PROTOTYPE DEVELOPMENT OF OPTIMUM IRREGULAR MILLING TOOLS FOR CHATTER SUPRESSION IN MACHINING AUTOMOTIVE PRODUCT

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ABSTRACT (120 words)

Machining processes with high productivity cause tool wear and materials defects even damage machine spindle and limited by self-excited vibration or chatter. Chatter is a kind of self-excited vibration common in machining operations when increasing material removal rate. This is undesirable because it results in premature tool wear, poor surface finish on the machined component and the possibility of serious damage to the machine itself. In this project, optimum tool geometry of variable helix and variable pitch based on chatter stability lobe diagram created from modal analysis and cutting force coefficient determination developed. This prototype optimum irregular tools OF 12, 16 and 20 mm geometries achieved 20 percent more productivity than commercial regular milling tool in suppressing chatter.

1. INTRODUCTION

Milling is one of the most common manufacturing processes for various industries. However, its productivity is limited by self-excited vibration identify as chatter. To suppress chatter, modal analysis was done to determine dynamic properties and predict stability lobe diagram. However, earlier work do not considered material removal rate effect to modify the tool geometry of variable helix and variable pitch. The above review indicates that besides reducing chatter, increasing tool life and maintain surface quality, the regular tool geometry of uniform helix and uniform pitch angles should be optimized the geometry to increase productivity. Current method used passive or active method to suppress chatter either using damper, absorber or spindle speed variation do not considered tool geometry variation. Motivated from the succeed high productivity affected by irregular milling tool can suppress chatter by disturbing the phase between the outer and the inner surface modulation left by previous cutting. Thus, the maximum material removal rate can be achieved with at optimum geometries to suppress chatter consequently shorter production time and longer tool life. In previous FRGS, a 20 mm 4 flute of optimum irregular milling tool can improve 20 percent productivity compare to regular milling tools.

This project embarks on the following objectives:

• To evaluate the chatter stability from dynamic properties and cutting force coefficients determination from different tool sizes of prototype tools.

• To design the prototype optimum irregular milling tools from variable helix and variable pitch geometry based on chatter stability and optimization algorithm

• To evaluate the machining performance of developed prototype optimum irregular milling tools geometry in automotive industry.

2. LITERATURE REVIEW

Quality and productivity play significant role in today's manufacturing market. In the aerospace, automotive, mold/die and general manufacturing industries, there is great pressure to ensure lower cost, greater productivity and improved quality in order to encourage economic growth. However, machining productivity using a high material removal rate is inhibited by the dynamic deflection of tool and workpiece systems, which generates an unstable cutting force. This causes sudden large vibration amplitudes where energy input exceeds the energy dissipated from the system, producing chatter. Chatter is a self excited type of vibration that occurs in metal cutting if the chip width is too large with respect to the dynamic stiffness of the system, especially when machining with a high material removal rate. Davies et al. [1] found that at high temperature was an undesirable phenomenon which can limit the productivity of the machine, reduce the material removal rate (MRR), can lead to a waste of materials and energy and poor surface finish of the end products. Stability lobe diagram (SLD) is an efficient tool which helps to select specific spindle speeds during production to avoid chatter in machining.

To predict the SLD, one need to know the frequency response function of tool tip, which is usually obtained by the modal testing [2]. The impact hammer test is widely used due to its simplicity. However, machine tool industries apply strict safety operations. An impact test requires a person be capable of tapping the spindle in such a way as to enable the reliable measurement of the frequency response functions (FRFs), which is clearly not suitable for measurement automation. Thus, a non-contact excitation system was developed [3]. Non-contact actuator offers advantages in terms of easiness to use, reduced test time, quick and easy setup as well as removal. To date, Long et al.[4] presented an alternative approach modification of ball bearing to predict SLD of high-speed milling with the consideration of speed-varying spindle dynamic. The spindle displacements were measured with laser displacement sensors. The frequency response functions (FRFs) were obtained from the measured load and displacement. Subsequently, a force determination using force dynamometer will be carried out. This involves a deep investigation of cutting force coefficient determination at different spindle speed. Yet, the effect of variable dynamic properties with respect to the change of speed on the stability of milling processes[5].

