



MODELLING AND ANALYSING THE CUTTING FORCES IN HIGH SPEED HARD END MILLING USING NEURAL NETWORK

Amin M. F. Seder, Muataz Hazza F. Al Hazza and Erry Y. T. Adesta

Faculty of Engineering - International Islamic University Malaysia, Malaysia

E-Mail: muataz@iiu.edu.my

ABSTRACT

High speed hard end milling is one of complex and costly shape machining compared to other machining processes. In high speed end hard milling, the tool wear or breakage are mostly happened due to the cutting forces which lead. In this research, the influencing of cutting speed, feed rate and depth of cut on cutting forces have been analysed and modelled using the artificial neural network approach using experimental data. The experiment was conducted using high speed end milling of AISI D2 cold work tool steel material hardened to 52 HRC under dry cutting condition. The measured data have been used to train and validate the outputs. The artificial neural network (ANN) has been used for modeling and predicting the cutting forces using the JMP software. The new model shows high accuracy compared the measured forces.

Keywords: cutting force, high speed, end milling, hard milling and ANN.

INTRODUCTION

Milling process is divided into peripheral and face milling. Peripheral milling produces a surface parallel to the spindle rotation, while face milling generates a surface normal to the spindle rotation. End milling is a type of face milling (Zain, *et al*; 2010) and according to Mahesh, *et al*; (2015) it is a process of generating a machined surface by gradually removing a predetermined amount of material from the work piece with a minimum feed rate of a milling cutter rotating at a high speed. Although high speed hard end milling is complex and costly shape machining compared with turning because of complicated machine tool linear motions and repeated intermittent engagement and disengagement of rotating cutting edges, it is indispensable in industry and continuously finding further applications particularly with the developments of new cutting tool. Some of those applications are facing, profiling, slotting, engraving, surface contouring and pockets on finished parts (Kondayya and Krishna; 2012).

High speed end milling is one of the most important and common metal cutting process since it has high removal rate and its ability to produce complex geometric parts with good dimensional accuracy and an acceptable surface quality (Raju, *et al*; 2011). And according to Adesta *et al*., (2010) high speed end milling of hard alloy steels can minimize machining costs, enhance surface roughness and increase productivity by reducing of operation time which leads to raise the flow of producing, decreasing the number of industrial operations, improving the surface quality and prolongation of tools life.

However, some of the problems which occur during end milling operation involve shank or flute breakage, machining instability and production of defective parts. These drawbacks, including surface

accuracy or machined surface error and surface texture, are often due to excessive levels of cutting force being applied to the end milling cutter and they are highly dependent on it. Thus, cutting forces are central to these problems and counted as primary measure of end milling cutting performance (Sutherland; 1988). In this research, CNC high speed hard end milling is employed for investigation in order to utilize full automation in end milling, have greater accuracy of results, attain better machining process, increase the quality of the machined surfaces and spend less operation time.

Cutting force is, in many cases, the most fundamental and significant parameter to be predicted during cutting operation due to its strong correlation with cutting performance. In milling process, tool wear or breakage and work piece deflection are mostly due to abnormal cutting forces which lead to tolerance violations (Chandrasekaran, *et al*; 2010; Budak; 2006). One main source of vibration while machining is the continual changing of cutting force and the prediction of cutting conditions that have impact on cutting performance like surface accuracy, tool wear, tool breakage, cutting temperature, self-excited or forced vibrations and stability of machining requires developing accurate modeling of cutting forces. Accurate modeling of machining forces exerted by the cutting tool on the work piece during a machining action is necessary for the performance prediction of the process as well as to find the mechanisms and cutting variables which impact the stability of cutting process and to control the tool wear and occurrence of vibration to improve tool life (Patwari, *et al*; 2009). But according to Sivarao, *et al*. (2010), numerous interrelated parameters that influence the machining forces such as cutting speed, feed, depth of cut, cutter geometry and physical or chemical features of the finished components make it quit difficult to establish a sound model.



