Prediction of Chatter in CNC Machining based on Dynamic Cutting Force for Ball End Milling

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Abstract: This paper presents the suitable depth of cut, spindle speed and feed rate that will be chosen during machining. If thus parameters are not considered, this can provoke abnormal tool behavior such as chatter. Chatter will limit the tool life which only can be use for just a few times. To predict the chatter occurs, the parameters will be use are spindle speed, depth of cut and feed rate. CNC machine will be use. This process will base on dynamic cutting force model for ball end milling. The selections of cutting tool are depends on the process that will done where the chatter can be observed during this machining process. Cold work tool steel (AISI-D2) chosen as a material and its parameter is 100x100x25 mm. Cutter used was high speed steel 2 flute ball nose. Force dynamometer will be use to measure force and 27 tests will be done to observe the chatter occur. Analysis done by referring the result that be measured by force dynamometer. The chatter in ball end milling can be detected from the calculated cutting forces and their frequency spectra. A comparison of the predicted and measured cutting forces demonstrated that the proposed method provides accurate results.

Keywords: Chatter, Dynamic Cutting Force Model, Kiestler Dynamometer

I. INTRODUCTION

The metal cutting technology growth rapidly and has enrolled as important aspect in manufacturing industry especially for aerospace industry and also in producing high precision part. In modern cutting technology, the trend continues unabated toward higher availability with more flexibility. Milling is the most important and widely useful operation process for material removal compared to turning, grinding and drilling. Milling can be defined as machining process in which metal is removed by a rotating multiple-tooth cutter with each tooth removes small amount of metal in each revolution of the spindle.

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A machine tool directly influences the quality, productivity, and competitiveness of various production processes found in the automotive, aerospace, and die/mold industries [1, 2, 4 and 12]. To maximize the productivity in a machining process, both the speed at which the tools can machine without causing deterioration in the stability of system and accurate evaluations of machining stability are crucial [2].

The cutting process is given a great deal of weight in the development and production of products. Therefore, reducing the time required for the cutting process is one of the most effective methods of achieving rapid product development and improving productivity. The cutting speed must be increased to reduce the machining time, but this can provoke abnormal tool behavior such as chatter, which it is the most critical problems in the cutting process [1].

II. LITERATURE REVIEW

Chatter is an abnormal tool behavior which it is one of the most critical problems in machining process and must be avoided to improve the dimensional accuracy and surface quality of the product [1, 2 and 4]. Its causes excessive tool wear, noise, tool breakage, and deterioration of the surface quality, it is essential to detect and prevent its occurrence. A varied uncut chip thickness in the cutting process induces variations in the cutting force, which repeatedly induce tool vibration. This phenomenon is called the regenerative effect and is a major source of chatter [1].

The end milling process is characterized by an interrupted cutting process in which the uncut chip thickness varies continuously. A varied uncut chip thickness in the cutting process induces variations in cutting forces, which repeatedly induce tool vibrations. This phenomenon is called the regenerative effect and is major source of chatter [1].

In the real world, machine tools are stiff as compared to the tools that go on them; however, they are not infinitely stiff. Understanding the dynamic characteristics of the tools becomes especially important when it comes to high velocity machining. This knowledge can help quantify vibration and lead to improvements in cutting performance. An understanding of chatter theories in milling cutters helps in recognizing dangerous cutting operations, optimizing the cutting parameters to eliminate chatter, and enhancing productivity [1 and 7]. The reflex to slow down the cutting process when chatter is audibly recognized can be detrimental to a cutter, especially when dealing with high velocity machining. In many cases, as this report will show, speeding up the cutting process may reduce or eliminate chatter most effectively. Developed an improved an uncut chip thickness model to consider the back-side cutting effect in unstable cutting states. Experimental results demonstrate that the chatter was predicted effectively by the developed dynamic cutting force model [1, 12, 13 and 14].

A Dynamic cutting force

In general, a cutting process is a closed loop system consisting of structural dynamics and cutting dynamics, and the chatter arises from the interaction between two dynamics. In other words, the relative displacement between the tool and workpiece brings about variations in the cutting forces due to the cutting dynamics, and the varied cutting forces bring about variations in the relative displacement due to the structural dynamics. An accurate cutting force model of ball-end milling is essential for precision prediction and compensation of tool deflection that dominantly determines the dimensional accuracy of the machined surface [1 and 15].

