Development of a Vibration Signal Data Acquisition System for Fault Diagnosis of a Machine

Sanjay K Asati[1]
Faculty,Mech. Engg.,
MIET Gondia (M.S.)

Dr P. M. Bapat[2]
Principal, VPS College of Engb & tech
Lonavala, Pune (M.S)

Abstract:
In operating the machines, occurrence of vibration due to various factors affecting machine operations are very crucial to diagnose and analyse as it has adverse effect on its performance and effectiveness. In turning operations, the variation in cutting parameters and failure in any one of its machine parts or elements of driving mechanism of a lathe machine results in vibrations. This results in deteriorated machined surface and defectives being produced for not meeting the specifications. In order to prevent the losses due to this, it is imperative to keep the machine in well healthy condition by minimizing the vibration of the machine while turning on lathe. The analysis revealed that for the specified range of speed, feed and depth of cut, any change in the depth of cut causes a large change in the tool vibration while change in the cutting speed causes comparatively lowest change in tool vibration. It is long observed that the maintenance of machine is a very critical activity and is a major cost burden activity for any organization. It is therefore demanded to develop a system which assist in condition monitoring of operative members/machine so that the machine may be restore to its initial condition before any failure occur. For this an effort is made to develop a vibration signal measurement system which shall acquire the relevant data for further study and analysis. In this regard a series of such systems are studied and a simple cost effective vibration signal acquisition/measurement system suitable for use for small industries is developed and tested for its successful performance.

Keywords: Vibration Sensor, Data Acquisition system,vibration, amplitude, frequency.

1. Introduction:

In a typical machining process, in the cutting region there are several cutting variables, such as cutting forces, vibrations, acoustic emission, temperature, surface finish, etc. that are influenced by the cutting tool condition and the material removal process conditions. These variables which are prospectively effective for machining process monitoring can be measured by the use of suitable sensors. Signals detected by these sensors are subjected to analogue and digital signal conditioning and processing with the objective to generate functional signal features w.r.t. the cutting tool and cutting parameters. The acquired signals/features are then used to analyse and evaluate by appropriate decision making techniques for the ultimate diagnosis.

In turning operation checking the tool vibration is very important for the machined part. Occurrence of vibration exceeding the permissible limit may have adverse effect on the cutting tool and surface finish and the part being manufactured may not meet the desired specification limits. Vibration in machine tool and cutting tool is one of the most important factors limiting its performance. Lot of research work and investigations have been carried out across the world to help industries in sorting out the problem. Many researchers have succeeded on some fronts but limitations in data acquisition and insufficient knowledge and inappropriate technology in signal analysis could not permit them to reach a stage from where a dedicated flawless system may be developed to minimize remove the problem and industries are working with improved efficiency and effectiveness. However, it has also been found that, limiting conditions minimizes the production rate [1]. A large number of analytical and experimental study has been carried out for vibration control [2,3,4]. An effort is made in this direction through this research work to develop a vibration signal measurement system which shall not only include a sophisticated signal acquiring sensor but a supportive system that shall record and collect the data that can be retrieved for further analysis.

Vibration in a turning operation can be classified as [3] free, forced and self-excited vibration. Free vibration has short transient response than forced & self excited vibrations little practical significance. Self excited vibration is the result of a dynamic instability of the turning process. Forced vibration emerges due to periodic cutting forces acting on the cutting tool. Tool vibration analysis [2,5] has revealed that cutting parameters not only have an effect on the amplitude of vibration, but also on the variation of the natural frequency of the tool. [6] predicts surface roughness based on the cutting parameters and tool vibrations in turning operations. [7] also predicts surface roughness and dimensional deviation by measuring cutting forces and vibrations in turning process. [8], According to [9], the cutting forces depend primarily on the feed rate and the depth of cut. It is also learnt that the optimum parameters for reducing vibration are achieved by observing a judicious combination of each.

