ISSN : 2249-5762 (Online) | ISSN : 2249-5770 (Print)

Signal Based Conditioning Monitoring of Lathe Turning Tool

[1]Partha Pratim Borah, [2]Ronal Kakoti, [3]Bitupan Kumar Baruah, [4]Saurav Krishna Mahanta, [5]Shravankumar C
[1,2,3,4,5]BMS College of Engineering, Bangalore, Karnataka, India

Abstract
This paper deals with condition monitoring of machine tools which is a key factor to identify any significant change in the machining process. This paper discusses about monitoring the health of a tool during a turning operation. Instabilities in machining processes shortens the life time of a machine tool. The main contributions of this paper are to study the parameters of turning operation, i.e., cutting forces and tool tip displacements for a given feed, depth of cut and cutting speed. The effect of the tool wear is analysed by means of signal based condition monitoring. A simple and novel procedure has been adopted for the acquisition and processing of force and displacement signals without the use of digital acquisition systems. The identification of the growth of tool wear in turning operation will also prove useful for establishing the tool life.

Keywords
Condition Monitoring, Cutting Forces, Tool Tip Displacements, Tool Wear, Turning Operation

I. Introduction
Condition monitoring is a vital component of preventive and predictive maintenance programs which includes the measurement of various parameters related to the mechanical condition of the machinery. It seeks to reduce the cost and avoid unplanned downtime. Condition monitoring systems include both measurement hardware and signal processing software that acquire and interpret signals generated by the machine being monitored. If the mechanical condition is bad, then condition monitoring makes it possible to determine the cause of the problem. Fundamentally, condition monitoring aids to regulate the safety and economy of the setups.

The lathe is a versatile machine tool used in almost all manufacturing industries. During the operation of the lathe different kinds of failures are possible which have a direct effect on the industrial efficiency. When failure occurs it is crucial to identify the cause and take appropriate measures. Application of condition monitoring can help in detection of these early faults. The cutting tool can be regarded as the limiting component of the machining process and is the main reason why machining process condition monitoring is mostly concerned with the actual state of the cutting tool. When the cutting tool is worn the cutting force and vibration amplitudes tend to grow and the machining process may become unstable. In metal cutting operations, the cutting tool is subjected to wear and arbitrary shocks. If proper modifications are not made during a long production period, the risk of tool failure surges and the quality of the product decreases, ensuring in a large proportion of non-conforming items.

This paper mainly focuses on carrying out condition monitoring of a lathe tool during turning operation by measuring the process parameters. The cutting forces and tool tip displacements were measured using a force sensor (analog lathe tool dynamometer) and a displacement sensor (analog Linear Variable Differential Transducer) respectively. The signals collected were analysed using Fast Fourier Transformation (FFT) to predict the symptoms and detect the tool wear. A major part of this paper is therefore dedicated to calibrate the sensors, to acquire analog signals of force and displacements, develop a simple methodology that process the acquired analog signals in to discrete data for further condition monitoring. This work enables the lathe operator to predict the tool wear.

II. Literature Review
In this section, a brief literature review on condition monitoring of lathe tool turning operation is provided.

Bhuiyan et al. (2012) have studied tool condition monitoring for lathe turning operation using an acoustic emission vibration signals in a lathe turning operation. In this paper, an acoustic emission sensor and a triaxial accelerometer have been placed on the tip of the cutting tool holder to monitor the condition of the cutting tool. Fast Fourier transform (FFT) was used to demonstrate the output of sensors. The result was that the tendency of the vibration (along x-axis, y-axis, z-axis) components increases with the increase of feed rate and depth of cut, whereas they show a decreasing tendency with the increase of cutting speed. Saini (2010) has monitored the change in tool wear caused by increasing the cutting speed, through the variation of acoustic emission in turning process, under different feed and depth of cut conditions. From these experiments, he observed that acoustic emission monitoring was a good method for monitoring the growth of tool wear. Magdum and Nayak (2013) studied the cutting forces in a turning operation of EN 8 steel to estimate the tool wear. A strain gauge dynamometer was used to measure the cutting forces. The workpieces used were EN 8 steel bars of dia 30mm and length 100mm. Cutting conditions were feed rate 0.5mm/rev, depth of cut 1.5mm and cutting speed 572rpm. A correlation was observed between the tool wear and cutting forces. The relationship observed was that as the cutting forces increases, the tool wear also increases gradually and hence it drastically decreases the life of the tool.