Most of current work have in general not considered the temperature and spindle speed effects in the machining process. According to Cao et al. [6], the thermal affecting machining process for 40–70% of the total error. The heat generated at the tool-work material interface affects the efficiency of the milling process and may limit the material removal rate. This is due to a large amount of the input power is lost in the form of heat [7]. Therefore, online monitoring of tool temperature with speed dependency is essential to optimise the process parameters. The most widely used contact techniques include numerous types of thermocouples. Bagavathaiappan et al [8] critically reviewed several temperature measurement techniques used in manufacturing processes, tribology and material removal processes. In those reviews, the applicability, advantages and disadvantages of various temperature measurement techniques are discussed in detail. However, such contact techniques suffer from various drawbacks, such as restricted access and a higher response time and a larger contact area. Thus, a non-contact technique using an infrared camera will be used. It has a lower response time and temperature measurement is possible without disturbing the cutting zone in a non-contact and remote manner. Hence, an alternative method is presented to predict chatter stability lobes of high speed milling with consideration of speed-varying spindle dynamics with thermal effect. By applying a non-contacting electromagnet, milling machining will be conducted to validate the speed dependent stability lobes. The dynamic properties behaviors to the systems such as natural frequency, damping ratio and machining properties will be considered in machining validation of SLD.

To further illustrate the correlation of spindle speed and thermal dependence in machining processes, the influence of tool geometry will be considered. The tool geometry modification [9] based on spindle speed has an important function in reducing vibration and increases the performance towards lowering the tool wear and improve surface roughness. Recently, [10] has proved that irregular milling tool geometries with spindle speed and feed rate parameters can be used to suppress the chatter by exploiting the process damping behaviour. The effect of irregular tool geometries also shows that variable helix and variable pitch tools have the best wavelength performance compared with regular and other irregular tools. Thus will improving machining productivity by considering thermal and spindle speed effects in machining irregular milling tools.

3. METHODOLOGY

Description of Methodology to achieve all 3 objectives.

Phase 1: Evaluation of properties determination for chatter stability lobe Modal testing uses non-contacting modal testing using electromagnet actuation (available in UMP) and the displacement will sense by a laser displacement sensor (need to buy) to determine dynamic properties for other tool size.Dependencies analysis of modal testing using a dynamic testing will be conducted with speed (need to buy tachometer)as material removal rate effect. Then, cutting force determination will be conducted with productivity dependency. Different type of tool sizes 6 to 24 mm are evaluated the dynamics properties and cutting force coefficients.

Phase 2: Design and manufacture irregular milling tools To predict a stability lobe diagram using Matlab software (available in UMP), dynamic properties and cutting coefficient (Kn, Kt) of machining are needed other tool size diameters. From chatter stability lobe diagram, Differential Evolution as optimization algorithm is combined to determine optimum variable helix and variable pitch tool geometry. Machining performance evaluation based on acceleration and fast Fourier transform (FFT), workpiece roughness using roughness tester. Vibration test and surface integrity need to examine the surface texture(SEM need to have professional service from UMP). This similar method will be implemented for tool diameter sizes of 6 to 24 mm.

