Proceedings of the 2010 International Conference on Industrial Engineering and Operations Management
Dhaka, Bangladesh, January 9 – 10, 2010

Investigation of Effect of Chatter Amplitude on Surface Roughness during End Milling of Medium Carbon Steel

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Abstract

Chatter is a self-excited vibration that occurs during machining operations resulting from instability of the cutting process with system responses of the spindle-tool-chuck system. In metal cutting operation, surface finish of the machined parts is vital issue that most machinists are concern on. A particular emphasis is given to chatter formation study during end milling to proof that surface roughness or surface integrity of the machined parts is critically dependent on the stability of the whole system during machining operation. In this paper an effort towards determining the influence of chatter formation during end milling operation of medium carbon steel (S45C) specimen and surface roughness generated is proposed. A study on the stability lobes for the prediction of chatter formation was first conducted considering the effects of cutting parameters and tool cutter on the amplitude of chatter. Vibration data were recorded using on line vibration data monitoring system for different diameter of end-milling cutters at different cutting speeds and depths of cut. The stability lobes diagrams for the two tool cutters of different diameters were drawn based on cutting speed and depth of cut. Certain restrictions had been made during machining operation to eliminate the effect of tool wear and heat generated. The dependence of surface roughness generated on chatter amplitude is justified /explained through surface roughness analysis. The surface roughness analysis is obtained based on calculation of surface roughness (Ra) for both tool cutters at different cutting speeds. It is observed that the vibration between the cutting tool and the work piece affects the machining accuracy and quality of surface generated. The result shows that at stable cutting speed both cutters resulted in good surface finish with small difference of Ra value but at higher speed the effect of chatter amplitude causes a significant difference in Ra value.

Keywords
Surface roughness, Chatter, End Milling.

1. Introduction
Chatter can be best described as a self-excited vibration that can occur during machining operations. Quintana et al. [1] specified that chatter can be obviously predicted from the loud noise and the poor surface integrity due to the chatter mark. In the other hand, Campa et al. [2] described chatter as a dynamic problem at high removal rate conditions. The thing that is for sure is that the vibration between the cutting tool and the work piece obviously affects the end result of the machining process. Kim et al. [3] explained that most of the drawbacks that caused by chatter is excessive tool wear, noise, tool breakage, and deterioration of the surface quality. Surface roughness refers to the small, finely spaced deviations from the nominal surface, which is determined by the material characteristics and the process that formed the surface. Currently researcher [4] focused on effect of various cooling strategies on surface roughness and tool wear during computer aided milling of soft work piece materials. These milling operations were selected as dry, cool air cooling and fluid cooling. As a result, the surface roughness values for air cooling end milling are lower than dry end milling and are higher than fluid cooling end milling. Prakasvudhisarn et al. [5] developed a combined approach for determining optimal cutting conditions for the desired surface roughness in end milling. The proposed methodology consists of two parts: roughness modeling and optimal cutting parameters selection which was then incorporated in an optimization problem with a relatively new, effective, and efficient optimization algorithm, particle swarm optimization. Routara et al. [6] investigated the influence of

machining parameters, viz., spindle speed, depth of cut and feed rate, on the quality of surface produced in CNC end milling. In their researches an attempt was made to obtain optimum cutting conditions with respect to each of the five different roughness parameters considered in the study with the help of response optimization technique. The study is mainly focused to investigate the chatter amplitude effect on surface roughness at various cutting conditions with two different tool holders during end milling operation of medium carbon steel.

2. Methodology

2.1 Experimental set up

The experiments were carried out into two stages. Initially the investigation of chatter formation was studied with the variation of cutting speed and depth of cut keeping the feed constant. Then the surface roughness profile was investigated at various chatter conditions. The vibration data were recorded for two different end milling cutter at different cutting speeds and depth of cut using an on line vibration monitoring system where frequency responses were monitored during the cutting process by attaching an accelerometer with the outer spindle. Machining operation was done using vertical machining center. The schematic diagram of the experiment is shown in Figure. 1.