From the literature review, the conclusion is drawn that the tool wear is influenced by parameters such as cutting speed, depth of cut, condition of the tool, feed rate etc. Hence, monitoring the health of the tool can be done by using sensors such as dynamometer to measure the cutting forces, acoustic sensors or LVDT or eddy current probes to measure any vibration signals from the tool tip. The data obtained thus is then processed for useful comparison and then further analysis is carried out.

III. Experimental Investigation
In this section, the experimental test rig for condition monitoring of turning tool is elaborated along with the calibration of sensors. The procedure adopted for converting the analog signals of force

and displacement in to discrete data in time domain is discussed. These experimental studies were carried out on a precision tool lathe at B.M.S. College of Engineering, Bengaluru.

A. Equipment Used and Specification

A 25 mm diameter mild steel bar of 250 mm length was used as a test specimen to study the cutting tool wear. A lathe was utilised, fitted with a High Speed Steel (HSS) cutting tool. The HSS tool is ground to standard tool face angles and end relief angles. It is fixed in the dynamometer for force acquisition. The capacity of the dynamometer was limited to 500kg-f and measured forces in X-axis (feed force), Y-axis (cutting force), and Z-axis (radial force) directions. To measure the tool tip displacement a LVDT sensor was used which had a measurement range of ± 5 mm. For capturing/ recording of the analog signals from both the dynamometer and LVDT read outs, a 30 fps (frames per second) camera was used. Also, a video splitting software (VLC) was used in order to analyse the analog signals collected from both the measurement sensors. The details of these are explained in a following section where data acquisition and processing is presented.

B. Calibration of the Measurement Sensors

Before starting the experiment, the lathe tool dynamometer was calibrated. The calibration tools that were put into use were a cutting tool, a weight hanger and three different weights of 1 kg each. At first the dynamometer was rigidly mounted on a machine bed. The tool was then fitted in to the fixture with a square hole to form a cantilever support. The dynamometer was then loaded with subsequent weights of 1kg using the weight hanger and at each load the dynamometer reader reading was noted. Same procedure was adopted to obtain the readings for the case of unloading. The calibration was done on all the three axes. The calibration results for the Y axis (cutting force direction) alone are presented in Table 1. Also, a calibrated LVDT was chosen for displacement measurements.

Table 1: Shows the Calibration Done Along Y-axis

Loading weight (kg)	Dynamometer reading During loading (kg-f)	Unloading weight (Kg)	Dynamometer reading during unloading (kg-f)
1	7	1	8
2	15	2	15
3	22	3	22

C. The Proposed Condition Monitoring System

1. Signal Acquisition

Turning operation was carried out for different tools (i.e. worn out and intact tool) and three independent cutting parameters namely cutting speed, feed and depth of cut. The cutting conditions were feed rate 0.05mm/rev, depth of cut 0.5mm and angular speed of turning were 32rpm, 52rpm, and 88rpm .While the cutting speeds were varied, depth of cut and feed rate remained constant. In the first initial stage turning operation was carried out with a healthy intact tool. The lathe tool dynamometer recorded the cutting forces in three different directions (i.e. Fx, Fy, Fz). The LVDT sensor measured the tool displacement. The LVDT sensor was attached to a holder and mounted on the tool tip. As and when the tool comes in contact with the workpiece, it experiences displacement which is immediately detected by the LVDT sensor and displayed in the monitor. One major factor to be considered in this experiment was that there was no Data Acquisition Systems (DAQs) to convert the analog signals obtained from the monitors of the lathe tool dynamometer and LVDT sensors into digital signals. Hence, temporary DAQs was built using a 30fps camera along with a video cutting software. Data from both the sensors were recorded using the 30fps camera and then analysed further via Fast Fourier Transformation (FFT). The same method was then applied for collecting the signals from a worn out tool considering the same cutting conditions with the speeds varying and keeping feed and depth of cut constant. Finally, FFT of different tool conditions were being compared and studied. Important point to be noted is that the analog type dynamometer measured forces in three principal directions but since the scenario of this whole experiment is based on cutting forces, therefore readings related to only Y-axis was put into consideration.

