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DEVELOPMENT OF A MATHEMATICAL MODEL FOR THE PREDICTION OF CHIP FORMATION INSTABILITY AND ITS VERIFICATION BY FUZZY LOGIC WITH GENETIC ALGORITHM

Anayet U. Patwari[1,2,] A.K.M. Nurul Amin[1], Waleed Faris[1], M.H. Istihyaq[1]
[1]Department of Manufacturing and Materials Engineering
International Islamic University Malaysia, Kuala Lumpur, Malaysia
[2] Department of Mechanical and Chemical Engineering, IUT, Dhaka
[1,2] Corresponding author e-mail: aupatwari@hotmail.com

ABSTRACT:
Chip morphology and segmentation play a predominant role in determining Machinability and Chatter during the machining of different materials. At lower cutting speeds the chip is often discontinuous, while it becomes serrated as the cutting speeds are increased. It has been identified that the chip formation process has a discrete nature, associated with the periodic shearing process of the chip during machining of different materials. Apart from the primary serrated teeth, a typical instability of periodic nature, in the form of secondary saw/serrated teeth, which appear at the free edge of the chip, has been identified. Mechanism of formation of these teeth has been studied and the frequency of their formation has been determined. In this paper a new interpretation of chip segmentation parameter in the cutting of different materials is presented in terms of chip forming instability to predict chatter phenomenon. On the basis of these interpretations, a new analytical technique is proposed to predict the frequency of chip formation instability as a function of cutting parameters. The analysis of chip-formation instability could be an effective tool for deeper understanding of the mechanism of chatter formation during metal cutting processes. In this technique, a mathematical model has been developed between the cutting parameters and the instability frequency of the chip serration based on RSM and the model is verified by fuzzy logic with GA.

Keywords: Chip formation instability, fuzzy logic, genetic algorithm, RSM.

1. INTRODUCTION

The technology of metal cutting has grown substantially over time owing to the contribution from many branches of engineering with a common goal of achieving higher machining process efficiency. Selection of optimal machining condition(s) is a key factor in achieving this condition. In today's rapidly changing scenario in manufacturing industries, applications of optimization techniques in metal cutting processes is essential for a manufacturing unit to respond effectively to severe competitiveness and increasing demand of quality product in the market. Optimization methods in metal cutting processes, considered to be a vital tool for continual improvement of output quality in products and processes include modeling of input–output and in-process parameters relationship and determination of optimal cutting conditions.

The fuzzy set also plays an important role in input-output and in-process parameter relationship modeling. The theory on fuzzy set admits the existence of a type of uncertainty (or indecision) in process decision variables due to vagueness (referred to as 'fuzzy uncertainty') rather than due to randomness alone, and many decisions in process control are in fuzzy environment [1]. Fuzzy set theory-based modeling technique is generally preferred when subjective knowledge or opinion(s) of process expert(s) play a key role in defining objective function and decision variables [2-3]. Shin & Vishnupad [4] observe that the fuzzy and ANN-based modeling techniques are an effective means of control in complex grinding process. Kou & Cohen [5] emphasize the importance of integration between fuzzy and ANN-based technique for effective process control in manufacturing.