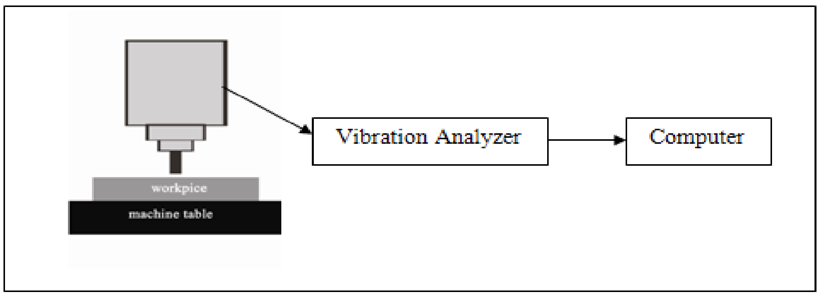


Figure 1: Schematic diagram of the experiment

2.2 Experimental conditions

Five cutting speeds were selected based on the results obtained in the first stage of the experiment where chatter was initiated and observed. The details of these experimental conditions are shown in Table 1. SANDVIK grade PM1030 Insert code: R390- 11 T3 08E- PL, Insert coating material: carbide, Working condition: light to medium milling. For insert geometry refer to Figure 2 and Table 2. After machining with the different cutter diameters the surface roughness were measured using surface measuring instrument (SURFTEST) SV-500 as shown in Figure 3.

Table 1: Experimental Details for Surface Roughness Analysis

Experimental Design Parameters	
Surface measuring equipment	Mitotuyo Surface Roughness Test
Selected cutting speed (m/min)	125, 150, 175, 200, 225, 250
Length of Cut	50 mm
Selected axial depth of cut	2.5 mm
Tool Inserts	Titanium Nitride, TiN
Type of Cutting	End milling side by side cutting
Feed	0.16 mm/tooth
Radial Depth of Cut	Full Immersion
Tool Cutter Diameter	16mm & 20mm

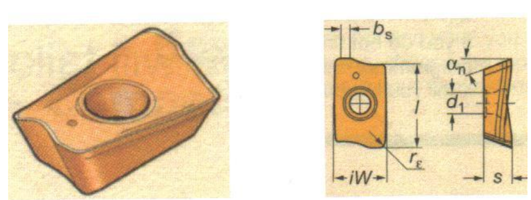
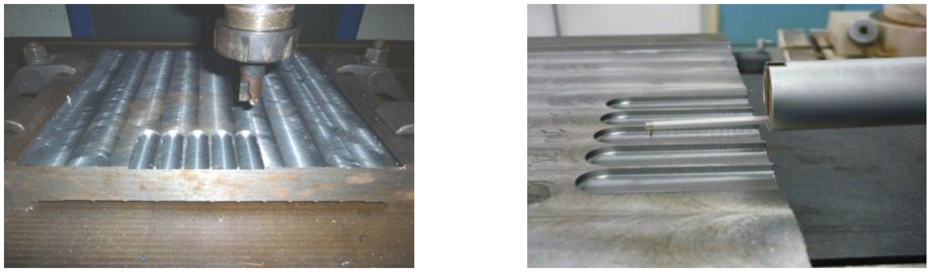


Figure 2: Insert Shape and Geometry

Table 2: Insert Geometry Values

L	**iW**	$\mathbf{d_1}$	**s**	$\mathbf{b_s}$	$\mathbf{r_\varepsilon}$	α_n°
11	6.8	2.8	3.59	1.2	0.8	21



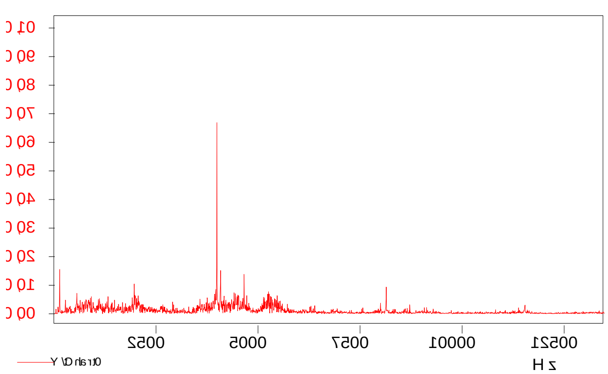
(a) (b)

