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Research paper

Study of Vibration Pattern Recorded While Turning of EN8 and EN24 using MPU6050

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Abstract

The need for precise along with optimum measurement and result oriented investigation of mechanical vibration has grown and implemented in various mechanical operations. The method adopted to measure the vibration of a particular piece of machinery is by mounting an accelerometer and measuring the accelerations produced by the vibration. The primary agenda of this work is to assess and study the vibrations generated in the machine while doing machining EN8 and EN24 at different depth of cut. The experiment was performed by mounting a 3-axis accelerometer (MPU-6050) on the tool post of lathe machine (LDLM-02) switched to turning centre. The device was calibrated using Arduino software whose output signals were logged in Microsoft Excel which turned out as desired vibration levels.

Keywords: *Machine, Vibrations, Accelerometer.*

1. Introduction to Work Done

The instruments used for vibration detection and analysis are an accelerometer, Data acquisition system, Arduino software, two work pieces and a single point cutting tool. Accelerometer is a device which convert mechanical movement into electric signal. This electric signal further converts into vibrational acceleration. An accelerometer contains a shielded cover case and a piezoelectric crystal.

2. Objectives of the Research Work

The main objective of this research work is to record and study the effects of a digital accelerometer resulted into vibration signatures on the turning centre of a lathe machine to determine if the machine is operating properly. This will be achieved by connecting the device to the machine and recording the vibration levels over SPI or I^2C communication protocols as it has a digital interface. The secondary objective is to observe the trends in the readings that follow on changing the parameters like depth of cut, and cutting forces to assess the quality of surface finish of the work piece. This research can also be extended to find out the dependency of vibration levels on parameters like feed rate, motor speed (rpm) and cutting forces.

3. Literature Survey

Conceptual Overview of Vibration sensors

Acceleration sensors have applied for the automobile industry, appliance industry, aerospace industry and structural maintenance industry. Application field of the MEMS acceleration sensor was expanded as MEMS (Micro Electro Mechanical Systems) technology was developed. Various researchers studied the influence of few out of the above mentioned several factors on the surface finish. Albrecht [1] investigated the effect of speed, feed, depth of cut and nose radius on the surface finish of a steel work-piece. Chandiramani and Cook [2], in their investigation on the effect of varying cutting speeds and surface finish in such a way a deteriorated surface finish generated due to formation of BUE (Built up Edge).

The following article revolves around the development of a new method to measure the surface roughness and dimensional deviation which are evaluated by measuring the vibrations and cutting forces in cylindrical turning operations. It highlights the significance of surface finish on the effective working of two mating parts especially, for slender jobs which may vary due to thickness. The methodology adopted for predicting the data is carried out by the neural networks of different topologies. These were fitted to determine and predict accuracy which didn't turn out on the positive side. Finally, out of the four chosen neurons, depth of cut was selected as the comparable parameter. These parameters are calculated by performing different number of trials. TCM and URL prognostics based on a wireless tri-axial accelerometer is presented. The wireless tri-axial accelerometer is used to detect the vibrations in three perpendicular directions (x, y and z) during cutting operations. This prognostic approach is easy to realize and provides a basis for proactive job shop scheduling through integrating the prognostic information into the manufacturing system. However, this study only focuses on TCM and URL prognostics based on one sensor with NFN in dry milling operations. In future work, multiple sensors will be used to measure the vibrations at different positions, such as the spindle and the jig. The information fusion of multiple sensors will be applied to predict the tool wear more accurately. At the same time study of TCM and URL prognostics will helpful. [3, 4, 5]

4. Technologies Involved

The primary set-up of this experiment widely depends on the calibration of Arduino Uno Microcontroller on which the MPU-6050 is programmed and mounted as an accelerometer device. The following set of apparatus was used to carry out the experiment:-

Triple-axis Digital Accelerometer

In MPU 6050's 3 Axis Accelerometer uses a sensors proof masses for each axis separately over a distance equivalent to predefined coriolis forces. Each axis induces displacement on the sensors proof masses and that displacement can be detected with a capacitive sensor. By placing the sensor horizontally on the surface measures 0g on the X and Y axis and +1g on Z axis. The sensor output is proportional to the displacement of moving plate (mass) which unbalances the differential capacitor. The following mechanism is used to get output from microcontroller.