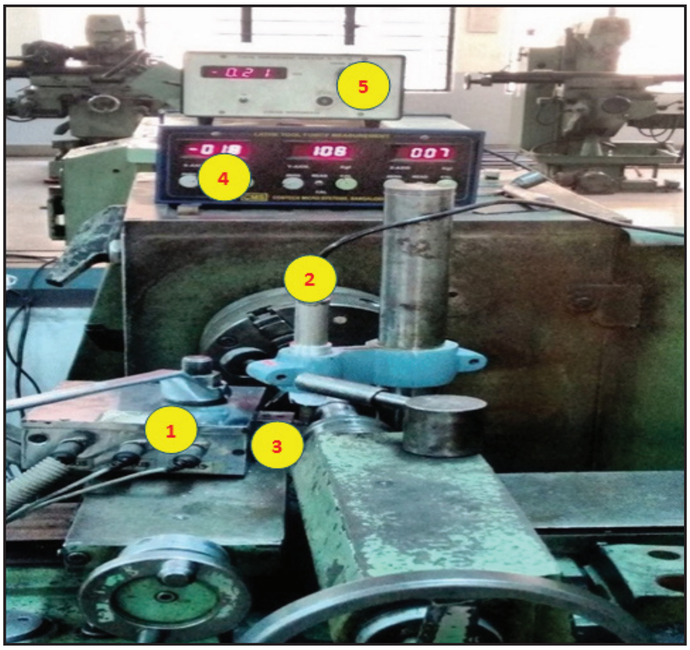

Fig. 1: Experimental Test Rig for Condition Monitoring of Lathe Tool During Turning Operation (1) Lathe Tool Dynamometer (2) LVDT Sensor Placed on Tool Tip (3) Cutting Tool and Fixture in Lathe Tool Dynamometer (4) Analog Read Out for Cutting Forces (5) Analog Read Out for Tool Tip Displacements

2. Discretization of Analog Sesnor Signals

The cutting force signal F(t) and tool tip displacement signal x(t) are obtained as analog readouts from their corresponding sensors i.e., the lathe tool dynamometer and the LVDT sensors respectively. Their corresponding voltage values are displayed in the read-outs. For further processing of the signals in the frequency domain (using Fast Fourier Transforms FFT), it was required to convert them in to discrete time dependent data. As stated in the previous section data acquisitions DAQs were not procured to convert the analog data into digital signals, instead an alternative methodology was adopted. This was achieved by means of a digital camera (Motorola 30 fps mobile camera) and a video splitting software VLC which can record at 23fps. The digital camera that was used, recorded the analog readouts that displayed in the read outs of both the lathe tool dynamometer and the LVDT displacement sensor. The recorded video was then split into each time frame by the VLC software for a fixed time interval and the discrete time dependent data were obtained. An illustration of the same is presented in the following paragraph.

 ISSN : 2249-5762 (Online) | ISSN : 2249-5770 (Print)

For example, considering the speed of the turning operation at 52 rpm (i.e., turning frequency f = 0.867 Hz). The frequency of the camera is f ' = 30 frames per second (fps). Therefore, the time period (1/f ') of the camera to capture one frame is 1/30 i.e. 0.033 s. Whereas, the time period of the shaft to complete one rotation (1/ f) is 1.153 sec. Hence, for one revolution of the shaft at 52 rpm, the digital camera acquires 35 samples of discrete data. This data can then used in FFT procedures for frequency domain analysis of various harmonics present.

It can be seen that the sampling rate (using camera) at 52 rpm is around 30.35 Hz. As the signal frequency is 0.867 Hz, the ratio of sampling to signal frequency is 35, which obviously satisfies the Nyquist criterion for sampling, i.e. the time period required by the shaft to complete one rotation should be greater than the time period of the camera to capture one frame. The video recorded by the camera was then analysed using VLC video splitting software. The VLC software which is video editing software has the capability of recording 23 fps compared to that of the camera (30 fps). In the VLC software, the video was split into frame by frame within a time interval or time step of 0.04 s and the corresponding values from the lathe tool dynamometer and LVDT sensor were noted.