It is observed that despite all efforts taken to prevent maintenance of machine through various maintenance activities it has been a tedious job for the maintenance crew to keep the machine in good operating condition. Still machines are unreliable and demand for ways to anticipate the failure likely to occur in future. It may go out of action or may run in faulty condition that can lead to a catastrophic fault with time. In faulty running condition the quality of product also suffer. Such an erroneous situation motivates to monitor the parameter of machine condition i.e. condition monitoring [10] [11]. Condition monitoring is one of the ways to address such problem. In support of condition monitoring techniques, there must be dedicated fault detection techniques available for use. The machine health can be well diagnosed based on the variation in vibration signals recorded. Hence there is a need to design and develop a system which can record those signals and store for its further use by retrieval for diagnosis and analysis.

Machine performance is based on various parameters that vary with change in machine condition and such observed variation in any of the observed parameter can be used for monitoring the condition of machine. Machine vibration is one of the parameters for monitoring purposes to directly monitor machine health condition. During operation each machine vibrates with its natural frequency and the coupled sections transmit these vibrations. The machine has its own unique vibration signature that indicates normal machine behavior. In the event of any failure/defect come to fore, the frequency components in the spectrum changes and give an exclusive vibration pattern. It means that variation in the machine vibration is the indication of emerging problem/defect in machine to call it a faulty one. Vibration monitoring methods are capable of detecting and identifying such more other faults than other fault detection methods as vibration acquisition has no effect on the operation of machine [12] [13] [14].

Vibration signal acquisition and interfacing of acquisition system with PC have been discussed in few papers. In [15] accelerometers is used to sense Vibration signals, vertically measured signal for analysis and the horizontally one for verification. Data acquisition board having inbuilt anti aliasing filter, is used for signal collection. In [16] Vibration acquisition is done by Dytran 3035AG accelerometer. The signal is amplified by the Dytran 4105C and low pass filtered. In [17] Vibration signal is amplified and converted into digital by ADC 0808. The processing is done for interfacing to PC data acquisition. In [18] ADXL330, a tri axial, MEMS type piezoelectric accelerometer is preferred because of their high frequency response. Vibration data acquired and saved in the computer using Shielded Collector Block, DAQ card and LABVIEW 8.6. In [19] simple and low cost instrument system for online structural vibration monitoring is developed using MEMS accelerometer MMA7260QT based on RS-485 network topology consisting of a master and four slave units. Master is interfaced with PC through RS-

485 while Slave is a vibration sensor coupled with microcontroller based data acquisition system.

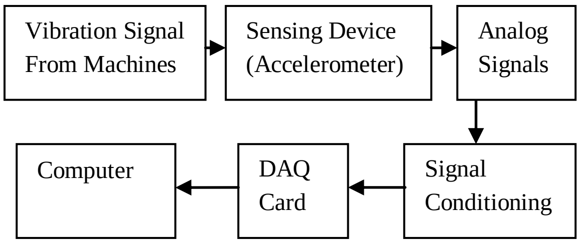

Fig. 1. Block diagram of general Data Acquisition System

The past researches who worked on machine vibration used technically old accelerometers interfacing with pc through USB port as shown in fig. 1. The shortcomings of these vibration acquisition systems are costly; bulky, complicated and its interfacing method. With this paper an attempt is made to develop an economical and useful vibration data acquisition system for small machines using latest, low cost, small size, capacitive micro machined accelerometer MMA7260QT of new technology like MEMS (Micromachined Electromechanical system) and interfacing with PC through line in port of sound card. This sensor features signal conditioning, a 1-pole low pass filter, temperature compensation and g-select to select among 4 sensitivities. The salient feature surface mount Micromachined capacitive accelerometer is its small size, compactness, sensitive, lightweight, and relatively cheap, on board signal conditioning [20].

In this system preconditioned analog output signal is amplified, conditioned, and filtered by circuit components mounted inside the same IC package. Thus the need for signal conditioning is eliminated [21]. Sensor with 5v circuit is mounted on PCB board. The acquisition system is interfaced with computer through line in port of sound card. The block diagram of presently used data acquisition system is shown in figure 2. The experimental set up is established on a centre lathe for turning operation with the specifications: Motor 1 Hp, 1400 rpm, 4 feet, 4-speed cone pulley headstock with backgears.