A 16 bit Analog to Digital Convertor is used to get digitized output. +/- 2g, +/-4g, +/-8g, +/- 16g is the measurement scale of ADC, g refers to gravity force unit.

6.2 Accelerometer Specifications

VDD = 2.375V-3.46V, VLOGIC (MPU-6050 only) = 1.8V±5% or VDD, T_A = 25°C

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS	NOTES
ACCELEROMETER SENSITIVITY						
Full-Scale Range	AFS_SEL=0		±2		*g*	
	AFS_SEL=1		±4		*g*	
	AFS_SEL=2		±8		*g*	
	AFS_SEL=3		±16		*g*	
ADC Word Length	Output in two's complement format		16		bits	
Sensitivity Scale Factor	AFS_SEL=0		16,384		LSB/*g*	
	AFS_SEL=1		8,192		LSB/*g*	
	AFS_SEL=2		4,096		LSB/*g*	
	AFS_SEL=3		2,048		LSB/*g*	
Initial Calibration Tolerance			±3		%	
Sensitivity Change vs. Temperature	AFS_SEL=0, -40°C to +85°C		±0.02		%/°C	
Nonlinearity	Best Fit Straight Line		0.5		%	
Cross-Axis Sensitivity			±2		%	
ZERO-G OUTPUT						
Initial Calibration Tolerance	X and Y axes		±50		m*g*	1
	Z axis		±80		m*g*	
Zero-G Level Change vs. Temperature	X and Y axes, 0°C to +70°C		±35			
	Z axis, 0°C to +70°C		±60		m*g*	
SELF TEST RESPONSE						
Relative	Change from factory trim	-14		14	%	2
NOISE PERFORMANCE						
Power Spectral Density	@10Hz, AFS_SEL=0 & ODR=1kHz		400		µ*g*/ √Hz	
LOW PASS FILTER RESPONSE	Programmable Range	5		260	Hz	
OUTPUT DATA RATE	Programmable Range	4		1,000	Hz	
INTELLIGENCE FUNCTION INCREMENT			32		m*g*/LSB	

1. Typical zero-g initial calibration tolerance value after MSL3 preconditioning
2. Please refer to the following document for further information on Self-Test: *MPU-6000/MPU-6050 Register Map*

Fig.5: Accelerometer properties of MPU-6050

6.3 Electrical and Other Common Specifications

VDD = 2.375V-3.46V, VLOGIC (MPU-6050 only) = 1.8V±5% or VDD, T_A = 25°C

PARAMETER	CONDITIONS	MIN	TYP	MAX	Units	Notes
TEMPERATURE SENSOR						
Range			-40 to +85		°C	
Sensitivity	Untrimmed		340		LSB/ºC	
Temperature Offset	35°C		-521		LSB	
Linearity	Best fit straight line (-40°C to +85°C)		±1		°C	
VDD POWER SUPPLY						
Operating Voltages		2.375		3.46	V	
Normal Operating Current	Gyroscope + Accelerometer + DMP		3.9		mA	
	Gyroscope + Accelerometer (DMP disabled)		3.8		mA	
	Gyroscope + DMP (Accelerometer disabled)		3.7		mA	
	Gyroscope only (DMP & Accelerometer disabled)		3.6		mA	
	Accelerometer only (DMP & Gyroscope disabled)		500		µA	
Accelerometer Low Power Mode Current	1.25 Hz update rate		10		µA	
	5 Hz update rate		20		µA	
	20 Hz update rate		70		µA	
	40 Hz update rate		140		µA	
Full-Chip Idle Mode Supply Current			5		µA	
Power Supply Ramp Rate	Monotonic ramp. Ramp rate is 10% to 90% of the final value			100	ms	
VLOGIC REFERENCE VOLTAGE	MPU-6050 only					
Voltage Range	VLOGIC must be ≤VDD at all times	1.71		VDD	V	
Power Supply Ramp Rate	Monotonic ramp. Ramp rate is 10% to 90% of the final value			3	ms	
Normal Operating Current			100		µA	
TEMPERATURE RANGE						
Specified Temperature Range	Performance parameters are not applicable beyond Specified Temperature Range	-40		+85	°C	