The modeling of cutting forces is often made difficult by the complexity of the tool/workpiece geometry and cutting configuration. Analytical cutting force is difficult due to the large number of interrelated machining parameters. The large number of interrelated parameters that influence the cutting forces (cutting speed, feed, and depth of cut, cutter geometry, and tool wear, physical and chemical characteristics of the machined part) makes it extremely difficult to develop a proper model.

Researchers [3], [4], [5] and [6] have been trying to develop mathematical models that would predict the cutting forces based on the geometry and physical characteristics of the process. However, due to its complexity, the milling process still represents a challenge to the modeling and simulation research effort.

Most previous research estimated the stability in flat end milling using only a simple tool path, such as a single line or corner paths. However, the calculation of dynamic forces in multi-tool paths must be performed to predict chatter in general NC machining operated by an NC code.

To calculate the dynamic cutting force in ball end milling, a structural dynamic model of the ball end mill was linked to a mechanistic cutting force model. Cutter runout and penetration effects were also considered in our models to permit a more accurate evaluation of the machining [1].

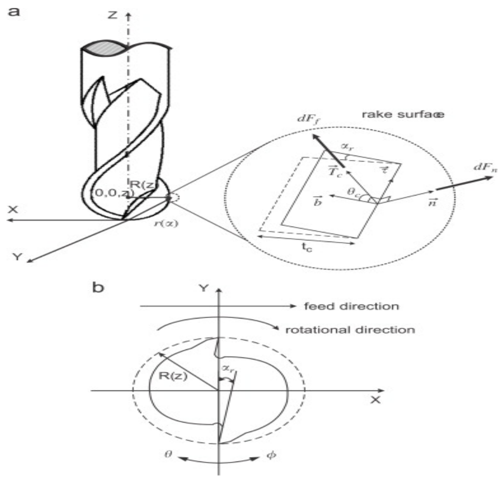

Figure 1.1: Cutting force model

III. EXPERIMENTAL METHOD

The prediction of stable cutting regions is a critical requirement for milling operations. In order to achieve the aim and objectives of this research, a sequence of works have been planned as shown in (Figure 3.1) below. The process involved in achieving notified objectives are including determining apparatus, method and parameters, conducting machining/experiment, result analysis and data discussion. The result obtained from the research will be applied in identifying significant and insignificant parameters to chatter occurrence.

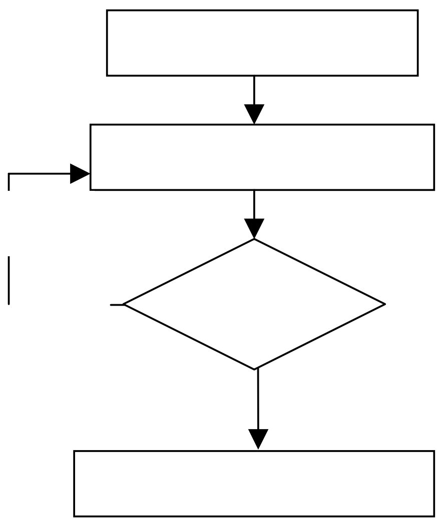

Figure 1.2 Procedure flow diagram.

A Table of Experiment

To build an experiment table, a lot of source and formulae are referred to get the number of test for this experiment and finally get 27 tests.

Table 1: Table of Experiment.

Test no.	Total Depth of cut, d_w (mm)	Feed rate, *f* (mm)	Spindle speed RPM (rev/min)
1	3	300	1000
2	3	300	2000
3	3	300	3000
4	4	300	1000
5	4	300	2000
6	4	300	3000
7	5	300	1000
8	5	300	2000
9	5	300	3000
10	3	400	1000
11	3	400	2000
12	3	400	3000
13	4	400	1000
14	4	400	2000
15	4	400	3000
16	5	400	1000
17	5	400	2000
18	5	400	3000
19	3	500	1000
20	3	500	2000
21	3	500	3000
22	4	500	1000
23	4	500	2000
24	4	500	3000
25	5	500	1000
26	5	500	2000
27	5	500	3000

For this experiment, about 27 tests are done to observe chatter occur by using dynamometer which it's detect rapidly increase force value during machining. When this happened, the chatter has occurs on that time.