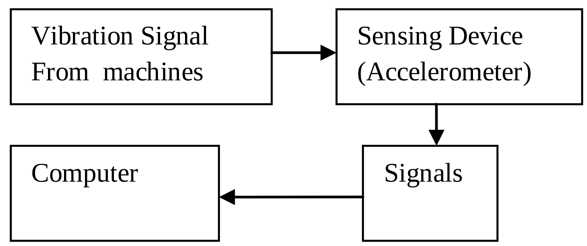

Fig 2. Block diagram of Newer Data acquisition system

2. Introduction to lathe machine and its vibration signals:

The purpose of lathe machine is to remove extra material from the cylindrical surface penetrating a single point cutting tool against the workpiece material at given cutting parameters. In this, material is normally held in the chuck and power is transmitted from motor through cone-pulley headstock via spindle. A cutting tool is mounted on the tool post and the depth of cut is adjusted with the movement of cross slide. The feed is given using the carriage mounted on feed red or lead screw. The size of machine varies from 4 feet to 10 feet. The headstock accommodates the cone-pulley drives with backgears for obtaining number of speeds. Normally the machine capacity is rated with the motor being used and it ranges from 1 Hp, 1440 rpm onwards as per the requirement. The expected frequencies of induction motor will be 1440/60 = 24 Hz and integer or fractional multiple of it and frequency of gear box also depends on (gear shaft rpm × no of teeth of gear) and its harmonics. Typically frequency range of machines is 10 Hz to 10 KHz [12] [14].

3. Development of a signal acquisition system:

3.1. Selection of sensor, mounting and interfacing method: The selection of an appropriate vibration sensing device depends on specification of the machine under monitoring in terms of its motor power, rpm, driving mechanism, output capacity desired accuracy and precision of the data to be collected. Normally available devices with high frequency sensors have low sensitivity and vice-versa. Thus selecting a suitable device is based on making judicious selection between sensitivity and frequency range to suit the requirement. The ranges of sensors available are Piezo-resistive, piezo-electric and MEMS type. Piezo-electric sensors are the widely used accelerometers offering a very wide frequency range (upto 20 kHz or so) with range of sensitivities, weights, sizes and shapes. These accelerometers are available with a charge or voltage output. These sensors can be expensive and require additional signal conditioning circuits. Piezo-resistive accelerometers generally have low sensitivity making them desirable for shock measurements [22] [23] [24]. The latest in sensors available are MEMS, (technology based on very small mechanical devices driven by electricity). With surface Micromachined Capacitive approach prices of sensor have gone down dramatically and cost/Performance ratio is also improving. The salient feature of surface mount Micromachined capacitive accelerometer is its low cost and on board signal conditioning.

In the present signal acquisition work accelerometer MMA7260QT is used as vibration sensor with its 5V regulated power supply circuit mounted on PCB board. There are a number of ways to mount an accelerometer to the target. Mounting of sensor on machine for signal acquisition plays an important role in the overall performance therefore the best sensing location must be identified and a suitable place for sensor positioning is decided. The sensor must be mounted using fasteners to achieve better signal transmissibility. Adhesive mounting may be recommended especially on small surfaces and PCB boards [25] [26]. For PCB mounted accelerometer MMA7260QT adhesive mounting being is most suitable is used for the purpose. In the present data acquisition system line in port of sound card is used for interfacing the sensor with computer. The analog to digital conversion or vice versa takes place in the sound card itself.

3.2. Hardware: A 5v regulated power supply circuit is designed using 9v transformer, 1N4007 diode, 2.2mF, 100uF and 220uF capacitors and IC-7805 is given to the sensor circuit. The sensor circuit is integrated signal conditioning with low pass filter and high sensitivity 800mV/g at maximum acceleration1.5g avoiding the need of further pre-amplification and filtering. The output of sensor circuit is in the range of input of line in port of sound card. The developed signal acquisition system is shown in fig. 3.