Fig.6: Electrical and other specifications of MPU-6050

4.1. Arduino Uno Micro-controller

The Arduino Uno is a microcontroller board based on the ATmega328 (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analogue inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started. The Uno differs from all preceding boards in that it features the Atmega8U2 programmed as a USB-to-serial converter.

4.2. Lathe Machine

A Light Duty Lathe Machine (LDLM-02) was used to perform the turning operations whose specifications are mentioned below:

- Length of bed = 4.5 feet
- Motor speed = 400rpm
- Centre Height = 165mm
- Swing over bed = 325mm
- Swing over cross slide = 175mm
- Spindle speeds = 8
- 3 phase motor
- Motor power = 1HP

4.3. Workpiece

The work piece materials to be machined are selected as EN8 and EN 24 of diameter = 50mm and length = 60mm. The desirable properties of both of them are mentioned as we follow:-

EN24:-

Table 1: Properties of EN24

✓ Chemical Properties of EN24

C	SI	MN	S	P	Cr	Mo	Ni
0.36/0.44	0.10/0.35	0.45/0.70	0.040 max	0.035 max	1.00/1.40	0.20/0.35	1.30/1.70

✓ Mechanical Properties of EN24

Size (mm)	Tensile Strength (N/mm^2)	Yield Stress (N/mm^2)	Elongation	Impact Izod J	Impact KCV J	Hardness HB
63 to 150	850-1000	680 Min	13%	54	50	248/302
150 to 250	850-1000	654 Min	13%	40	35	248/302

EN8:-

Table 2:

Properties of EN8

✓ Chemical Properties of EN8

Standard	Grade	C	Mn	P	S	Si
BS970	EN8/080M40	0.36-0.44	0.60-1.00	0.05	0.005	0.10-0.40

✓ Mechanical Properties and of EN8

Heat Treatment	Tensile Strength Rm	Yield Strength Rm	Rp 0.2	A min on 5.56√So	Impact Izod Ft.lb	Impact KCV J	Hardness
	MPa	MPa	MPa				HB
N	550	280	-	16	15	16	152/207
	510	245	-	17	-	-	146/197
Q	625/775	385	355	16	25	28	179/229
R	700/850	465	450	16	25	28	201/255

4.4. Tool

A high speed steel cutting tool is used to machine the work pieces in order to achieve a fine surface finish.

5. Methodology

MPU-6050 triple axis accelerometer is used to measure the vibration of a lathe machine performing turning operation. This device sends serial data through a USB cable to the COM port of a computer. Then, using the Microsoft Excel spreadsheet, this data is parsed, analysed and used to determine if the machinery is operating properly. The accelerometer device is distinctly shown in the diagram below.

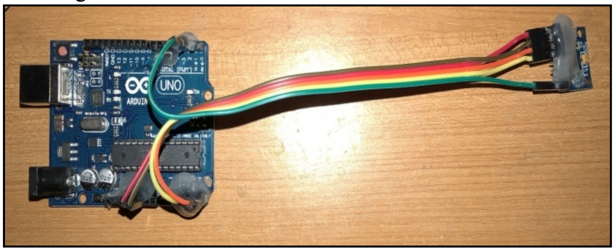

Fig. 7: Set-up of Accelerometer device based on circuit diagram

As it can be seen in the figure, connections are made according to the circuit diagram with help of male to female connectors (jumper wires). The micro-controller is programmed by Arduino software so that MPU-6050 displays its accelerometer features which help to note and analyse the nature of vibrations produced while performing turning operation. Also the state of machinery can be predicted if it is working properly or not.