Calculation for number of test:

Spindle speed values = $3^1 = 3$
Feed rate values = $3^1 = 3$
Depth of cut values = $3^1 = 3$

Total number of test = 3x3x3 =27 tests.

B Material Cutting Designation

Cold work tool steel was considered as the workpiece. As the cutter tools material, High-speed steel (HSS) have become among the premier choices beside Solid Carbide and Coated Carbide cutter tools. Even though both Solid and Coated Carbide have better hardness and can undergo higher cutting speed and material removal rate without fracture, but HSS cutter tools are more effective due to high resistance of softening effects of heat in which they are capable to attain a high hardness at elevated temperature. Moreover, HSS has less distortion in heat treatment and also, they are less expensive if compared on prices with both Carbide cutter tools.

The preferred method of milling operation of our experiment is slot milling. Research will be carried on using CNC machine. So, developing any G-codes are required.

In this experiment depth per cut for every cutting process is 0.5mm. The cutting process will be run with depth per cut of 0.5mm until get the total depth of cut needed. During cutting, the Force Dynamometer will connect to get the result and the graph in x, y and z axis. The data will take during cutting process. Figure 3.3 shown below illustrated CAD design on how workpiece will be set up for chatter vibration analysis.

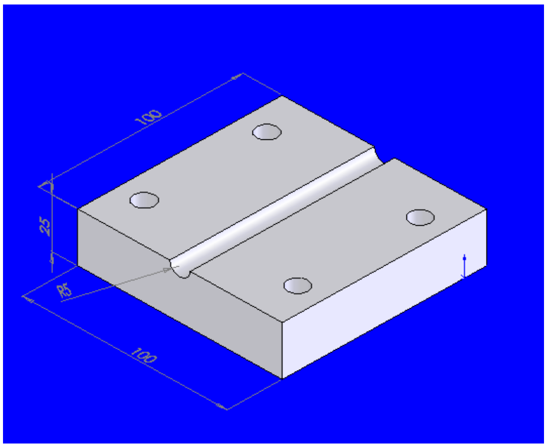

Figure 1.3: CAD design of workpiece for machining

IV. RESULTS AND DISCUSSION

A Preliminary Finding Research

Excessive cutting forces produced during milling process will result in increasing percentage of chatter occurrence and thus, lead to premature tool wear, spindle failure and low-quality surface finish. In accordance to the previous research by Lacerda and Lima (2004) before, depth of cut will be the most significant factor contributes to the onset of chatter vibration followed by spindle speed. As stated in vibration principles, cutting forces are varies with respect to selection of spindle speed and depth of cut.

B Result of Cutting Forces

The result gained from force dynamometer came in four different outputs which is cutting force in x, y and z direction (Fx), (Fy), (Fz) and moment in z-direction (Mz). However, only a cutting force in x-axis, (Fx) and y-axis, (Fy) will be considered to be analyzing as these two function enrolled the major part in causing the chatter. By using Kistler® Dynoware, the x-axis and y-axis force reading for milling is gather and being converted directly into force-time graphical figure where it is much better to understand compared to the raw data obtained. Then, a mean value of each graph is taken as these data will be used in identifying significant factor in chatter occurrence. Table 4.1 below illustrated all the data attained from previous 27 experiments.

Table 1.2: Cutting force in x, y-direction.

No of Test	Depth of Cut (mm)	Feed rate (mm/min)	Spindle Speed (rpm)	Fx (N)	Fy (N)
1	3	300	1000	952.63	920.04
2	3	300	2000	926.88	914.04
3	3	300	3000	940.18	890.5
4	4	300	1000	1007.57	939.33
5	4	300	2000	1002.85	928.89
6	4	300	3000	1001.27	918.75
7	5	300	1000	3237.94	2964.04
8	5	300	2000	815.31	854.74
9	5	300	3000	761.56	945.02
10	3	400	1000	834.26	897.66
11	3	400	2000	785.65	934.01
12	3	400	3000	71.41	20.14
13	4	400	1000	643.18	865.62
14	4	400	2000	708.24	934.66
15	4	400	3000	924.32	879.18
16	5	400	1000	843.5	915.04
17	5	400	2000	849.9	927.25
18	5	400	3000	840.33	926.27
19	3	500	1000	792.72	885.99
20	3	500	2000	836.36	910.52
21	3	500	3000	823.61	907.84
22	4	500	1000	826.78	909.91
23	4	500	2000	855.95	929.69
24	4	500	3000	854.12	932.98
25	5	500	1000	834.35	886.35
26	5	500	2000	796.25	885.62
27	5	500	3000	794.55	909.3

