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Artificial Neural Network Chip Serration Frequency Model in End Milling of Medium Carbon Steel

[1]Anayet U. Patwari, [1]A.K.M. Nurul Amin and [2]Waleed Faris
[1]Department of Manufacturing and Materials Engineering,
[2]Department of Mechanical Engineering, Faculty of Engineering,
International Islamic University of Malaysia, Kuala Lumpur, Malaysia

Abstract: In this research, an Artificial Neural Network (ANN) model was developed for the investigation and prediction of the relationship between cutting parameters and chip serration frequency during high speed end milling of medium carbon steel (S45C). The input parameters of the ANN model are the cutting parameters: cutting speed, feed and axial depth of cut. The output parameter of the model was chip serration frequency. For this interpretation, advantages of statistical experimental design technique, experimental measurements, artificial neural network were exploited in an integrated manner. Cutting experiments are designed based on statistical central composite design experimental design technique. A predictive model for chip serration frequency was created using a feed-forward back-propagation neural network exploiting experimental data. The network was trained with pairs of inputs/outputs datasets generated, when end milling steel with TiN coated carbide inserts. A very good predicting performance of the neural network, in terms of concurrence with experimental data was attained. The model can be used for the analysis and prediction for the complex relationship between cutting conditions and the chip serration frequency in metal-cutting operations.

Key words: ANN model, chip serration frequency, end milling, scanning electrol microscope, responce surface methodology

INTRODUCTION

Problems with surface finish, work-piece accuracy, chatter and tool life can be caused even by minor changes in the chip formation process. At lower cutting speeds the chip is often discontinuous, while, it becomes serrated as the cutting speeds are increased. In metal cutting, the present tendency is towards achieving increased material removal rates with very reliable machining processes, where the predictability of surface finish, work-piece accuracy, chatter and tool life are of prime importance. One of the restrictions limiting large material removal rates is the tendency of the machine tool to chatter. But to maintain stable machining, much attention must also, be paid to the formation of the desired type of chip and chip controls to facilitate its easy removal. This is because, the chip formation and breaking aspect is very significant in machining. Trent (2000), Talantov *et al*. (1980), Amin (1983) considered the formation of chips with serrated teeth to be the primary cause of chatter. They found that chatter arising during turning is a result of resonance, caused by mutual interaction of the vibrations due to serrated elements of the chip and the natural vibrations of the system components, e.g., the spindle and the tool holder (Amin, 1983).

Komanduri (1981) and Kamanduri and Schroeder (1982) has made some remarkable progress in the research of chip segmentation and instability in chip formation. Nevertheless, it appears that very few works have been done to investigate the nature of chip formation in end milling because of its complexity and geometrical difficulty Several researchers have studied the end milling process in the recent years. The researchers also used Response Surface Methodology (RSM) to explore the effect of cutting parameters as cutting speed, feed rate and axial depth of cut. Alauddin *et al*. (1995) developed a mathematical model to predict the surface roughness of steel after end milling. The prediction model was expressed via cutting speed, feed rate and depth of cut. Fuh and Hwang (1997) used RSM to construct a model that can predict the milling force in end milling operations. But as the machining process is nonlinear and time-dependent, it is difficult for the traditional identification methods to provide an accurate model. Compared to traditional computing methods, the Artificial Neural Networks (ANNs) are robust and global. ANNs have the characteristics of universal approximation, parallel distributed processing, hardware implementation, learning and adaptation and multivariable systems (Tandon *et al*., 2001). ANNs have been extensively applied in modeling

Corresponding Author: Anayet U. Patwari, Department of Manufacturing and Materials Engineering, Faculty of Engineering, International Islamic University of Malaysia, Kuala Lumpur, Malaysia

many metal-cutting operations such as turning, milling and drilling (Liu *et al*., 1998; Dimla, 1999; Ezugwu *et al*., 1995). However, this study was inspired by the very limited research on the application of ANNs in modeling the relationship between cutting conditions and the chip serration frequency during end milling of steel.

Chip analysis technique: Chips are extensively studied and analyzed, since chatter has direct influence on chip serrated behavior and vice versa. For studying chip morphology Scanning Electron Microscope (SEM) model: JEOL JSM 5600 and optical microscope NIKON EPIPHOT 200 are used. Frequency of chip segmentation is analyzed to determine relationship between chip segmentation/serration frequencies and chatter parameter.