Table 2: Shows the Sample Readings obtained for one cycle (i.e., time period of the shaft to complete one rotation which is 1.156 s) from the lathe tool dynamometer and LVDT sensor of at a cutting speed of 52 rpm.

Time (in seconds)	Cutting Force (Y-direction)	Tool Displace-ment (in mm)	Time (in seconds)	Cutting Force (Y-direction)	Tool Displace-ment (in mm)
0.0	078	-0.14	0.60	068	-0.15
0.04	011	-0.14	0.64	068	-0.15
0.08	011	-0.14	0.68	068	-0.15
0.12	011	-0.14	0.72	068	-0.15
0.16	011	-0.11	0.76	068	-0.15
0.20	011	-0.11	0.80	068	-0.15
0.24	011	-0.11	0.84	097	-0.15
0.28	011	-0.11	0.88	097	-0.15
0.32	011	-0.11	0.92	097	-0.15
0.36	011	-0.11	0.96	097	-0.16
0.40	011	-0.11	1.00	097	-0.16
0.44	068	- 0.11	1.04	097	-0.16
0.48	068	-0.11	1.08	-019	-0.16
0.52	068	-0.19	1.12	-019	-0.16
0.56	068	-0.15	1.16	-019	-0.16

From this the variation of force and displacements can be studied. Similarly, data were recorded for multiple time periods. As stated earlier, the force and displacement signals that were obtained as analog readouts and are supposed to be converted into discrete time domain and frequency domain signals. To achieve this Fast Fourier Transform (FFT) of the discretised data was implemented.

IV. Experimental FFT Analysis Plots

A. FFT Plots for Healthy Tool Condition

The following figures show the frequency spectrum plots and time domain plots for both the cutting force and displacement. The figures shown are for the case of healthy tool.

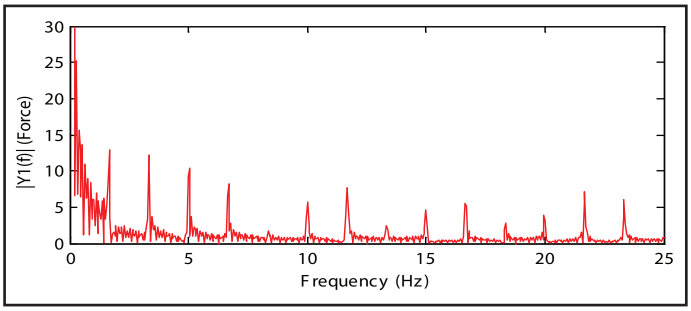

Fig. 2: Shows FFT Spectrum Plot of Forces for Intact Tool in Y-direction at Cutting Speed of 52 r.p.m

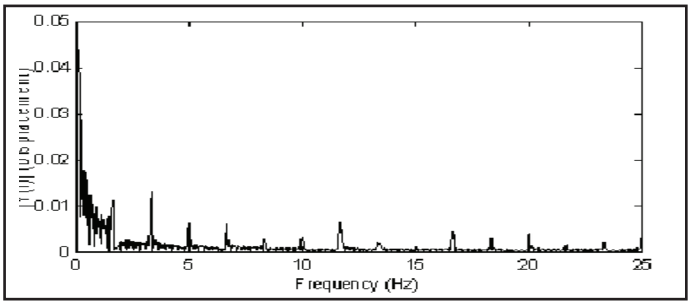

Fig. 3: Shows FFT Spectrum Plot of Displacements for Intact Tool in Y-direction at Cutting Speed of 52 r.p.m

B. FFT Plots For Worn Out Tool Condition

The next stage of the experimental investigation was to capture the signals for a worn out tool. The intact i.e. the healthy tool was detached from the dynamometer and a broken or a worn out tool with its tip broken was attached to the dynamometer. With similar cutting conditions, the values from both the measuring devices were recorded and later by using the VLC software the video was splitted into frame by frame and analysed with the same method as it was used for the new tool. Below are the FFT spectrum plots both in time domain and frequency domain of cutting forces and displacements.