Machining forces are divided into three components, which are tangential cutting force (F_x), radial thrust force (F_y) and feed force (F_z). The measurement of the three machining force components F_x , F_y and F_z will be zero until the cutting teeth engage with the workpiece. One essential characteristic of high speed hard end milling is the periodical fluctuation of machining forces which caused by chip thickness variations and interrupted entry and exit of the cutting teeth. This makes each cutting tooth generates a cyclic cutting force ranging from negative to maximum force and then back to negative. Amongst the three components, the tangential cutting force is often the largest. But, in finishing operations, the radial thrust force is the largest, while the feed force is maintained the minimal. Tangential cutting force is the force acting on the tool in the direction of the workpiece travel and often it is the greater (Babu *et al.*; 2008, Lai; 2000). It resists the rotation of the work and this makes the bulk of power to be consumed with this cutting force component since relatively high speeds are utilized. And this often makes the study of tangential force exerted by the depth of cut comprises the material removal rate and horsepower as these parameters are generated at the spindle at different depth of cut and integral in the shaping of tangential forces (Sivarao, *et al.*; 2010).

Babu *et al.* (2008) proposed and validated the fact that, tangential force is the most influential force while machining whereby the cutting variables which are given in levels are responsible for the formulation and magnitude of the tangential force. Machining forces in the tangential direction is also determined to be increased when the depth of cut increases (Babu *et al.*; 2008, Lai; 2000, Ekanayake and Mathew; 2007). Daud *et al.* (2009) found that at high depths of cut the elevated tangential forces causes vibration and chatter. This chatter will unavoidably worsen the quality of the finished parts.

Axial cutting force is the force perpendicular to the surface of the workpiece and it is required to keep the cutting tool edge in contact with the workpiece and resist the travel of the tool. Thus, unlike tangential forces, for all practical purposes of axial cutting force investigation, the horsepower consumption may be ignored because this is a relatively low speed is employed compared with rotation of the work (Riksiri and Parnichkun; 2004). Chen (2000) studied the cutting force and surface finish while cutting of medium hardened steel having hardness in the range of 45–55 HRC by utilizing CBN tool and stated that thrust force is the largest among the three cutting force components.

Experimental procedure

In this experimental study, the independently controllable parameters influencing the machining forces are depth of cut, feed rate and cutting speed while other parameters have been kept constant over the experimental domain such as tool geometry, the tool height and

hardness of the material. The performed experiment is high speed end milling of AISI D2 cold work tool steel material under dry cutting condition to avoid thermal shock and crack on the insert, using high speed steel end mill cutter with 32 mm diameter and three flute tool on a CNC vertical machine center called MAZAK modeled NEXUS 410A-II. Machining forces was measured by a stationary Piezo-electric three-component dynamometer (Kistler, type), a multichannel charge amplifier (Kistler, Type) and a data acquisition system. The stationary dynamometer was the connected element between the machine table of the machine tool and the workpiece. The workpiece was clamped on the dynamometer with which the reaction forces components in feed, tangential and radial directions of the machining process are measured. In the preparation stage of each experiment, the gauges have been used to set the tool height. Experiments were carried out under various cutting conditions.

To minimize the total number of experiments and to obtain data uniformly from all the regions of the selected working area, design-expert software of version 6.0.8 is utilized to establish the experimental plan for conducting the research investigation whereby central composite design (CCD) of RSM is selected to determine the suitable number of experimental runs since it can be run sequentially and efficiently. This resulted in seventeen of experimental runs, containing eight factorial points, six axial points and three center points. For each of the two output responses which are axial and tangential cutting forces, the experimental design provides three levels. The design matrix and the responses are presented in Table-1.

Table-1. Ranges of cutting parameters of the experiment.

Cutting parameters	Minimum	Maximum
Cutting speed(m/min)	120	240
Feed rate (mm/tooth)	0.05	0.15
Depth of cut (mm)	0.10	0.20

RESULTS

The result shows that with increasing the cutting speed, feed rate and depth of cut will increase the cutting forces for the three components as shown in Figure 1, 2 and 3. However, the results show that the most effective parameter was the feed rate as shown in Figure-2.

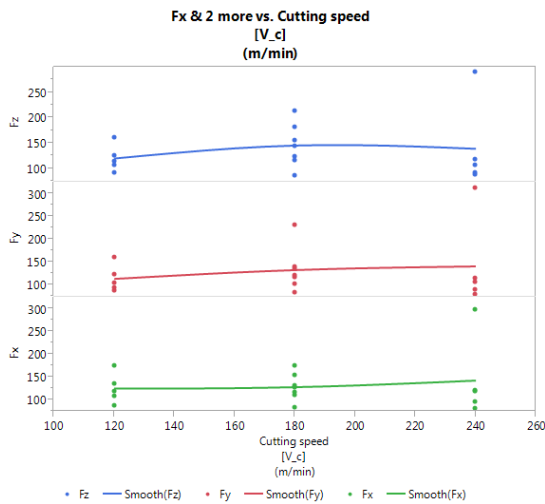


Figure-1. Relationship between cutting speed and cutting forces components.