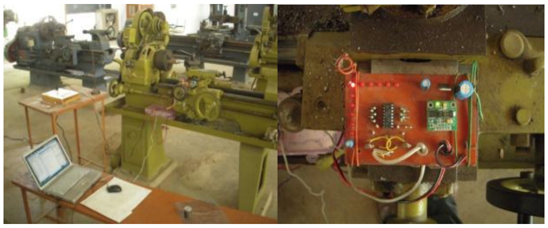

Fig 3. Developed acquisition system

3.3 Software: The vibration data signals are acquired using Matlab Simulink block and stored in the computer. Simulink is a multi domain simulation and Model-Based Design which provides an interactive graphical environment and a customisable set of block libraries to allow design, simulate, implement, and test a variety of time-varying systems, including communications, controls, signal processing. The details of used blocks are given below. 5V Regulated Supply configures an analog data acquisition device. The opening, initialization, and configuration of the device occur once at the start of the execution. During the model's run time, the block acquires data either synchronously or asynchronously. In synchronous acquisition mode the acquisition occur at each time step. The simulation will not continue until all data is acquired. In asynchronous mode the acquisition initiates when simulation starts. The block has no input ports. It has one or more output ports. In the used system data is acquired asynchronously. The scope block lies in sink library and display signals generated during simulation with respect to simulation time. The Scope block have multiple axes and all axes have a common time. For the continuous signal, the Scope generates point-to-point plot. In discrete signals, the plot is stair step. The Scope provides toolbar buttons to allow modification of signal to meet the requirement.

The To Wave File block streams audio data to a Microsoft Wave (.wav) file in the uncompressed pulse code modulation (PCM) format. For compatibility reasons, the sample rate of the discrete-time input signal should typically be one of the standard Windows audio device rates (i.e. 8000, 11025, 22050, or 44100 Hz), although the block supports arbitrary rates. While acquiring the signal using the sensor the audio device rate used is 8000 Hz.

4. Experimental results of developed acquisition system:

The signal data acquisition started with the set up of a lathe machine (turning operation) for the ideal running condition for one of the known cutting parameter and known specified condition .The machine is verified for its performance for the given condition and the signal data are acquired to ascertain that the data acquisition system is working in tune with the machine. For the known operating condition the signal are collected and the developed system indicated the waveform. To meet the objective of vibration data collection the cutting and machine condition are classified in terms of Normal/Healthy and Abnormal/Faulty condition.

The numbers of setup are run to test the data acquisition system on real time basis. The data acquisition began with the conditions for Normal being verified by the machine operator as well that the machine is running in healthy condition and there is no unfamiliar symptoms observed as part of the condition monitoring system. The monitor of computer indicated the relevant waveform to indicate the amplitude against time scale. The acquired waveform and its spectrum is indicated in fig 4 and fig 5.

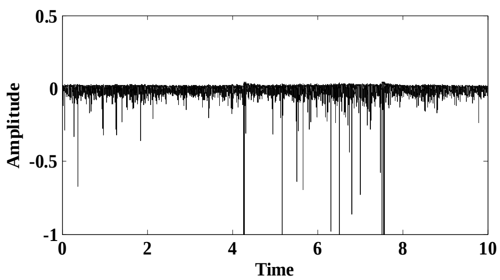

Fig 4. Vibration signal in normal condition

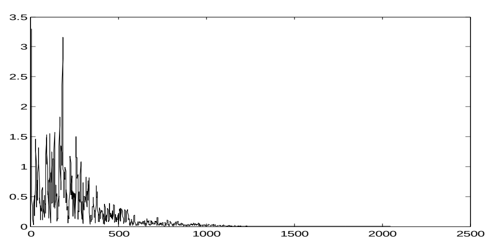

Fig 5. Spectrum of Normal Signal

To further analyse test data for Abnormal/Faulty condition one of the factors under consideration is varied to introduce Abnormal/Faulty behavior in the machine. The machine behavior is different than normal and the operator confirmed this as faulty condition. Signals are collected and the waveform and its spectrum obtain are as shown in fig 6 and Fig 7