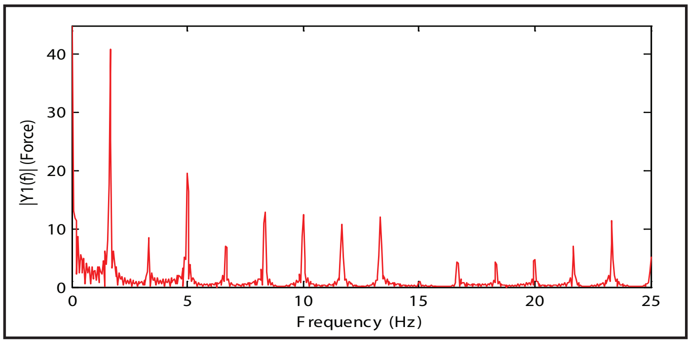

Fig. 4: Shows FFT Spectrum Plot of Cutting Forces for Worn Out Tool in Y-direction at Cutting speed of 52 r.p.m

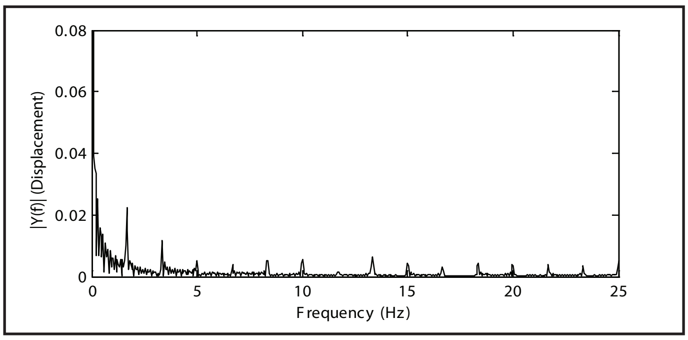

Fig. 5: Shows FFT Spectrum Plot of Displacements for Worn Out Tool in Y-direction at Cutting Speed of 52 r.p.m

V. Discussions on Test Results

The plots obtained were compared for the cases of both of a healthy tool and a worn out tool. The result drawn from the experiment was that, as seen from the plots, the magnitude of cutting forces is observed to be higher in the case of turning with a worn out tool as compared to that of a healthy tool. As in case of a worn out tool operating at cutting speed of 52 rpm, we can observed that in the frequency spectrum plot the maximum amplitude obtained was 41 kg-f whereas in case of a heathy tool it was 13 kg-f. Also, the magnitude of tool tip displacements in time domain is observed to be higher in the case of turning with worn out tool which is 0.022 mm compared to 0.012 mm in case of a healthy tool.

The frequency coefficients of the force as well displacement spectrum plots show higher coefficients for the case of worn out tool Thus, a worn out tool shows higher magnitude of forces and displacements as compared to a new tool. Experimental studies were carried out for cutting speeds at 32 rpm and similar results were observed.

Table 3: Shows the Maximum Amplitude of Cutting Force and Tool Tip Displacement Obtained During Turning Operation at 32 and 52 rpm

Cutting Speed (in rpm)	Cutting Force (in kg-f)		Tool Tip Displacement (in mm)	
	New Tool	Worn out Tool	New Tool	Worn out Tool
32	11	47	0.007	0.027
52	13	41	0.012	0.022

From the above values a correlation is established between cutting speed to that of cutting force and tool tip displacement.