The chips formed during end milling using TiN coated carbide inserts were mainly investigated considering the SEM pictures and micro-sections of chips under various conditions to observe the chip serration. It has been observed that chips formed in end milling have primary and secondary serrated teeth. The secondary serrated teeth are formed along one on the edges of the chip (the free edge away from the tool nose) at almost equal pacing. The frequency of the secondary 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^{-1} and the number of secondary serrated teeth, n, observed on the SEM picture (Talantov *et al*., 1980).

$$F_c = 1000\frac{nV}{60(LK)}(\text{Hz})$$

The microstructure pictures of the chips are taken by using the JEOL JSM 5600 Scanning Electron Microscope (Fig. 1a). Using the Automatic Focusing Device and Automatic Astigmatism Correction Device within the microprocessor, it could produce ranges from low magnification up to high resolution and magnification.

Optical microscope is used to identify the primary, secondary serrated teeth from the chip. The optical microscope used in this study is shown in Fig. 2b with many advanced features like: Reticle Imprinting Option for primary image plane position, the micrometer maintains fine focus without being affected by the state of the sample surface being observed.

Observation of secondary saw tooth formation: side cross sectional view: Similar to the findings by Amin (1982) the chips from the end milling operation show that the instability of chip formation is cyclic with two definite phases: the phase of compression marked by a steep ascension of the jagged edge and the phase of shear marked by a sloping and gradual decline of the peak. Also, these regular spaced edges appear on only one side of the chip, where the other is smooth. Figure 2 shows, a schematic of the chip showing where the chips were sectioned (along the line a-a) to be observed under the microscope. This sectioning is done in order to observe more clearly the jagged edges that appear on one side of the chip.

Fig. 1: a): Scanning Electron Microscope (SEM) and b): Optical microscope used for chip analysis

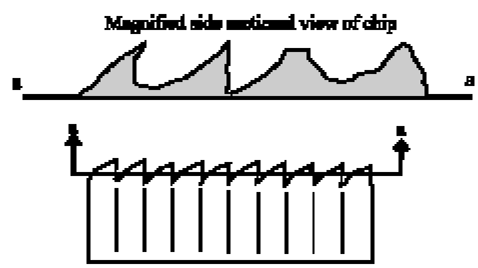

Fig. 2: Schematic of chip showing sectioning for viewing side cross sectional view

MATERIALS AND METHODS

Cutting tests were conducted mainly on Vertical Machining Center (VMC ZPS, Model: 1060) powered by a 30 KW motor with a maximum spindle speed of 8000 rpm. The design of experiment has a major effect on the total number of required experiments. A well planed experimental design can reduce the number of experiments quite substantially. For this reason, a small CCD with 2 blocks and 5 replication of center point in each factorial block was selected to design the experiments. This ultimately resulted in 15 experiments, with 4 other factorial points and 6 axial points. This experimental design provides 5 levels for each of the independent variables. The cutting conditions are as follows:

x_1, Cutting speed, V (m min^{-1}): 100, 114.25, 158, 218.5, 250
x_2, Axial Depth of Cut (mm): 1.005, 1.15, 1.59, 2.2, 2.516
x_3, Feed (mm tooth^{-1}): 0.039, 0.05, 0.089, 0.16, 0.204

The transforming equation of each individual variable is expressed as:

$$x_1 = \frac{\ln V - \ln 158}{\ln 218.5 - \ln 158}$$

$$x_2 = \frac{\ln a - \ln 1.59}{\ln 2.2 - \ln 1.59}$$

$$x_3 = \frac{\ln f_z - \ln 0.089}{\ln 0.16 - \ln 0.089}$$

From the experimental results, empirical equations were developed to predict the chip serration frequency and the significant parameters involved using response surface methodology. From the Analysis of Variance (ANOVA) and fit summary test results by Design Experts Software (2000) it has been observed that quadratic model is more significant for the prediction of chip serration frequency. The quadratic model for chip serration frequency in its transformation state is developed as:

$$\hat{y}_2 = 8.94 + 0.36x_1 - 0.16x_2 - 0.05x_3 - 0.058x_1^2 - 0.013x_2^2 - 0.18x_3^2 - 0.10x_1x_2 + 0.43x_1x_3$$

Analysis of chips produced in end milling: The chips formed during end milling using rectangular inserts were mainly investigated and it has been found that at some specific cutting conditions chip formation presents extreme cases of secondary and primary chip serration. Typical SEM pictures and micro-sections of chips formed under various conditions were studied. Effort has been also made to observe the effect of the parameters used in this research on the structure of chip produced at each cutting condition and their relationship with vibration and chatter. Firstly, the chip at different cutting conditions were collected and chip specimens were prepared, polished and etched for viewing under the microscope to capture the structure of the chip. General observation shows that chip has the primary saw teeth. The primary saw teeth are produced due to the alternative phase compression and adiabatic shear process resulting in fluctuation of the force exerted on the tool. A sample picture of the chip top view (SEM view) and length-wise sections of the chips produced in end milling is shown in Fig. 3.

