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Research Article

Real Time Monitoring of Surface Roughness by Acoustic Emissions in CNC Turning

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Abstract

Machining is the most important part of the manufacturing processes. Machining deals with the process of removing material from a work piece in the form of chips. Machining is necessary where tight tolerances on dimensions and finishes are required. The common feature is the use of a cutting tool to form a chip that is removed from the work part, called Swarf. Every tool is subjected to wear in machining. The wear of the tool is gradual and reaches certain limit of life which is identified when the tool no longer produce the parts to required quality. There are various types of wear a single point cutting tool may be subjected to in turning. Of these, flank wear on the tool significantly affects surface roughness. The other types of tool wears are generally avoided by proper selection of tool material and cutting conditions. On-line surface roughness measurements gained significant importance in manufacturing systems to provide accurate machining. The Acoustic Emission (AE) analysis is one of the most promising techniques for on-line surface roughness monitoring. The AE signals are very sensitive to changes in cutting process conditions. The gradual flank wear of the tool in turning causes changes in AE signal parameters. In the present work investigations are carried for turning operation on mild steel material using HSS tool. The AE signals are measured by highly sensitive piezoelectric element; the on-line signals are suitably amplified using a high gain pre-amplifier. The amplified signals then recorded on to a computer and then analyzed using MAT LAB. A program is developed to measure AE signal parameters like Ring down count (RDC), Signal Rise Time and RMS voltage. The surface roughness is measured by roller ended linear variable probe, fitted and moved along with tool post on a CNC lathe machine. The linear movements of probe are converted in the form of continuous signals and are displayed on-line in the computer. The results thus plotted show a significant relation between Surface Roughness and AE signal parameters. The conclusions are made for predicting surface roughness by suggesting consistent values and ranges for on-line monitoring AE signal parameters.

Keywords: Acoustic Emission, Surface roughness, Turning, Ring down count.

1. Introduction

Flank wear in single point cutting tool cause inaccuracies in machining resulting in rejection of parts and also causes problem for machine elements. There are various direct and indirect methods are there in practice for measurement surface roughness. The need for on-line monitoring is one of the important necessities for computer integrated manufacturing (CIM) that will lead to unmanned factory of the future. Within the CIM philosophy the entire activities of design, Production planning, production, quality control, tool monitoring will be integrated as a global system. As a subsystem of CIM, flexible manufacturing system (FMS) integrates machine tool with automated storage and retrieval system (AS/RS) to provide flexibility for meeting varied demands. CNC machining centers are most widely used in FMS, such machines consists of large number of different tools for different operations equipped within a tool magazine. Thus monitoring large number of tools created a new era what it is called tool management systems (TMS). The prime function of this is to ensure availability of right tool at right time. On-line monitoring of surface roughness has presently acquired more importance than ever as the manufacturing systems are increasingly requested to provide greater automation and flexibility. In-process detection of surface roughness is very important for automation of the machining process. This detection provides compensations and ensures required surface roughness value to make machining process more accurate. One of the most promising NDT techniques for indirect on-line measurement of surface roughness is AE analysis. Acoustic emission may be defined as the class of phenomenon where transient elastic waves are generated by the rapid release of energy from localized sources within a

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material. In other words acoustic emission refers the stress waves generated by dynamic processes in material. Emission occurs as release a series of short impulsive energy packets. The energy thus released travels as a spherical wave front and can be picked from the surface of a material using highly sensitive transducers.

In the present work investigations are carried to find surface roughness on-line by measuring AE signal parameters.

2. Literature Review

Many researchers proposed to work in the area of in-process tool wear monitoring to increase the efficiency of machining. Ming - Shong Ian and Ynqve Naerheim (1986) used an adaptive signal-processing scheme for the cutting force signal to detect the fracture and chipping of a cutting tool during milling operation. The cutting force signal was modeled by a discrete autoregressive model where parameters were estimated recursively at each sampling instant using a parameter adaptation algorithm based on a model reference adaptive system approach. Sensitivity of the prediction error and the estimated parameter to the fracture and chipping of a cutting tool are presented. Influence of the adaptation algorithm parameters on estimation results was discussed. The effect of the changed cutting conditions on the estimation result was also investigated. [1]

Diet and Dornfeld (1987) applied the AE signal analysis for on-line sensing of tool wear in face milling. AE signals, feed and normal components of cutting forces and flank wear were measured and compared. The results indicate that both AE and cutting force have parameters that correlate closely with flank wear. It was also observed with both the mean AE RMS and growth of flank wear. [2]