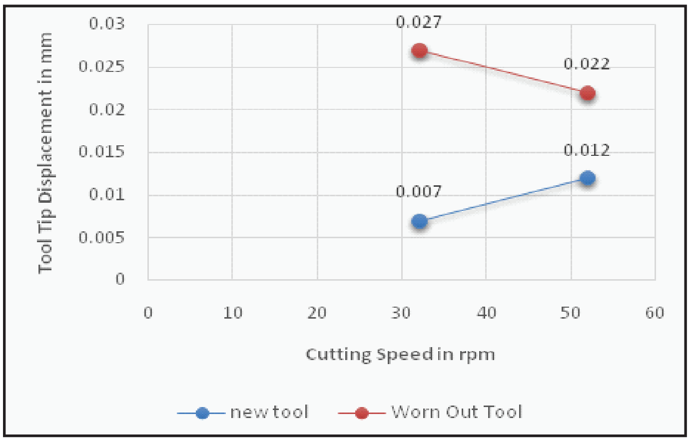

Fig. 6: Shows Relationship Between Cutting Speed

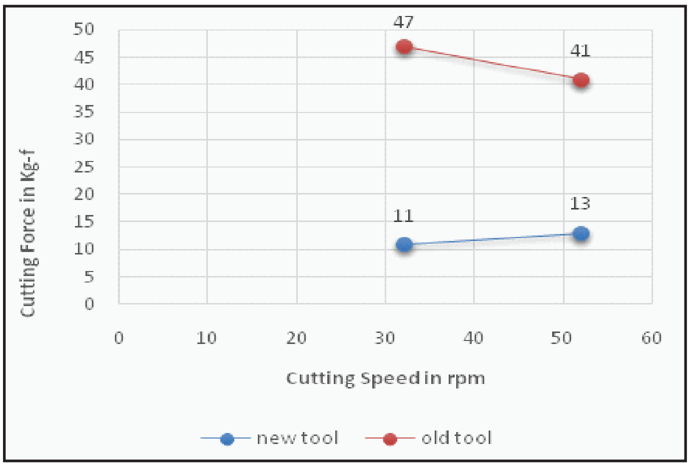

Fig. 7: Shows the Relationship Between Cutting Speed Tool Tip Displacement and Cutting Force

From the above graphs, it is seen that in case of a healthy tool as the cutting speed is increasing the cutting forces as well as the tool tip displacement increases , whereas in case of a worn out tool it's the opposite i.e, the force and tool tip displacements decreases with increase in speed.

VI. Conclusion

From the experiments it was found that development of practical and reliable condition monitoring system is an essential condition for flexible manufacturing process. The problem often faced is the breakage of the tool during machining, which if not sensed in time may lead to numerous complications connected with spoiled jobs, particularly in unmanned machining shifts. Hence, it is essential to have monitoring systems which can collect the data and process the signals to detect the wear and the ultimate breakage of the tool. A major part of this paper was therefore to capture the signals from the machine tool and further analysed those signals to predict the tool wear. A comparison of frequency domain plots was done which showed that the magnitude of cutting forces and displacements is found to be higher in case of the worn out tool thereby stating that a worn out tool has a higher amplitude of both cutting forces and tool tip displacement. Also, a correlation is found between the cutting speed to that of cutting force and tool tip displacement that as the cutting speed increases, the force and the displacement also increases for a new tool and vice versa for a worn out tool.

VII. Acknowledgements

The authors would like to thank Department of Mechanical Engineering, B.M.S. College of Engineering, Bangalore for providing the facilities and extending the help in different aspects of academia. Authors would like to thank the reviewers for their constructive comments and their suggestions.

References

[1] Joëlle Courrech, Ronald L. Eshleman, "Condition monitoring of machinery".
[2] Dennis H. Shreve, "Integrated Condition Monitoring Technologies", IRD® Balancing LLC.
[3] (Module 2 Mechanics of Machining Version 2 ME IIT, Kharagpur) NPTEL.
[4] Wanjun Huang for Dr. Duncan L. MacFarlane, "Fast Fourier Transform and MATLAB Implementation".
[5] Vishal S. Sharma, S.K. Sharma, Ajay K. Sharma "Cutting tool wear estimation for turning" published online: July 2007.
[6] Azlan Bin Mohd. Saini,"Monitoring Tool Wear Process in turning machine using acoustic emission technique", published in December 2010.
[7] M. S. H. Bhuiyan, I. A. Choudhury, Y. Nukman,"Tool Condition Monitoring using Acoustic Emission and Vibration Signature in Turning", Published 29th March 2012.
[8] Vikas B Magdum, Vinay R.Nayak "Tool wear conditioning monitoring when turning" published in May 2013.
[9] "Tool Condition Monitoring using Acoustic Emission and Vibration Signature in Turning", M. S. H. Bhuiyan, I. A. Choudhury, and Y. Nukmam Monitoring Tool Wear Process.
[10] H.Chelladurai, V. K. Jain, N. S. Vyas,"Development of a cutting tool condition monitoring system for high speed turning operation by vibration and strain analysis".
[11] Vikas B Magdum, Vinay R.Nayak,"Tool wear conditioning monitoring when turning".