In Manufacturing Industries, Chip morphology and segmentation play a predominant role in determining Machinability and Chatter during the machining operation of materials. Problems with surface finish, work-piece accuracy, chatter and tool life can be caused even by minor changes in the chip formation process, especially in high speed machining, where undesirable chip formation will have a more detrimental effect because of the high cutting speed. At lower cutting speeds the chip is often discontinuous, while the chip becomes serrated as the cutting speeds are increased. In metal cutting, the present tendency is towards achieving increased material removal rates with a very reliable machining processes, where the predictability of surface finish, work-piece accuracy, chatter and tool life are of prime importance. For the accurate control of machining it is very essential to predict the chip formation. Amin [6] concluded based his investigations on mainly three work materials- AISI 1045, a titanium alloy and heat resistant alloy steel, that with the increase in cutting speed during turning, there is an inherent instability in metal cutting process which lead to the formation of secondary serrated teeth with a certain frequency at the free edge of the chip (away from the tool nose). The side teeth were termed as 'secondary serrated teeth' to distinguish them from the primary serrated teeth that appear in the entire cross section of the chip during machining of titanium and its alloys. It was also observed that as the cutting speed was increased, the secondary serrated teeth extended to the whole cross-section of the chip to form the primary serrated teeth in the chip. It was observed that the frequency of chip serration increased with the cutting speed and was higher for harder materials tike, titanium alloys and hardened steel, compared to softer and more ductile materials, like, plain carbon steels. The phenomenon of chip serration during the machining of Ti–6Al–4V was also observed by Komenduri [7] who proposed the well-known 'catastrophic shear band' theory. Amin [8] determined the frequency of the secondary serrated teeth and found that chip serration frequency is responsible for the chatter formation in machining. In this paper a Fuzzy controller was developed to predict the chip serration frequency from the cutting parameters and it is coupled with the GA and RSM for verification of the model.

2. ANALYSIS OF CHIPS PRODUCED IN END MILLING:

The chips formed during end milling using TiN insert were mainly investigated and it has been found that chip formation presents extreme cases of chip serration like secondary and primary. Typical SEM pictures and micro-sections of chips formed under various conditions were studied. It has been observed that chips formed in end milling are serrated in nature. The serrated teeth are formed along one on the edges of the chip (the free edge away from the tool nose) at almost equal spacing.

In order to have a close look at the chip to identify its morphology and inspect the presence of the primary and/or the secondary serrated teeth and any other type of instability that might be present in the outer view of the chip, the latter was viewed under a scanning electron microscope (SEM). A sample SEM view of the chip, shown in Fig. 1, indicates the presence of the serrated teeth with in the chip. The frequency of the serrated teeth formation, F_c, in the cases of milling cutting operations was calculated knowing the length of the portion of the chip in the SEM pictures, L, the coefficient of chip shrinkage, K (determined by dividing the uncut chip length by the actual chip length), cutting speed, V m/min and the number of secondary serrated teeth, n, observed on the SEM picture.

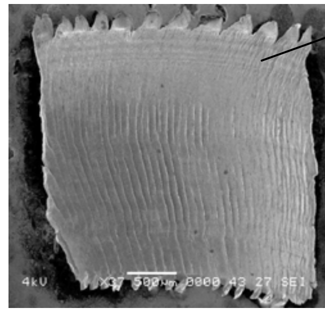

Fig 1: Schematic of the chip: SEM top view of the chip with the serrated element

3. CODING OF THE INDEPENDENT VARIABLES:

The independent variables at different levels were coded taking into considerations the limitation and capacity of the cutting tools. Levels of independent and coding identification are presented in Table 1, for experiment using Coated TiN inserts, respectively.

Table 1: Coding Identification for end milling using Coated TiN insert

Levels Coding	Lowest $-\sqrt{2}$	Low -1	Centre 0	High +1	Highest $+\sqrt{2}$
x_1, cutting speed, V (m/min)	59.5	71	109.2	168	200.78
x_2, axial depth of cut, a (mm)	1.005	1.15	1.59	2.2	2.516
x_3, feed, f, (mm/tooth)	0.039	0.05	0.089	0.16	0.204

3.1 Developed RSM Quadratic Model

In the experiment, small central composite design was used to develop the chip serration model. The analysis of mathematical models was carried out using Design-expert 6.0.8 package [9]. Cutting conditions in coded factors and the chip serration values obtained using TiN coated cemented carbide insert are presented in Table 2.