T. A Carolan et al., (1997) investigated the relationship between tool wear and the energy of acoustic emission produced during various face milling finishing operations. A model detailing how the AE energy, quantified by the RMS value, varies depending on the material and the detailed tool geometry formed by flank and crater wear was described. Validation of the model was achieved in a series of practical machining tests covering a range of materials and tool types which resulted in various different wear forms. A non-contact fiber optic interferometer was employed for AE detection directly from the work piece. For comparison purposes, piezoelectric AE transducer was also used to acquire data and these data have been processed to give an indication of tool wear. The different evolutions of AE energy with wear were evaluated. [3]

H. Pan et al. (1995) investigated the usage of AE signal obtained in a relative low frequency range through a solid path for the monitoring of tool wear. Data analysis was conducted in both time and frequency domains. A clear pattern in such signals corresponding to the tool wear conditions has been identified. Several components in spectra were found in pattern for indicating sudden changes of tool wear or breakage occurring at major cutting edges. It was also observed that the RMS and variance values of the signals could indicate the specific wear condition of the tool. Thus the AE signal was found to carry sensitive information about the progress of tool Wear and could be implemented on-line for monitoring tool wear. [4]

P. k. Ramakrishna Rao et al., (1996) made an attempt to monitor tool wear using AE signal analysis using parameter like Ring down count for the detection of developing tool wear.

The results indicate a close correlation between tool wear and Ring down count. Therefore the feasibility of using AE technique as an in-process tool wear-monitoring method was established. [5]

Wang Z. J., A. K. Balaji and I. S. Jawahir (2002) have shown the methods for selection of optimal cutting parameters for machining [6]. Haili [2003] used AE and motor power signals to develop an on-line breakage monitoring in turning. Time-frequency analysis was used for the AE signals processing and a neural network based on adaptative resonance theory (ART2) for signal classification [7].

Teti reported an interesting work on tool wear where different laboratories analyzed the same AE signals using different processing methods. Besides, Teti has other relevant studies for the development of in-process monitoring of cutting conditions and tool wear using AE [8-11].

3. Experimental Procedure

The experiments were carried out on a CNC Lathe Machine. The work piece material was mild steel. The cutting tool is made up of HSS. The optimal cutting parameters are found by conducting number of trails at various speeds, feeds and depth of cut values. The surface roughness is measured on-line for every trail using a LVDT having high accuracy up to microns. The LVDT is mounted on the tool post as shown in Figure 1. It consists of a mechanical probe with high strength roller end made up of hardened steel with nylon as shown in Figure 3. As the cutting tool moves the probe also moves along the machined surface, thus scans entire surface in machining. The deviations of the probe are displayed on digital display meter through signal conditioner. The signal conditioner consists of a series of filters, a 3-way phase detector with which positive and negative deviations can be set and are displayed on digital meter. The junction card takes the output from the signal conditioner and transforms the voltage within the acceptable limits of the computer. The data acquisition card takes the input from the junction card and converts the signals from analog to digital form. The digital data is thus available for the software to process further to find surface roughness parameters. Figure 2.and Figure 4. Shows the set-up components and the PCI-O2 card used for data conversion and data acquisition. The PCI-02 is an ADC/DAC/TIMER/DIGITAL-I/O card. It is a 2-layer board with sufficient ground plate to give high noise immunity. The card provides the bridge between the PCI bus and the peripheral bus. It provides the control, address and data interfaces for peripheral to work as a PCI compliment peripheral. The ADC/DAC signals are brought out through a 25-pin D type of connector. Preliminary investigations shows the Rmax is minimum at cutting speed of 580 m/min and the consistency plot where minimum Rmax readings consistently lies between 5μm and 14μm for various trails taken at selected cutting parameters such as speed 580 m/min, feed 0.10 mm/revolution and depth of cut 0.1mm. The further predictions for, acoustic emission signal parameters and surface roughness parameters are found at this optimal cutting speed and depth of cut, the feed is changed from 0.05 to 0.2mm/revolution. The AE signals were measured by highly sensitive microphone, the signal were suitably amplified using a high gain pre- amplifier. The amplified signals were then recorded in the computer and then analyzed using MATLAB. A program was developed to measure AE signal parameters such as Ring down count (RDC), Signal Rise time and RMS voltage. The surface roughness is measured by highly sensitive linear variable differential amplifier. The linear movements of roller ended high strength probe are converted to continuous signal and are displayed on computer.

Number of experiments is conducted for different feeds, each experiment involves number of cuts performed up to 560 seconds with 28 trails. Each trail is taken for the interval of 20 seconds. For every trail AE and surface roughness parameters are noted.