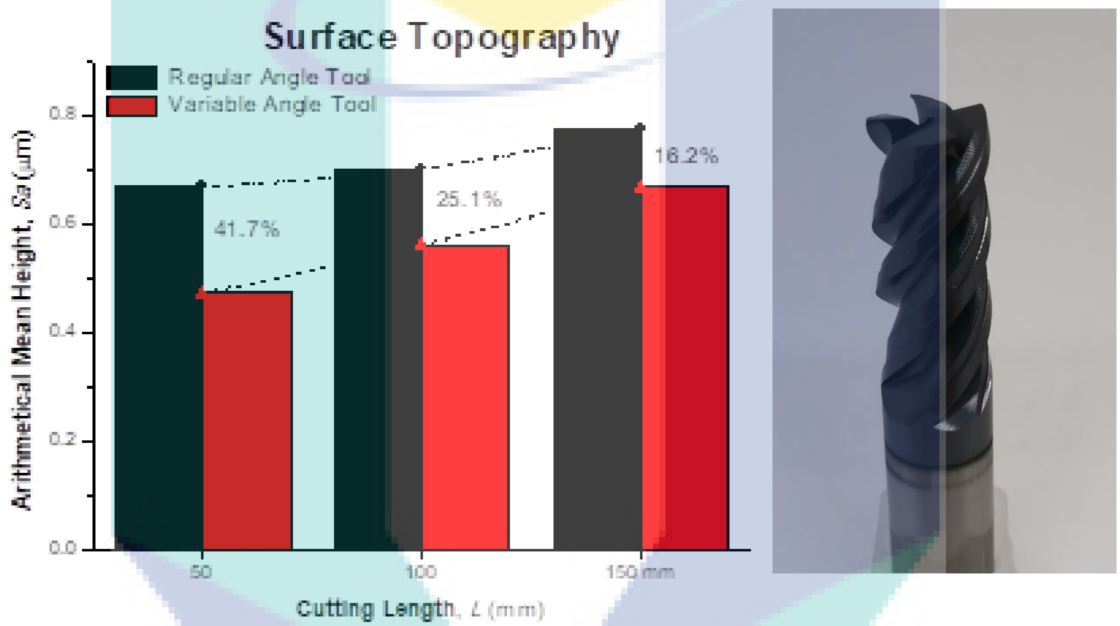
Phase 3: Industrial testing in Sapura Industrial testing through collaborative works with industries. All sizes of optimum irregular milling tools manufactured by TMEH Manufacturing Sdn Bhd will be tested at Sapura Machining to complete the practicability study. These optimum prototype of irregular milling tools geometry are evaluated the machining performance of based on tools' life and wear and surface roughness in machining automotive product. Current optimum irregular tool sizes performance are compared with available irregular tools in term productivity and product quality. A concise report on the whole project will be completed and submitted in the period given.

4. RESULTS AND DISCUSSION

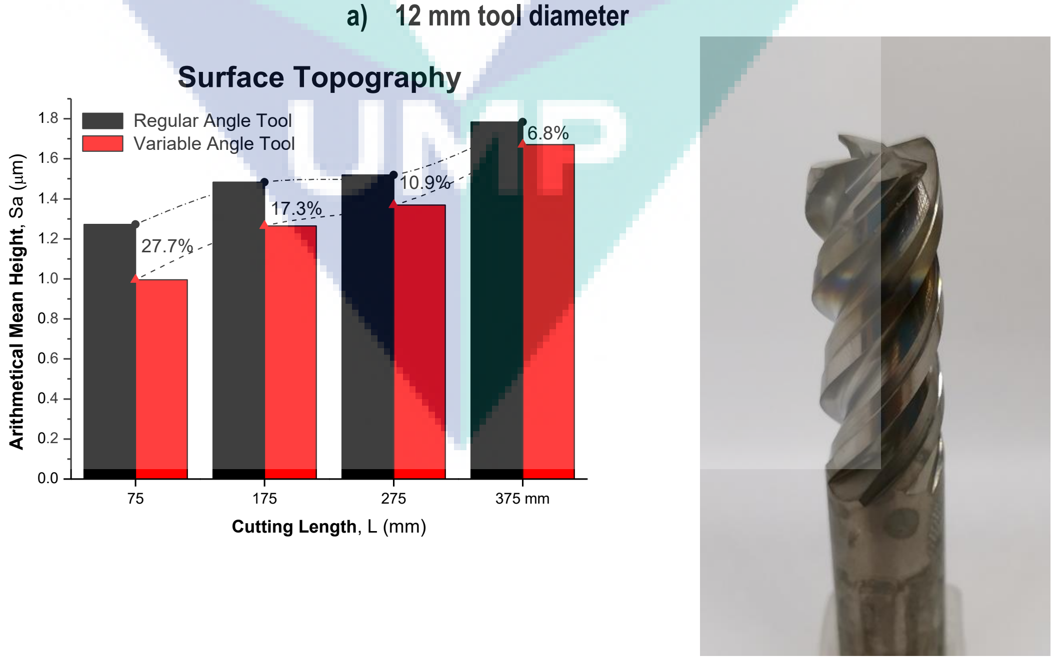
Table 1: Dynamic properties and cutting stiffness of the tools