Table 2: Chip Serration Frequency results and cutting conditions in coded factors

Std. Order	Type	Coding of Level			Chip segmentation Frequency, Hz
		x1	x2	x3	
1	Fact	1	1	-1	10558,09
2	Fact	1	-1	1	13096,18
3	Fact	-1	1	1	2695,41
4	Fact	-1	-1	-1	2522,17
5	Center	0	0	0	6428,12
6	Center	0	0	0	5994,74
7	Center	0	0	0	5607,42
8	Center	0	0	0	5671,63
9	Center	0	0	0	7605,48
10	Axial	-1,41	0	0	2458,74
11	Axial	1,41	0	0	9356,23
12	Axial	0	-1,41	0	9748,24
13	Axial	0	1,41	0	6635,11
14	Axial	0	0	-1,41	5630,81
15	Axial	0	0	1,41	2977,40

The second order Chip Forming Frequency model by RSM is given as:

$$\hat{y}_2 = 8.70 + 0.47x_1 - 0.087x_2 - 0.23x_3 - 0.099x_1^2 + 0.16x_2^2 -]$$
$$0.18x_3^2 - 0.30x_1x_2 - 0.28x_2x_3 \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

3.2 Analysis of the Model:

The model developed by RSM was analyzed by considering the effect of different cutting parameters on chip serration frequency. Fig 2 indicates the effect of depth of cut on chip serration frequency at constant cutting speed of 168 m/min. It has been observed that with the increase of depth of cut the chip serration frequency decreases and also with the increase of feed chip serration decreases.

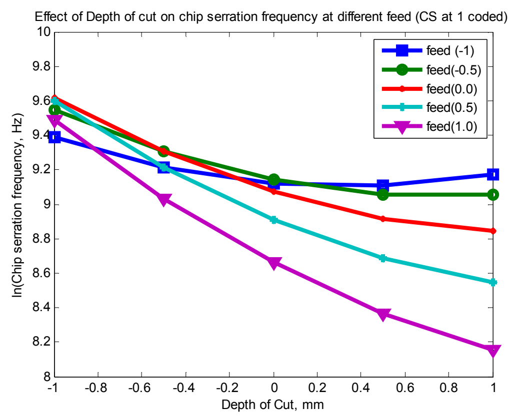

Fig 2: Effect of depth of cut on chip serration frequency at constant cutting speed (168m/min, coded level +1).

Fig 3 indicates the effect of cutting speed on chip serration frequency at constant Depth of cut of 2.2 mm. It has been observed that with the increase of cutting speed the chip serration frequency increases and also with the increase of feed chip serration decreases.

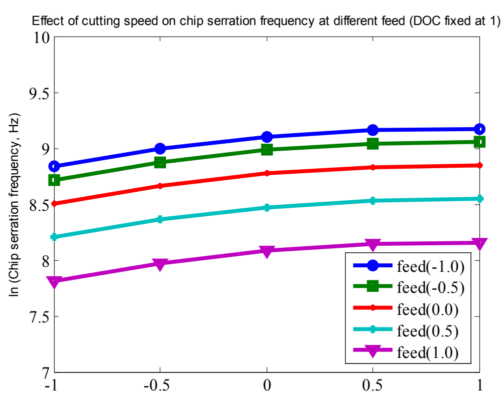

Fig 3: Effect of Cutting speed on chip serration frequency at constant Depth of cut (2.2mm, coded level +1).

Fig 4 indicates the effect of cutting speed on chip serration frequency at constant feed of 0.16mm/tooth. It has been observed that with the increase of cutting speed the chip serration frequency increases and also with the increase of depth of cut chip serration decreases.

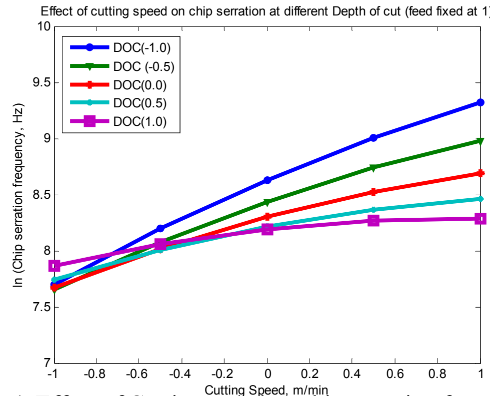

Fig 4: Effect of Cutting speed on chip serration frequency at constant feed (01.6mm/tooth, coded level +1).