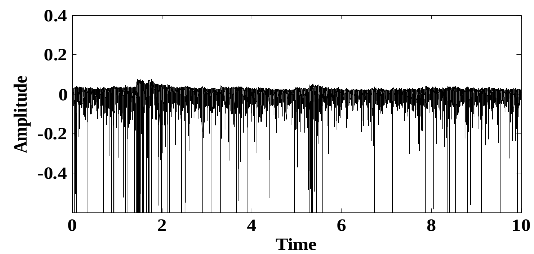

Fig 6. Vibration signal in normal condition

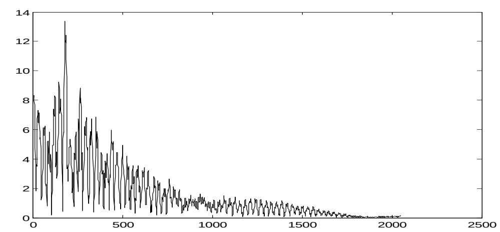

Fig 7. Spectrum of Abnormal Signal

Many signals from machine are acquired in normal condition and this is confirmed with the help of working machine operator. One normal signal and its spectrum are shown in fig 4 and fig 5. An abnormal condition is created by losing the four base screws of foot of motor connected to the hard base. Then abnormal signals are acquired from motor at the same place. The abnormal signal and its spectrum are shown in fig 6 and fig 7.

The comparison of the signals being displayed in the waveforms and spectrums are sufficient to draw some conclusion. In faulty state, high amplitude and frequency components are present and hence spectrum ranges are high to state that as the machine starts behaving Abnormally there are rise in the amplitude and frequencies. On this basis it can be broadly concluded that the machine behavior in terms of Normal and Abnormal condition can be conveniently detected by comparing the real time vibration signals using the developed data acquisition system.

5. Conclusion

The vibration\data acquisition system is developed to acquire the vibration signal. On data collection and comparing the results with the actual condition of machine in real time ensures that the developed data acquisition system is functionally correct and giving satisfactory results. The developed system has indicated better characteristics in signal acquisition which prompted it to use for many other data collection processes for many other machine parameters and cutting conditions.

The faulty condition is detected by analyzing vibration signals. Generally the amplitude of vibration and the range of frequency in spectrum are the indicator of the machine condition and this data acquisition system succeeded in classifying the data correctly. In the present data acquisition and testing procedure it is observed that the amplitude and the frequency had increased in the faulty conditions. The developed data acquisition system is very useful for small and medium sized machines because it can acquire the vibrations of moderate frequency range. For early prediction of faults the very high frequency vibration should be acquired.

References:

[1] On-line control of machine tool vibration during turning operation, S.K. Choudhurya, M.S. Sharathb, Mechanical Engineering Department, I.I.T. Kanpur,

[2] Effect of tool vibrations on surface roughness during lathe dry turning process, Thomas M., Beauchamp Y., Youssef A.Y., Masounave J. Professor, Mechanical Engineering Department École de technologie supérieure Montréal, Canada.

[3] Design of dynamic vibration absorber against vibrations in turning operations, E.C. Leea, C.Y. Nianb, Y.S. Tarnga,, Department of Mechanical Engineering, National Taiwan University of Science & Technology, Taipei, Taiwan.

[4] On-Line Control of Machine Tool Vibration in Turning, S.K. Choudhury, N.N. Goudimenko and V.A. Kudinov,

[5] Tool vibration and its influence on surface roughness in turning, M. S. Selvam, Department of Mechanical Engineering, College of Engineering, Guindy, Madras

[6] Surface roughness prediction based on cutting parameters and tool vibrations in turning operations, O.B. Abouelatta, J. Mádl,, Mechanical Technology Department, Praha, Czech Republic

[7] Prediction of surface roughness and dimensional deviation by measuring cutting forces and vibrations in turning process, K.A. Risbood, U.S. Dixit, A.D. Sahasrabudhe, Dept of

Mechanical Engineering, Indian Institute of Technology, Guwahati

[8] Design optimization of cutting parameters for turning operations based on the Taguchi method, W.H. Yang, Y.S. Tarng, Department of Mechanical Engineering, National Taiwan University of Science and Technology, Taipei , Taiwan,

[9] Statistical investigation of modal parameters of cutting tools in dry turning, M. Thomas, Y. Beauchamp, Department of Mechanical Engineering, E´ cole de technologie supe´rieure, Notre Dame West, Montreal, Canada.