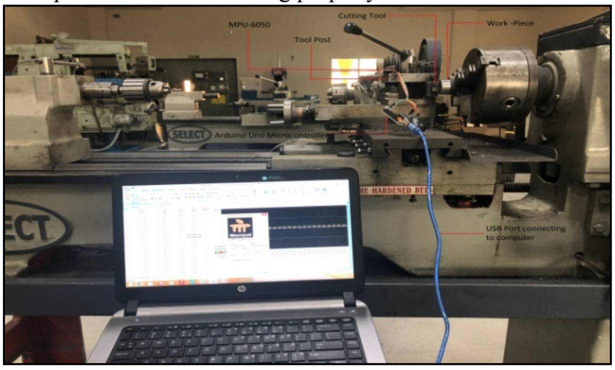

Fig. 8: Set-up of the experiment

After mounting the accelerometer device onto the turning centre of the lathe machine as shown in the figure above, the parameters like feed rate (automatic) and cutting forces are kept constant, and a depth of cut of 0.2 mm is provided to the workpiece. The device accurately senses the vibration signatures that are generated while machining of the work-piece. These values are then converted to electric signals and fed into the computer via a USB cable which then displays them in the form of real-time data. The work time of the machine is taken as 30 secs during which the device formulates spikes denoting the upper and lower values of vibratory motion in all three axes altogether. The values are logged in Microsoft Excel as real values.

6. Results and Analysis

- EN8 (depth of cut 0.2mm)

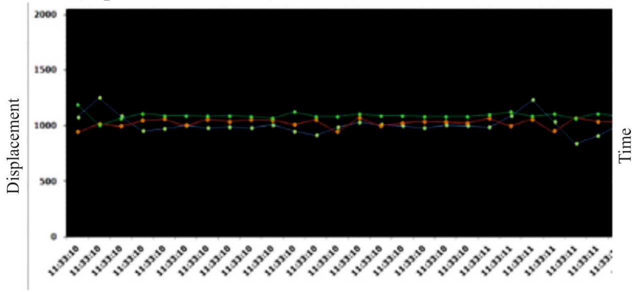

Fig.14: Real-time data log of EN8 for 0.2 mm depth of cut

- EN8 (depth of cut 0.5mm)

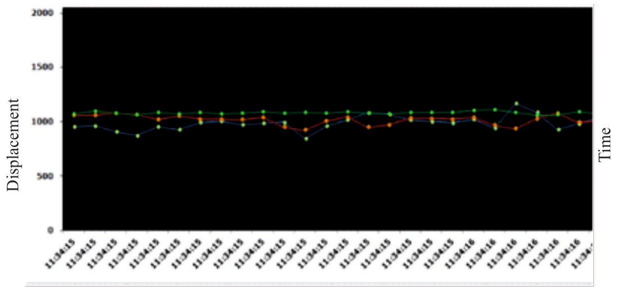

Fig. 15: Real-time data log of EN8 for 0.5 mm depth of cut

Table 3:- Vibration readings for EN8

Sr.no	Name of Material	Feed (mm)	Speed (rpm)	Depth of cut (mm)	Mean Vibrations (m/s²)		
					X-axis	Y-axis	Z-axis
1.	EN8 (dia. 50mm)	0.2	400	0.2	0.093	0.104	0.106
2.					0.122	0.101	0.107
3.					0.097	0.102	0.109
4.					0.093	0.104	0.113
5.					0.098	0.106	0.108
6.				0.5	0.099	0.100	0.112
7.					0.100	0.101	0.109
8.					0.100	0.099	0.104
9.					0.101	0.103	0.110
10.					0.090	0.105	0.108

Data Analysis for EN8:-

- It can be clearly seen from the graphical and tabular values that the maximum vibration takes place in the cutting force direction, i.e., z-axis.
- The longitudinal and transverse direction values are relatively lower in comparison.
- The degree of vibration is also co-related to the yield strength of the material which is less in comparison to the EN24.
- The surface finish of EN8 thus produced is much smoother and polished.
- The readings also justify the type of metal that is medium carbon steel (soft).
- Overall, depth of cut is an important parameter to be taken into consideration which has an impact on the surface finish of the job produced.
- Other parameters to be considered are feed rate, speed of motor, cutting forces, etc.