4. Fuzzy Model of Chip Serration Frequency:

In this paper the fuzzy model has been designed to predict the chip serration frequency for milling operations uses three inputs and one output. The different cutting parameters cutting speed, depth of cut and feed are the inputs and chip serration frequency is the output. The first step in establishing the algorithm for calculating the chip serration frequency is to choose the shape of the fuzzy membership function or fuzzy sets for the process variables based on the experimental results.

Table 3: Fuzzy Expression for Cutting parameters input

Cutting Parameters	Abbreviation	Expression
Cutting speed, m/min	LOCS	Lowest Cutting speed
	LOC	Low Cutting speed
	MCS	Medium Cutting speed
	HCS	High Cutting speed
	HICS	Highest cutting speed
Depth of Cut, mm	LODOC	Lowest Depth of Cut
	LDOC	Low Depth of Cut
	MDOC	Medium Depth of Cut
	HDOC	High Depth of Cut
	HIDOC	Highest Depth of Cut
Feed, mm/tooth	LOF	Lowest Feed
	LF	Low Feed
	MF	Medium Feed
	HF	High Feed
	HIF	Highest Feed

Table 4: Fuzzy Expression for Chip serration output

Output function	Abbreviation	Expression
Chip serration frequency [Hz]	LOCF	Lowest Chip serration
	LCF	Low Chip serration
	MCF	Medium Chip serration
	MHCF	Medium High Chip serration
	HCF	High Chip serration
	HICF	Highest chip serration

The controller is based on the inter-relationship between the input and output that is modeled by RSM. The fuzzy expression for the cutting speed, depth of cut, feed and the corresponding chip serration are shown in Table 3-4 respectively.

4.1 Membership Functions For Input And Out Put Fuzzy Variables:

The membership functions for the inputs and output are well distributed triangular shape. The membership function for each fuzzy set for input fuzzy variables (Cutting speed, Depth of cut, feed) and for output variable (Chip serration frequency) are shown in Fig 5-6 respectively.

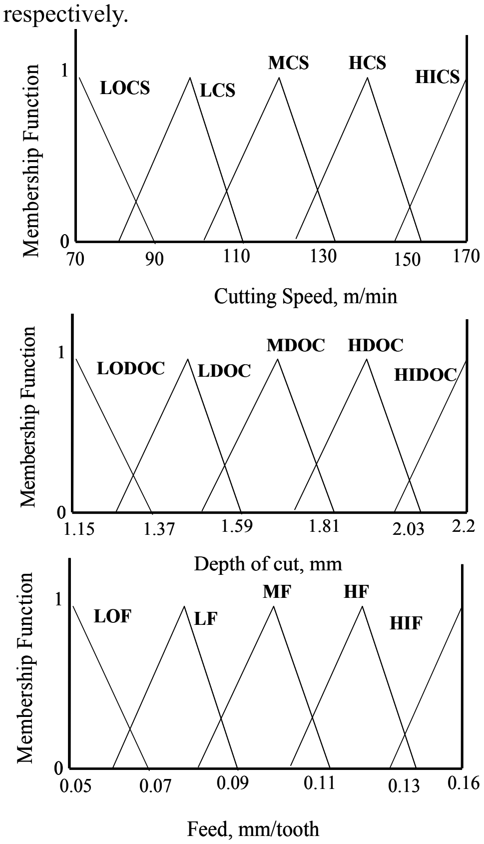

Fig 5: Membership function of input Variables

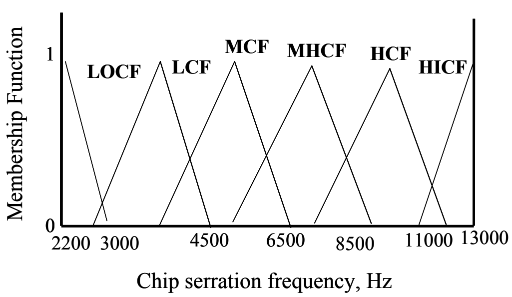

Fig 6: Membership function of output Variable (Chip serration frequency)