Figure 3: (a) Side by side cutting operation (b) Surface roughness measurement

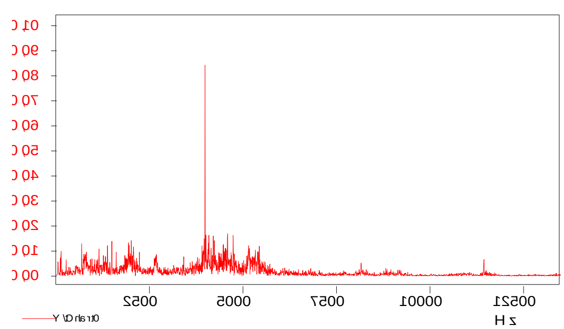
3. Results and Discussions

3.1 FFT Power spectrum Analysis

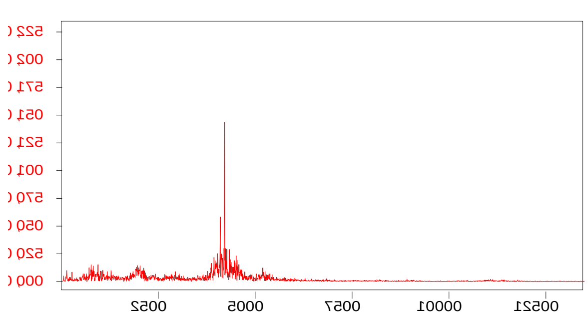
From the experiment, it has been observed that chatter amplitude is higher with in the cutting ranges of 150 m/min to 225 m/min for 16 mm tool holder diameter whereas for 20mm tool holder the cutting speed ranges started from 200 m/min to 250 m/min. The maximum chatter amplitude observed at 225 m/min in case of 20 mm tool holder. It has also been observed that with the increase of cutting speed the chatter amplitude for a certain frequency mode increases up to a certain limit and then it goes to decrease and then the next dominating mode frequency is going to start exciting. The various sample FFT power spectrum at various cutting conditions for two different tool holders are shown in Figure 4.



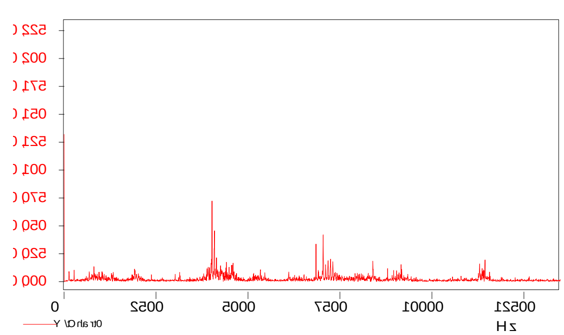
(a) Tool 16mm CS: 150 m/min



(b) Tool 16mm CS: 175 m/min



(c) Tool 20mm CS: 225 m/min



(d) Tool 20 mm CS: 250 m/min

Figure 4: FFT power spectrum at different cutting speed using 16mm and 20 mm tool cutter

Acceleration amplitude vs. cutting speed is also plotted in Figure 5. It has been observed that with the increase of cutting speed the chatter amplitude starts to increase and attains the maximum value at 225 m/min because of resonance effect between the secondary chip serration frequency with one of the dominating mode frequency of the system components and then its goes down.

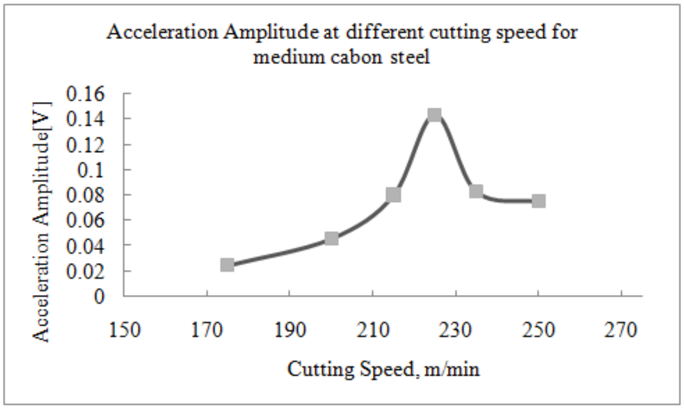
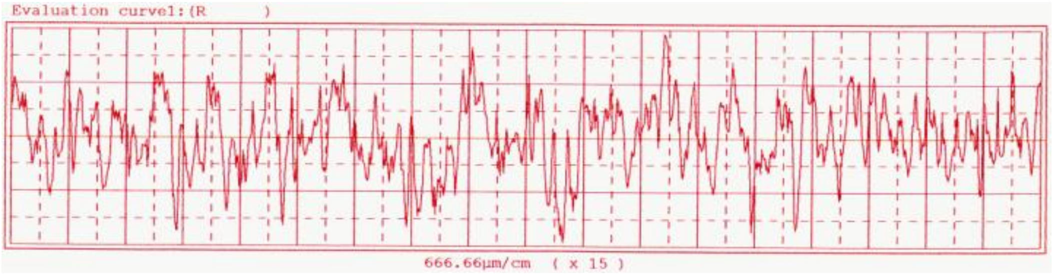