[10] "Extrasensory inspection", C.Sell,, Engineer, Vol.293, Issue25, 23 July 2004, pp. 31-34.

[11] M.Laszkiewicz,"Using maintenance as a strategic business asset", Plant Engineering, Vol. 58, Issue 10, 2004, pp 31-35.

[12] Design of Vibration Signal Acquisition System for Condition Monitoring of Plastic Extrusion Machine", S Rastogi, A Mitra, IJERT, Vol. 1 Issue 6, August - 2012

[13] "P.J. Tavner, "Review of condition monitoring of rotating electrical machines", IET Electrical Power Applications, Vol. 2, No. 4, 2008, pp. 215

[14] V. Alexej, and Barkov, "The Capabilities of the new generation of the monitoring and diagnostic systems", Metallurg, No.11, 1998.

[15] A. R. Fairclough, and A. Wienese, "Practical experiences of Vibration Condition Monitoring", Proceedings of The SAST Association, June 1988.

[16] Jie Liu, "An Intelligent System for Bearing Condition Monitoring", a thesis presented to the University of Waterloo, for the degree of Doctor of Philosophy in Mechanical Engineering, Waterloo, Ontario, Canada,2008

[17] Shahab Hasan Ghafari, "A Fault Diagnosis System for Rotary Machinery Supported by Rolling Element Bearings", A thesis presented to the University of Waterloo, for the degree of Doctor of Philosophy in Mechanical Engineering, Waterloo, Ontario, Canada, 2007

[18] Dilip Das, S. Sheetal, "Data Acquisition Using AT89c51 and PCL-207" A project submitted at, NIT, Rourkela

[19] Himanshu Jain, "Detection and severity classification of rotor imbalance faults in induction machines", A thesis submitted to the University of Texas at Arlington for the Degree of M.S. in electrical engineering, August 2010.

[20] D. R. Santoso, "A Simple Instrumentation System for Large Structure Vibration Monitoring", TELKOMNIKA, Indonesian Journal of Elect. Engineering.

[21] R. Joel, L. William, Cleghorn, & K. M. James, "Design and analysis of a low frequency MEMS vibration sensor for automotive fault detection", International Journal of

Vehicle Design, 54(2), 2010, pp. 93-110

[22] Freescale Semiconductor, MMA7260Q XYZ 3-Axis Low g Acceleration Sensor, available on http://www.freescale.com/files/sensors/doc/factsheet_MMA 7260QFS.pdf.

[23] Bob Judd, "Using Accelerometers in a Data Acquisition System" UEI App Notes, United Electronics Industries, Inc.

[24] Patrick L. Walter, "How High in Frequency Are Accelerometer Measurements Meaningful?" PCB Piezotronics, Inc. and Texas Christian University.

[25] Petr Kadaník, PC-Based Data Acquisition Systems", Gerstner Laboratory for Intelligent Decision Making and Control Czech Technical University in Prague.

[26] Kaveh Mollazade, Hojat Ahmadi, Mahmud Omid, Reza Alimardani, "An Intelligent Combined Method Based on Power Spectral Density, Decision Trees and Fuzzy Logic for Hydraulic Pumps Fault Diagnosis", International Journal of Electrical and Computer Engineering, vol. 3, Aug. 2008

[27] Asan Gani and Mje Salami, "Vibration Faults Simulation System: A Lab Equipment to aid Teaching of Mechatronics Courses", International J. Engg Ed. Vol. 20, No. 1, 2004, pp. 61-69.