4.2 Fuzzy Rules for Chip Serration Frequency:

The relationship between the inputs and the output in a fuzzy system is characteristics by a set of linguistic statements which are called fuzzy rules. They are defined based on experimental findings, expert and engineering knowledge. In this study there are three inputs each of which is classified into different fuzzy sets and there are six chip serration states to be determined. For a fuzzy system involving three input parameters to yield an output, rules can be described as a rule controller made by Matlab Fuzzy logic tool box. In the fuzzy rule controller the different fuzzy rules are made based on the analysis of the RSM model. A few examples of the fuzzy rules in linguistic forms are given below:

1. If Cutting speed is LOCS, Depth of cut is LODOC and feed is LOF, then chip serration frequency will be LOCF.
2. If Cutting speed is HICS, Depth of cut is HIDOC and feed is LOF, then chip serration frequency will be HCF.
3. If Cutting speed is HICS, Depth of cut is LODOC and feed is HIF, then chip serration frequency will be HICF.

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4.3 Fuzzy Logic Controller For Chip Serration Frequency:

Based on the fuzzy rules a fuzzy logic controller was designed to predict the chip serration frequency generated from the end milling of stainless steel. The different cutting parameters for machining are added as input as Cutting speed, feed and depth of cut and the fuzzy logic controller predicts the chip serration frequency based on the fuzzy rules. The schematic diagram of the controller is shown in Fig 7.

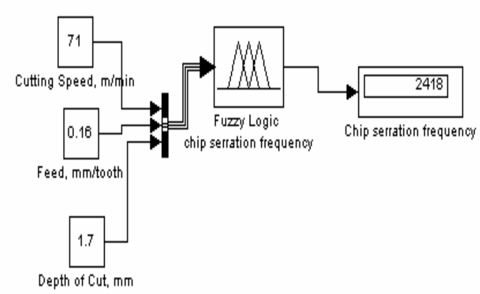

Fig 7 Fuzzy logic controller for the prediction of chip serration frequency.

4.4 Validation of Fuzzy Logic Controller for chip serration frequency with RSM and GA:

The validation of the fuzzy model was done with the RSM model and experimental measurement for six different tests. It has been observed that the prediction of chip serration frequency made by the fuzzy model is in higher agreement by RSM and experimental results as shown in Fig 8. In between the RSM and Fuzzy model the fuzzy model prediction are close enough with the experimental. For further validation of the model to check the minimum chip serration frequency a GA code was made and coupled to RSM model to find out the combined cutting parameters. The predicted value made by GA was again verified by the RSM and Fuzzy model with the experimental measurements to check the accuracy of the chip serration model.

Genetic Algorithms are search algorithms for optimization, based on the mechanics of natural selection and genetics. The mechanics of GA is simple, involving copying of binary strings and the swapping of the binary strings. The simplicity of operation and computational efficiency are the two main attractions of the GA approach.

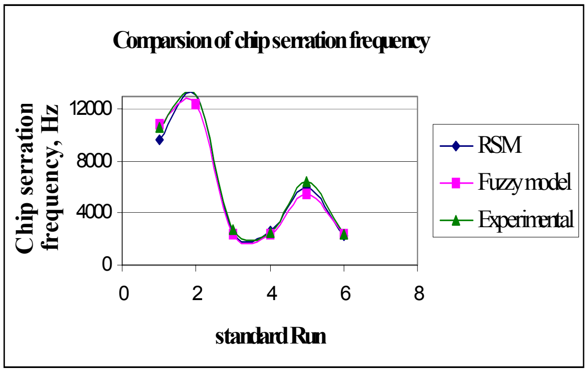

Fig 8: Comparison of chip serration frequency

The verification problem in this study is solved by coupling the developed RSM model, with developed GA and the validation is done by Fuzzy logic controller as shown in Fig. 9.