EN24 (depth of cut 0.2mm)

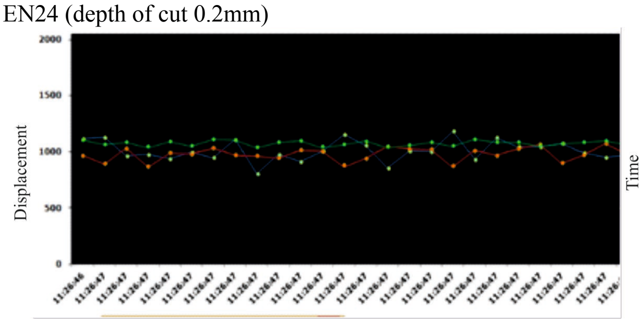

Fig.16: Real-time data log of EN24 for 0.2 mm depth of cut

EN24 (depth of cut 0.5mm)

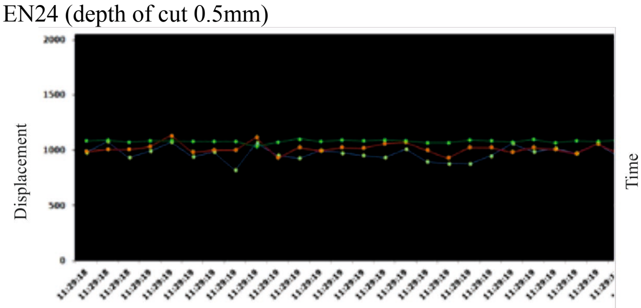

Fig. 17: Real-time data log of EN24 for 0.5 mm depth of cut

Table 4:- Vibration readings for EN24

Sr.no	Name of Material	Feed (mm)	Speed (rpm)	Depth of cut (mm)	Mean Vibrations (m/s^2)		
					X-axis	Y-axis	Z-axis
1.					0.100	0.103	0.110
2.					0.102	0.099	0.108
3.				0.2	0.097	0.101	0.107
4.					0.093	0.102	0.111
5.	EN24 (dia. 50mm)	0.2	400		0.105	0.101	0.104
6.					0.100	0.105	0.112
7.					0.102	0.099	0.108
8.				0.5	0.096	0.097	0.130
9.					0.110	0.105	0.107
10.					0.089	0.104	0.110

Data Analysis for EN24:-

- The values of vibration signatures are comparatively higher than that that of EN8 because of the hardness of the material and higher tensile and yield strength.
- Again, we see that values are higher in the cutting force direction rather than longitudinal or transverse direction.
- The hardness of the material plays an important role in the development of vibration signatures and the overall surface finish produced as the metal with high hardness tends to vibrate more which makes the surface finish coarse rather than smooth

Fig.18: Type of surface finish produced

7. Conclusion

- As in the turning centre the cutting force direction is in the z-direction so the vibration amplitude recorded by 3 – axis accelerometer shows maximum vibration amplitude in cutting force direction.
- As EN24 is high yield strength and EN8 is medium yield strength, the result also shows that while machining of EN24 the recorded vibrations were high as compared to vibrations recorded in machining of EN8
- The parameters such as depth of cut, feed and cutting speed subjected to cutting force, result shows that the cutting forces highly affect the amplitude of vibrations generated.
- The vibration determined in transverse direction i.e. y direction observed least amplitude of vibrations. The result shows that the high amplitude vibrations observed in the cutting force direction i.e. z- direction. Therefore from the results, it has been identified that the depth of cut has least effect of vibration. Additionally, the feed and the cutting force has maximum effect on the vibration and surface finish.

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