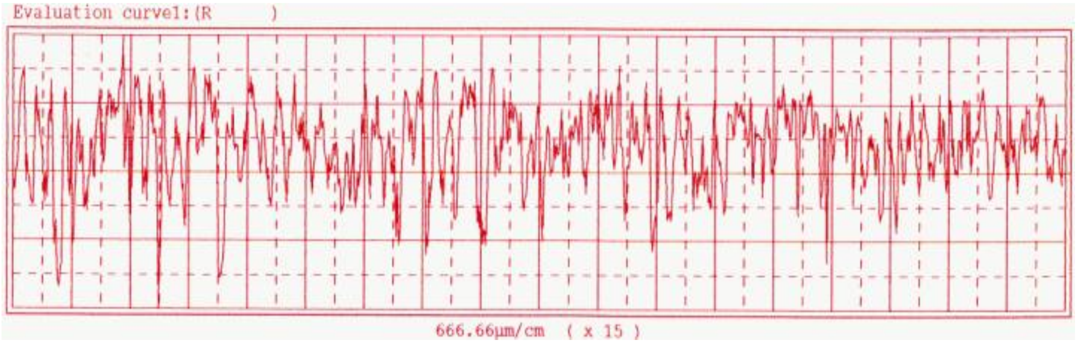
Figure 5: Effect of cutting speed on chatter acceleration amplitude (AISI 45)

3.2 Surface Roughness Analysis

From the result obtained in surface roughness analysis, it is observed that chatter has direct influence on surface roughness. Surface roughness value measured at the chatter condition is much higher compared at the stable cutting condition where chatter is absent. For cutting operation using 20 mm diameter tool cutter, the highest Ra value measured is 2.49µm at cutting speed 225 m/min while for the 16 diameter tool cutter, the highest Ra value measured is at 150 m/min which is said to be at unstable cutting condition where chatter occurs. Some of the surface profiles generated are shown in Figure 6.



(a) Surface profile for cutting speed 150 m/min using 16 mm tool cutter with R_a value= 2.87 µm



(b) Surface profile for cutting speed 150 m/min using 20 mm tool cutter with R_a value= 1.49 µm

Figure 6: Surface profile at different cutting conditions for two different tool holder

The measured surface roughness value at different cutting speeds for two different tool holders are shown in figure 7. It has been observed that the surface roughness value goes increasing up to a certain cutting speed and then it goes down. This behavior shows the similar trends with the chatter amplitude. It is also found that with the increase of chatter amplitude the surface roughness value is going to increase and with the decrease of chatter amplitude the roughness goes down. The overall surface roughness values obtained in different experiments are shown in Figure 7.

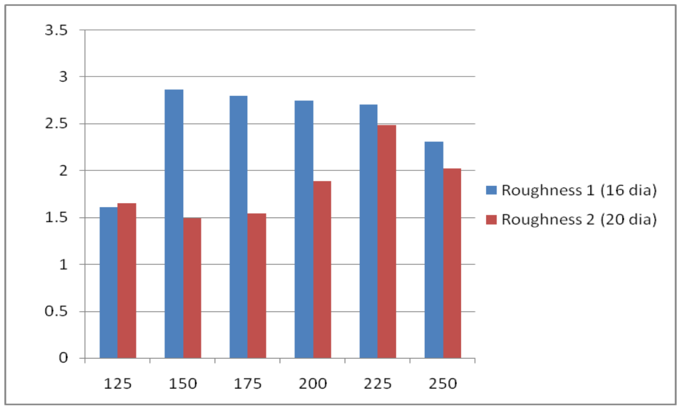


Figure 7: Graph of surface roughness analysis (R_a value in µm vs Cutting speed in m/min)

4. Conclusion

Chatter amplitude has a dominant effect on surface roughness generated in end milling operation of medium carbon steel. At stable cutting condition, both tool diameters resulted in lower R_a value but at higher speeds, the effect of chatter amplitude causes a significant difference in R_a value. From this experiment, it is also found that smaller tool diameter results poor surface finish compared to larger tool diameter.

References

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