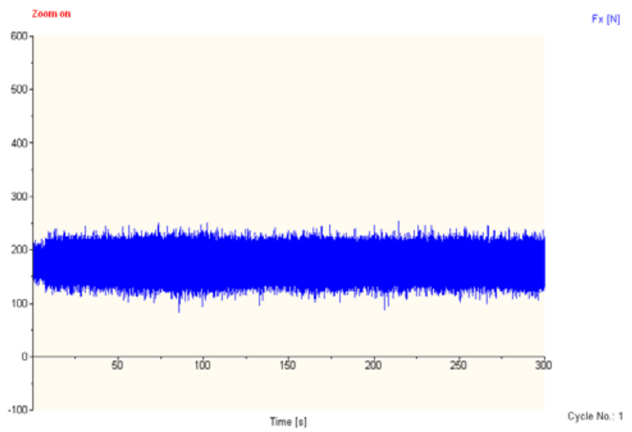

Figure 1.4: Cutting force Fx (N) versus time (s)-test 1.

Figure 1.4 Show the graph that chatter did not occur. For this experiment, the parameters are, 3mm depth of cut, 300 mm/min feed rate and 1000rpm spindle speed. From the graph, we can see that the force Fx (N) are constant and there has no rapidly force increase occurred. Show that, on this experiment, chatter does not occur.

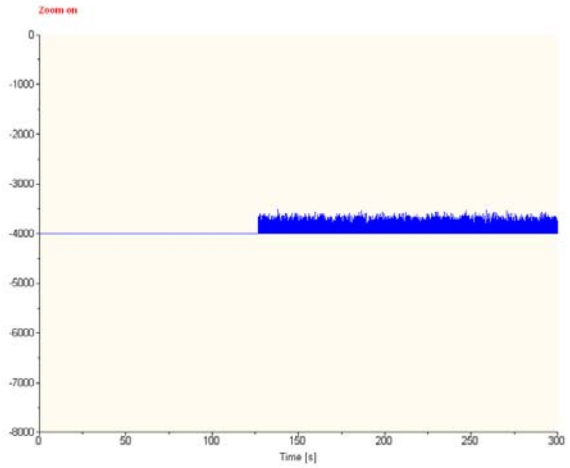

Figure 1.5: Graph cutting force Fx (N) versus Time (s)-test 7.

Figure 1.5 show the cutting force Fx (N) versus time (s) which the parameters are 5mm depth of cut, 300mm/min feed rate and 1000rpm spindle speed. As shown in the graph, the force rapidly increased from constant to high value of force. It shows that high vibration happened and therefore onset of chatter.

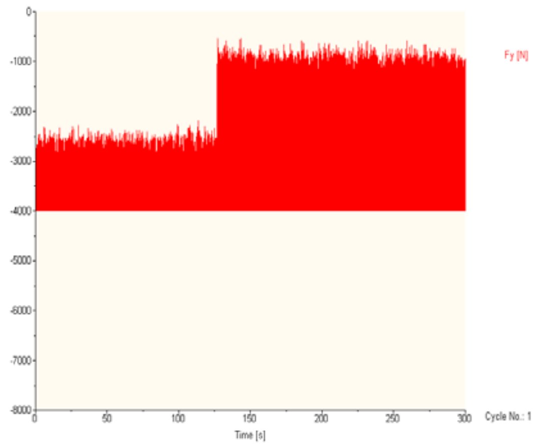

Figure 1.6: Graph cutting force Fy (N) versus Time (s)-test 7

Figure 1.6 show cutting force Fy versus time. In this graph, the constant force extremely increased to the high value. It shows that chatter was occurred on that time. This happened when the vibration so extreme and its make the cutter vibrate to fast and let the chatter to occur. During this experiment, the parameters are 5mm depth of cut, 300mm/min feed rate and 1000rpm spindle speed.