Figure 1. LVDT Set up

Figure 2. Set up Components

Figure 3. LVDT Probe

Figure 4. PCI-O2 Card

4. Results and Discussions

The Ring down count (RDC) is the number of times the signal amplitude croses the preset reference threshold. Figure 5 shows the behavier of Ring down count with cutting time, Initially the RDC increases rapidly later it was gradual up to 450 seconds and then again increases rapidly due to high intensity of rubbing of the work piece with the cutting tool. The initial increase is becouse of the microfracturing takes place when the tool comes in contact with the work piece. The Micro-uneveness on the cutting edge is removed producing more burst emissions. Then, as machining continues, there will be normal metal removal in the form of chips, which will give rise to continious emissions. However, as machining continues the flank face come in contact with the machined surface leading to rubbing and friction, giving rise to flank wear. As cutting progresses, there will be more rubbing and hence more flank wear, giving rise to burst emissions. This is becouse the flank/workpiece contact area increases as a result of tool wear. Fig 6 shows the variations of Rise time with Cutting time. The Rise time of the AE signal is gradual up to 420 sec later decreases rapidly due to increase in frequency of signals coused due to more rubbing. As shown in figure 7 the RMS voltage also increases beyond the critical value becouse of increase in cotact area of the tool tip with workpiece. In general, it is expected that flank wear and notch wear will increase the area of contact and hence will increase RMS voltage.

Figure 8 to Figure 10 shows variations of surface roughness parameters such as Rz, Rmax and Ra with cutting time. These parameters are consistant with gradual variation up to 400 seconds later increases rapidly, the inconsistancy is due to increase in intensity of rubbing couses increase in tool wear rate and thus couses rapid change in surface roughness beyond critical value. Table 1 and Table 2 shows the consistant values for AE and roughness parameters. Table 3 shows the correlation between AE parameters and Roughness parameters, for all parameters the Pearson correlation coefficient lies between -1 and +1 hence they have good correlation.

Cutting conditions:

Cutting speed: 580 m/min, Depth of cut = 0.1 mm,
Feed = 0.05-0.20 mm/rev, Cutting tool material: HSS,
Work material: Low carbon steel