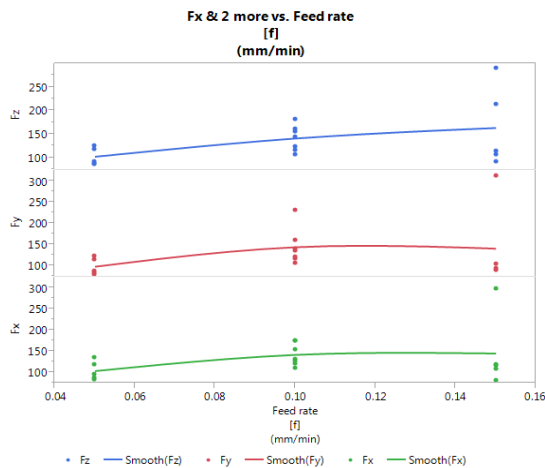


Figure-2. Relationship between feed rate and cutting forces components.

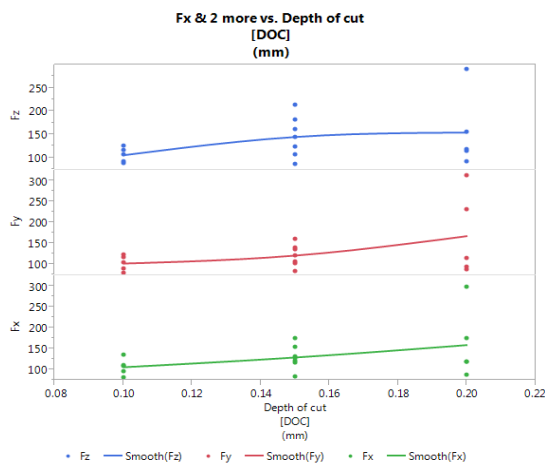


Figure-3. Relationship between depth of cut and cutting forces components.

The cutting forces components: F_x , F_y , and F_z have been plotted to show the trend of independent factors on the three components forces as shown in Figure-4.

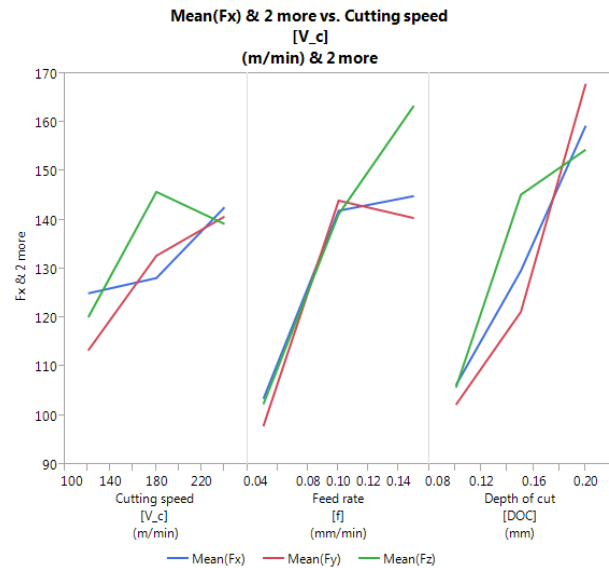


Figure-4. Cutting forces trend with respect to the independent factors.

ANN application

The results have been used as a row data for the neural network method. Figure-5 show the neural network structure.

