish milling. Adv Mater Process Technol [Internet]. 2021;00(00):1–24. Available from: https://doi.org/10.1080/2374068X.2021.1971002
5. Tlusty J, Andrews GC. A Critical Review of Sensors for Unmanned Machining. CIRP Ann - Manuf Technol. 1983;32(2):563–72.
6. Yaldiz S, Ünsaçar F, Sağlam H, Işik H. Design, development and testing of a four-component milling dynamometer for the measurement of cutting force and torque. Mech Syst Signal Process. 2007;21(3):1499–511.
7. Ramachandran KA/ L. DESIGN AND DEVELOPMENT OF SMART CUTTING TOOL. Available from: http://www.researchgate.net/publication/284936318
8. Miroslav RĆ, Predrag DĆ, Predrag JĆ. Experimental Determination of Cutting Force By Longitudinal Turning of C60E Steel. 2006;2(August 2017):113–9.
9. Hasibuzzaman M, Shufian A, Shefa RK, Raihan R, Ghosh J, Sarker A. Vibration Measurement Analysis Using Arduino Based Accelerometer. 2020 IEEE Reg 10 Symp TENSYMP 2020. 2020;(June):508–12.
10. Teti R, Jemielniak K, O'Donnell G, Dornfeld D. Advanced monitoring of machining operations. CIRP Ann - Manuf Technol. 2010;59(2):717–39.
11. Dimla D. Sensor signals for tool-wear monitoring in metal cutting operations—a review of methods. Int J Mach Tools Manuf [Internet]. 2000;40(8):1073–98. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0890695599001224
12. Abellan-Nebot JV, Romero Subirón F. A review of machining monitoring systems based on

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artificial intelligence process models. Int J Adv Manuf Technol. 2010;47(1–4):237–57.
13. Sundara Murthy K, Rajendran I. Design and development of strain gauge based milling tool dynamometer. Int J Mach Mach Mater. 2010;7(3–4):286–98.
14. Rehorn AG, Jiang J, Orban PE, Bordatchev E V. Erratum: State-of-the-art methods and results in tool condition monitoring: A review (International Journal of Advanced Manufacturing Technology (2004)DOI: 10.1007/s00170-003-2038-2). Int J Adv Manuf Technol. 2005;26(7–8):942.
15. Audy J. Appraisal of techniques and equipment for cutting force measurement. J Zhejiang Univ Sci. 2006;7(11):1781–9.
16. Li X. Development of current sensor for cutting force measurement in turning. IEEE Trans Instrum Meas. 2005;54(1):289–96.
17. Ateş E, Aztekin K. Design, manufacturing, and calibration process of one piece lathe dynamometer for measurement in two axes. J Manuf Sci Eng. 2013;135(4):1–6.
18. Panzera TH, Souza PR, Rubio JCC, Abrão AM, Mansur TR. Development of a three-component dynamometer to measure turning force. Int J Adv Manuf Technol. 2012;62(9–12):913–22.
19. Yaldiz S, Ünsaçar F. Design, development and testing of a turning dynamometer for cutting force measurement. Mater Des. 2006;27(10):839–46.
20. Totis G, Sortino M. Development of a modular dynamometer for triaxial cutting force measurement in turning. Int J Mach Tools Manuf [Internet]. 2011;51(1):34–42. Available from: http://dx.doi.org/10.1016/j.ijmachtools.2010.10.001
21. Wang C, Rakowski R, Cheng K. Design and analysis of a piezoelectric film embedded smart cutting tool. Proc Inst Mech Eng Part B J Eng Manuf. 2013;227(2):254–60.
22. Yaldiz S, Ünsaçar F. A dynamometer design for measurement the cutting forces on turning. Meas J Int Meas Confed. 2006;39(1):80–9.
23. Karabay S. Design criteria for electro-mechanical transducers and arrangement for measurement of strains due to metal cutting forces acting on dynamometers. Mater Des. 2007;28(2):496–506.
24. O'Dogherty MJ. The design of octagonal ring dynamometers. J Agric Eng Res. 1996;63(1):9–18.
25. Patel VK, Patel MN. Development of Smart Sensing Unit for Vibration Measurement by Embedding Accelerometer with the Arduino Microcontroller. Int J Instrum Sci [Internet]. 2017;2017(1):1–7. Available from: http://journal.sapub.org/instrument
26. Rice WB, Salmon R. Effects of Cooling and Heating Workpiece and. 1966;6(c):143–52.
27. Pervaiz S, Deiab I, Ibrahim EM, Rashid A, Nicolescua M. A coupled FE and CFD approach to predict the cutting tool temperature profile in machining. Procedia CIRP [Internet]. 2014;17:750–4. Available from: http://dx.doi.org/10.1016/j.procir.2014.01.104
28. Minton T, Ghani S, Sammler F, Bateman R, Fürstmann P, Roeder M. Temperature of internally-cooled diamond-coated tools for dry-cutting titanium. Int J Mach Tools Manuf [Internet]. 2013;75:27–35. Available from: http://dx.doi.org/10.1016/j.ijmachtools.2013.08.006
29. Ostasevicius V, Markevicius V, Jurenas V, Zilys M, Cepenas M, Kizauskiene L, et al. Cutting tool vibration energy harvesting for wireless sensors applications. Sensors Actuators, A Phys [Internet]. 2015;233:310–8. Available from: http://dx.doi.org/10.1016/j.sna.2015.07.014
30. Haider J, Hashmi MSJ. Health and Environmental Impacts in Metal Machining Processes [Internet]. Vol. 8, Comprehensive Materials Processing. Elsevier; 2014. 7–33 p. Available from: http://dx.doi.org/10.1016/B978-0-08-096532-1.00804-9
31. von Turkovich BF, Durham DR. Machining of Titanium and Its Alloys. 1982;257–274.
32. Taylor CM, Giovana S, Hernandez A, et al. ScienceDirect ScienceDirect ScienceDirect Cutting fluid application for titanium alloys Ti-6Al-4V and Cutting fluid application for titanium alloys and Ti-10V-2Fe-3Al in a finish turning process Ti-10V-2Fe-3Al in a finish turning process new methodology t. Procedia CIRP [Internet]. 2018;77:441–444. Available from: https://doi.org/10.1016/j.procir.2018.08.279.
33. Namb M, Paulo D. Influence of Coolant in Machinability of Titanium Alloy (Ti-6Al-4V). J Surf Eng Mater Adv Technol. 2011;01:9–14.

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