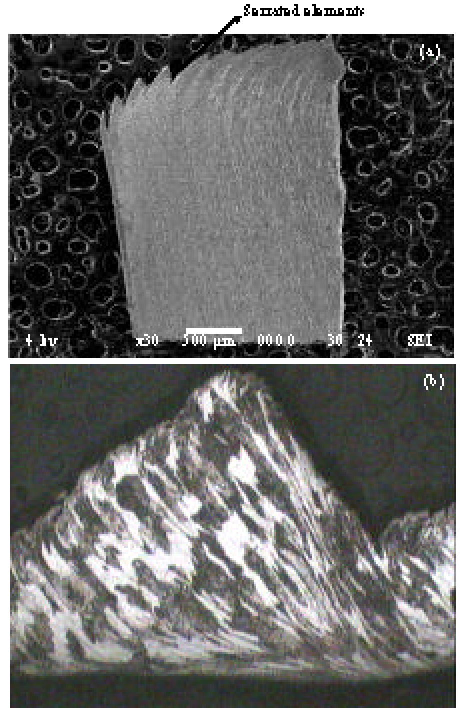

Fig. 3: Chip morphology, a): SEM view and b): Length-wise sectional view (under optical microscope) with the cutting conditions (V: 158 m min^{-1}; DOC: 2.51 mm, feed: 0.08 9 mm tooth^{-1})

Artificial neural network design: Supervised neural network was developed in this study for the prediction of chip serration frequency in end milling process and its performance was tested. The network was Back Propagation neural network (BP) with log-sigmoid transfer function in hidden layers and linear transfer functions in the output layers. The neural network architecture used in this study is shown in Fig. 4. It was designed using MATLAB Neural Network Toolbox MathWorks Incorporation (2007). The network consists of one input, two hidden and one output layers. Hidden layers have 15 neurons each, whereas input and output layers have three and one neurons, respectively. Neurons in the input layers correspond to cutting speed (v_c), feed (f) and axial depth of cut (a). Output layer corresponds to chip serration frequency (f_c).

ANN model development: training ANN model: Before the ANN can be trained and mapping learned, the experimental data was processed into patterns. So, Training, validation and testing pattern vector had been formed before the ANN was trained. Each pattern was formed with an input condition vector,

$$\text{Input}_i = \begin{bmatrix} \text{Cutting speed} \\ \text{depth\_of\_cut} \\ \text{feed} \end{bmatrix}$$

And the corresponding target vector,

$$\text{Target}_i = [\ln\{\text{Chip\_serration\_frequency}\}]$$

The back-propagation learning algorithm was used for training the network. For training the network, the TRAINLM function of MATLAB was utilized, which works on back propagation algorithm. These algorithms iteratively adjust the weights to reduce the error between the experimental and predicted outputs of the network. The 15 experimental results and further 36 generated results from the RSM model were used for this training, prediction and validation of the model. TRAINLM updates weights so as to minimize the Mean Square Error (MSE) between the network prediction and training data set. When, the network training was successfully finished, the network was tested with additional test data.

Data pre-processing: Since, only a limited number of experiments are representative of the feasible parameter space, it is important that the ANN realizes each set fully. This is achieved by normalizing the data as follows:

$$N = \frac{(R - R_{min}) \times (N_{max} - N_{min})}{(R_{max} - R_{min})} + N_{min}$$

where:

N = Normalized value of the real variable

N_{min} and N_{max} = Minimum and maximum values of normalization, respectively

R = Real value of the variable

R_{min} and R_{max} = Minimum and maximum values of the real variable, respectively

When, the network training was successfully finished, the network was tested with additional test data.

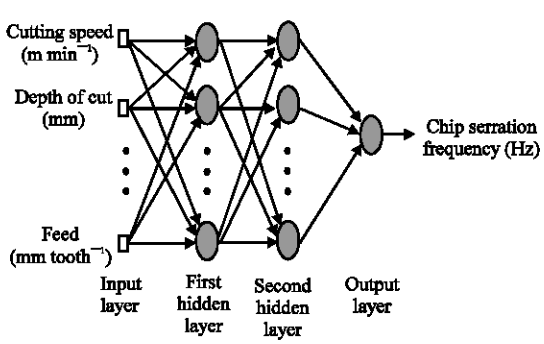

Fig. 4: ANN architecture designed

RESULTS AND DISCUSSION

The developed ANN model can predict chip serration frequency based on the cutting conditions, with a high degree of accuracy within the scope of cutting conditions investigated in the study. Hence, the influence of the cutting conditions on the chip serration frequency can be studied using the model.