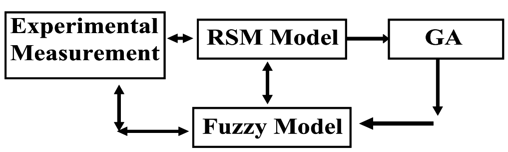

Fig 9: Interaction of experimental measurements, RSM model and GA during chip serration optimization.

By solving the optimization problem, the GA predicts the minimum chip serration frequency 2114.8 HZ for the machining of stainless steel SS304. The predicted conditions leading to minimum chip serration frequency are shown in Table 5. The predicted optimum conditions by GA were checked by Fuzzy logic controller and further validated with physical measurement. From the experimental results the chip serration frequency shows higher agreement with the values predicted by RSM and Fuzzy logic.

Table 5: Best cutting conditions and chip serration freq.

Parameters	Values
Optimized Cutting conditions: Cutting speed, m/min Depth of cut, mm Feed mm/tooth	 70.995 1.7022 0.16
Response	Results
Chip serration frequency (Predicted by GA) for RSM Model	2240.154 Hz
Chip serration predicted by Fuzzy system	2418 Hz.
Chip serration frequency(Experimental)	2381.338 Hz
Deviation: RSM model Fuzzy Model	5.9% 1.55%

5. CONCLUSION:

This research paper discussed the development of an verification technique of a RSM model by GA with Fuzzy logic for minimization of chip serration in machining of stainless steel (SS304) using coated TiN insert. The general conclusions are summarized below:

1. The three-stage effort for obtaining a chip serration model by surface response methodology, Fuzzy logic and validation of this model by Genetic Algorithms, has resulted in a fairly useful method of obtaining process parameters to predict the chip serration frequency.
2. The CCD model developed by RSM using Design Expert package. The equations are checked for their adequacy with a confidence level of 95%.
3. The application of the Fuzzy logic approach was found to predict more closely the chip serration frequency compared to that predicted by the developed RSM Model.

6. ACKNOWLEDGEMENT

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7. REFERENCES

[1]. H.J. Zimmerman, Description and optimization of fuzzy system, *International Journal of General* Systems 2 (1976), pp. 209–215.

[2]. Zadeh, L. A. (1973). Fuzzy sets and application: Selected papers. R. R. Yager, S. Ovchinnikov, M. Tong, & H. T. Nguyen (Eds.).

[3]. L.A. Zadeh, Outline of a new approach to the analysis of complex systems and decision processes, IEEE Transactions on Systems, Man, and Cybernatics SMC-3 (1973), pp. 28–44.

[4]. Y.C. Shin and P. Vishnupad, Neuro-fuzzy control of complex manufacturing processes, International Journal of Production Research 34 (1996) (12), pp. 3291–3309. 4. Hossain, M. Z. and Haq, M. Z., 2001, “Simulation of Otto Cycle with Multi-Fuel”, Proc. 4th Int. Conf. on Mechanical Engineering (ICME2001), pp. III:133-137.

[5]. R.Y. Kou and P.H. Cohen, Manufacturing process control through integration of neural network and fuzzy model, Fuzzy Sets and Systems (1998), pp. 15–31

[6] Amin, A.K.M.N., 1982, “Investigation of the Laws Governing the Formation of Chatter during Metal Cutting Processes and the Influence of Chatter on Tool Wear (in Russian)”, Ph.D. thesis, Georgian Polytechnic Institute, Georgia, 261.

[7] Komanduri, R., Von Turkovich, B.F., 1981, “New Observations on the Mechanism of Chip Formation when Machining Titanium Alloys”, Wear 69, 179.

[8] Amin, A.K.M.N., 1983, “Investigation of the Mechanism of Chatter Formation during the Metal Cutting Process”, Mech. Eng. Res. Bulletin, 6, 1, pp. 11-18.

[9] Design-Expert Software, Version 6.0.8,User’s Guide, Technical Manual, Stat-Ease Inc., 2000, Minneapolis, MN.