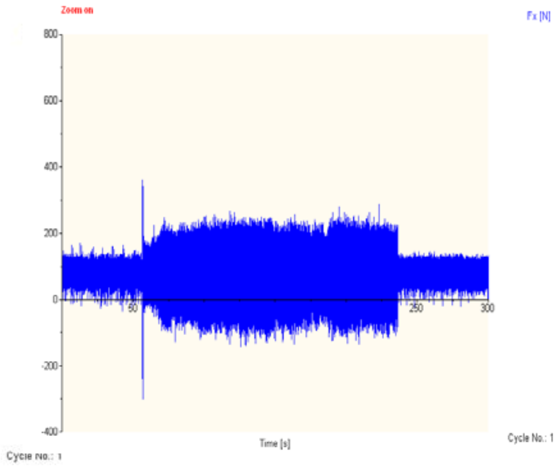

Figure 1.7: Graph cutting force Fx (N) versus Time (s)-test 27

Figure 1.7 show the cutting force Fx versus time. In this graph the cutting force Fx increased rapidly on 56.649s. On that time, the chatter was occurred. The parameters for this graph to obtain are, 5mm depth of cut, 500mm/min feed rate and 3000rpm spindle speed.

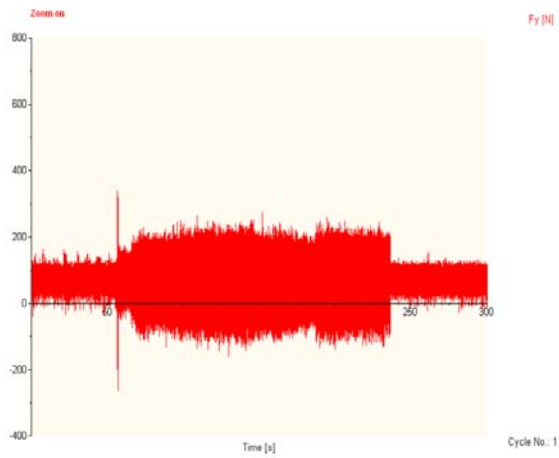

Figure 1.8: Graph cutting force Fy (N) versus Time (s)-test 27

Figure 1.8 show graph cutting force Fy versus time. In this graph, we can see that the cutting forces suddenly increased. Chatter occurred as shown in this graph. To obtain this graph, the parameters are, 5mm depth of cut, 500mm/min feed rate and 3000rpm spindle speed.

C Discussion on graph from Kitsler® Dynoware

As we can see from figures above, chatter only occurred in test 7 and test 27. In test 7 which shown in Figure 4.5, the parameters needed to run this experiment are 5mm depth of cut, 300mm/min feed rate and 1000 rev/min spindle speed.

Based on the graph, it show that when run the experiment with too deep depth which is 5mm and the feed rate and spindle speed was too slow, it will let chatter to occurred. It shows that, during milling process, it must have a good combination for thus three parameters. But in this test 7, chatter occurred a bit slower then test 27. Which in test 7, the chatter occurred on 126.85s. Compared with test 27 where the chatter occurred on 56.659s and faster then test 7. This is because, when the depth of cut is too deep, spindle speed and feed rate was too fast, it will let chatter to occurred very fast. It also let the cutter damage very

We can see that dept of cut influence chatter to occur. When the depth of cut is too deep, the spindle speed and feed rate should not too fast and too slow. So that, it should have suitable parameters to run the cutting in milling according to material that need to cut.

V. CONCLUSION

This paper is successfully completed and all of the noticed objectives already been achieved which are to predict the chatter occurrence of end milling by using ball end mill cutter. The cutting forces of mild steel machining was successfully obtained by Kitsler® Force dynamometer. From the graph obtained by Kitsler® force dynamometer, it's obviously showed that, the most significant factor for the chatter occurred is depth of cut and spindle speed. As we can see from the graph obtained by Kitsler®, the depth which is 5mm gave chatter to occur.

Even though the spindle speed and feed rate was slow, the depth of cut should not too depth. So, this will avoid chatter to occur. A commonly used method for avoiding chatter vibrations in machining is to select low spindle speed and small depth of cut.

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