Effect of cutting speed on chip serration frequency: Cutting speed is one of the most important cutting parameters in metal-cutting operations and it is very influential on chip serration frequency as shown in Fig. 5. It has been observed that with the increase of cutting speed at constant depth of cut and feed (0.5 normalized conditions) the chip serration frequency increases.

Effect of feed on chip serration frequency: Figure 6 shows, the effect of feed on chip serration frequency at constant cutting speed and depth of cut (0.5 normalized conditions). It has been observed that with the increase of feed the chip serration frequency decreases.

Effect of depth of cut on chip serration frequency: Figure 7 shows, the effect of depth of cut on chip serration frequency at constant cutting speed and feed (0.5 normalized conditions). It has been observed that with the increase of depth of cut the chip serration frequency also, decreases.

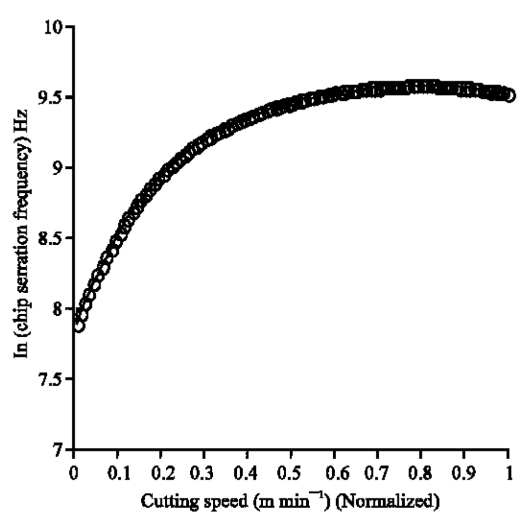

Fig. 5: Effect of cutting speed effect on chip serration frequency predicted by ANN

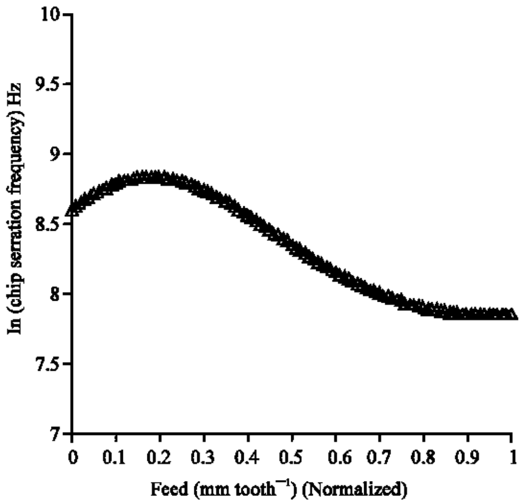

Fig. 6: Effect of feed on chip serration frequency predicted by ANN

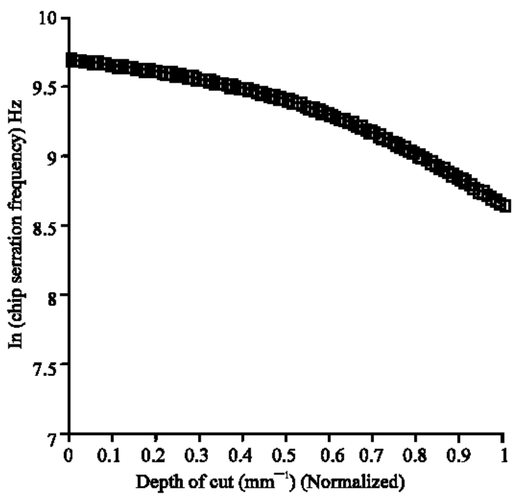

Fig. 7: Effect of depth of cut effect on chip serration predicted by ANN

CONCLUSION

This research discussed, the development of a ANN model with design of experiment for the prediction of chip serration frequency in end milling of Medium carbon steel using TiN insert under dry machining.

The multilayer network with two hidden layers having 15 log-sigmoid neurons trained with TRAINLM algorithm was found to be the optimum network for the model developed in this study.

It has been observed that the chip serration frequency proportional to cutting speed and inversely proportional to Depth of cut and feed.

The model can be used for the analysis and prediction for the complex relationship between cutting conditions and the chip serration frequency in metal-cutting operations, while end milling of medium carbon steel for efficient and economic production.

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