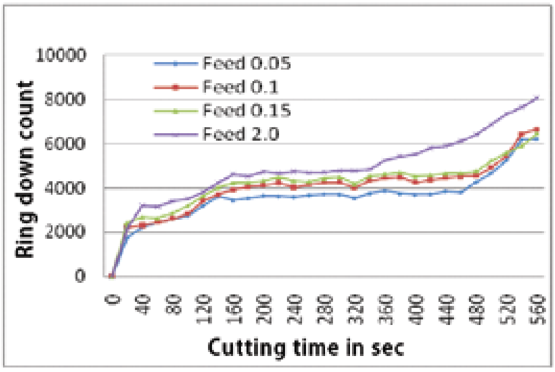

Figure 5. Cutting time v/s Ring down count

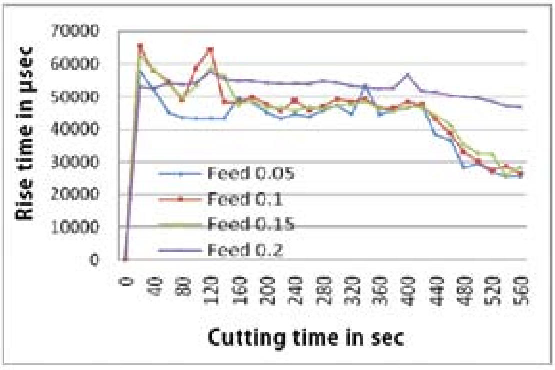

Figure 6. Cutting time v/s Rise time

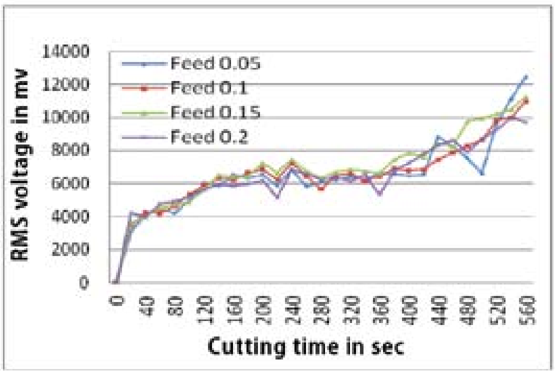

Figure 7. Cutting time v/s RMS voltage

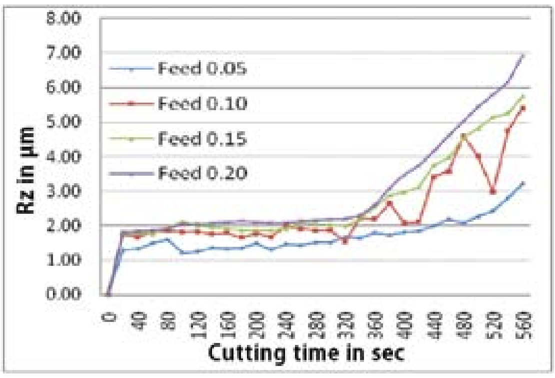

Figure 8. Cutting time v/s Rz

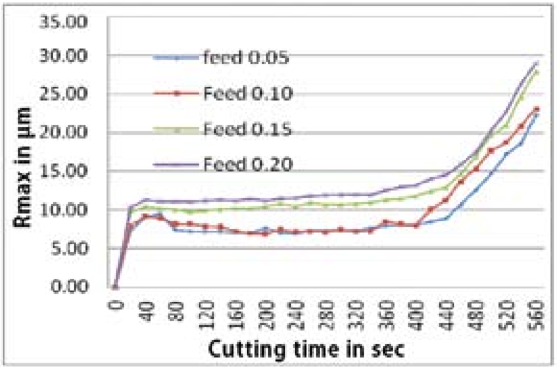

Figure 9. Cutting time v/s Rmax

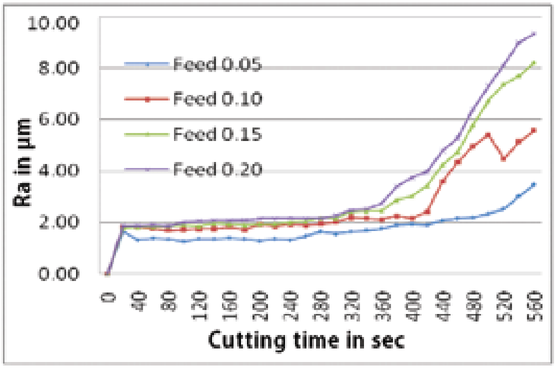

Figure 10. Cutting time v/s Ra

Table 1. Consistent values for Acoustic emission parameters.

Reference plots	Cutting time (sec)	Ring down count	Rise time (µsec)	RMS voltage (mv)
Cutting time v/s Ring down count	up to 450	4000 - 5000		
Cutting time v/s Rise time	up to 420		45000 - 65000	
Cutting time v/s RMS	up to 440			5000 - 6000

Table 2. Consistent values for Surface roughness parameters.

Reference plots	Cutting time (sec)	Rz (µm)	Rmax (µm)	Ra (µm)
Cutting time v/s Rz	up to 400	1.0-2.5		
Cutting time v/s Rmax	up to 400		5.5-14	
Cutting time v/s Ra	up to 380			1.2-3.0

Table 3. Correlation between AE parameters and Surface roughness.

	RDC v/s Rz	**RDC v/s Rmax**	**RDC v/s Ra**
Correlation Coefficient	0.860428258548424	0.860428258548424	0.845431418451068
	0.746482739965269	0.716641069107458	0.747921588443017
	0.778686016559	0.774519932860724	0.777116081962095
	0.917183276934207	0.870293316863743	0.90317416609183
Ra	**RMS voltage v/s Rz**	**RMS voltage v/s Rmax**	**RMS voltage v/s**
Correlation Coefficient	0.875516025824942	0.796374303824353	0.857289866213491
	0.81221286861568	0.812566658138098	0.896705331123623
	0.894118210923788	0.84765277524207	0.889046472118802
	0.916273743109259	0.851340931998773	0.899709331853683
	Rise Time	**Rise Time v/s Rmax**	**Rise Time v/s Ra**
Correlation Coefficient	-0.82851827389471	-0.845519880671063	-0.780120791328013
	-0.814175203907779	-0.82035654393314	-0.866471781751969
	-0.879108605475629	-0.875698568467252	-0.892285958813752
	-0.870736642787185	-0.879628744783275	-0.88647444692488

5. Conclusion

The acoustic emissions are used to monitor tool wear in machining [2][5]. In the present work AE signals are used as indicators to predict in real time the condition of surface roughness while machining. The experimental investigations revealed the suitability of using acoustic emissions for On-line monitoring of surface roughness. Experiments were carried out for turning operation in CNC Lathe machine for the given cutting conditions. Following are the observations made.

(1) The consistent behavior of AE parameters with cutting time shown in Table 1. Indicate the scope for using AE parameters for online monitoring in machining.
(2) The variations of Roughness parameters with the RDC have good correlation. Therefore the RDC can be used as indicator to predict surface Roughness while machining.
(3) The investigations also show that other Acoustic Emission Parameters such as RMS Voltage, Rise Time will also vary with cutting time and have good correlation with Surface Roughness parameters. Therefore they can also be used as indicators for predicting On-line surface roughness.

The results presented are based on the experiments carried out with H.S.S tool on mild steel material. The variations of AE Parameters are similar for any work piece/tool combination and for any other cutting conditions. There is a need to carry out studies to design an expert system, which predicts surface roughness on the basis of measured AE signal parameters. A Pattern recognition system may also be used to increase the reliability of online monitoring. Thus, it can be concluded that acoustic emissions can be used for on-line monitoring surface roughness along with consistant behavior in machining.

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