Tool diameter(mm)	12	16	20
Natural frequency, Hz	1000	1200	1500
Damping ratio	0.0078	0.0082	0.0001

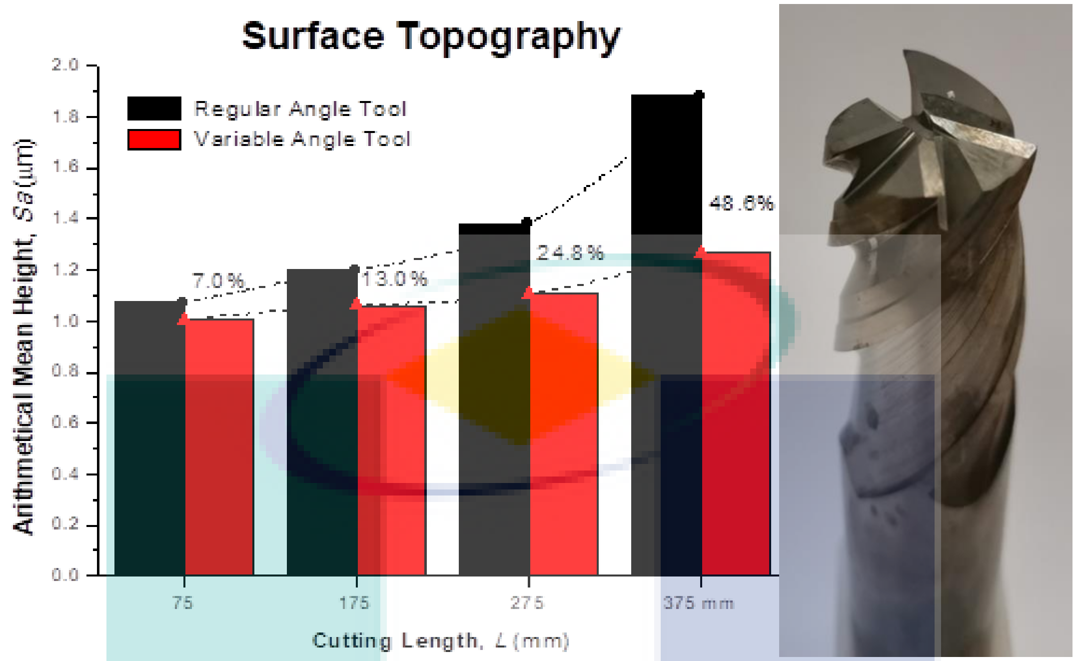
Modal mass, kg	1.41	1.60	1.82
Tangential Cutting stiffness, Kt	1250e6	1580e6	1850e6
Normal Cutting stiffness, Kn	188e6	203e6	242e6



a) 12 mm tool diameter



b) 16 mm tool diameter



c) 20 mm tool diameter

Figure 1: Variable and regular surface topography comparison in contour and slot cutting

Table 1: Reliability of industrial test in Sapura machining operation line (20 mm tools).

Roughness /Cycle	1	48	200	400	600	794	1020	1500
Regular(µm)	3.766	4.561	7.563	6.553	6.417	6.716	4.967	4.897
UMP(µm)	3.776	4.407	8.320	6.964	5.641	6.716	4.280	4.858

5. CONCLUSION

This prototype optimum irregular tools geometry achieved 50 percent more productivity than commercial regular milling tool in suppressing chatter.

ACHIEVEMENT

i) Name of articles/ manuscripts/ books published

ii) Title of Paper presentations (international/ local)

iii) Human Capital Development

Mohd Fawzi Zamri
Research Officer
890902065725

iv) Awards/ Others

PlatCOM Venture: Irregular milling tools

v) Others

1. Milling Tools, Industrial Design: 20-E0105-0101, 2020. Ahmad Razlan Yusoff
2. Milling tool geometry calculator, copyright, LY2019005415, Ahmad Razlan Yusoff

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