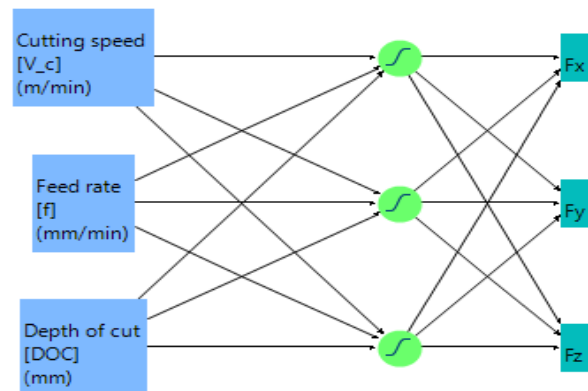


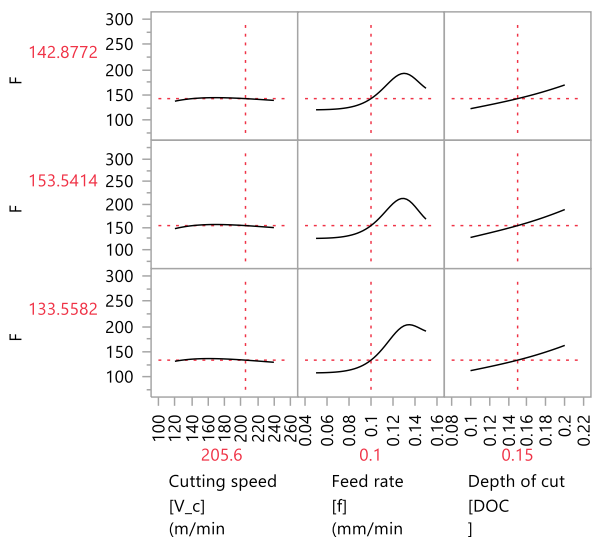
Figure-5. Neural network structure.

Three hidden layers have been used. The weights for the hidden layers are as in Table-2.

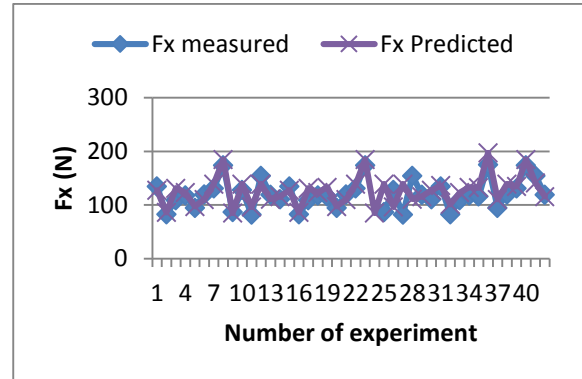
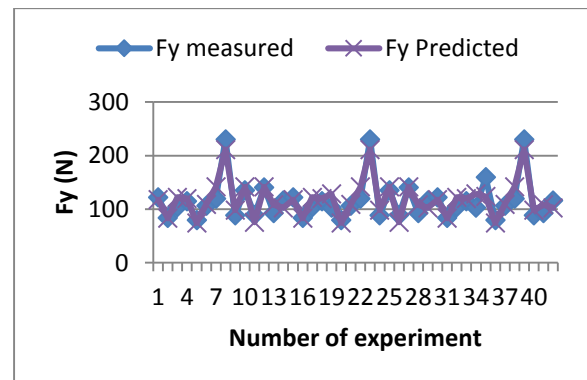
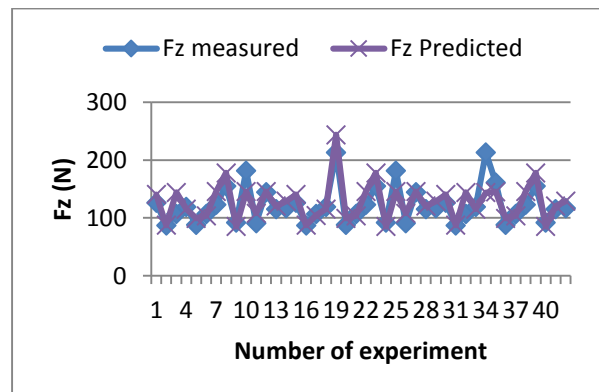
**Table-2.** Weights for hidden layers.

0.992391	-0.95334	-0.99964
0.221838	-0.09869	0.319445
0.999345	-0.99999	-0.99997
-0.98135	0.931444	0.999906
0.89645	-0.99963	-0.74658
0.986617	-0.99993	-0.98556
-0.49065	0.999402	-0.02853
-0.67544	0.642266	0.949602
0.685659	-0.97576	-0.30686
-0.05812	-0.99775	0.975126
-0.80210	-0.98748	0.998738
0.756547	-0.9996	0.598366
0.685659	-0.97576	-0.30686
0.598842	-0.14414	-0.86796
0.685659	-0.97576	-0.30686
0.976514	-1.00000	-0.54103
0.939950	-0.76418	-0.99294

From the predicted values of cutting forces, the predicted profile has been created by JMP software and the results is shown in Figure-6. The figure shows that cutting speed has the lowest effect on the cutting forces. On the other hand, increasing the depth of cut has a continuous and increasing effect on the three components. Increasing the feed rate also affects the forces negatively but the predicted profile shows that this effect is for a specific point.

**Figure-6.** Predicted profile.**Validation**

The measured values with the estimated values have been compared and plotted to measure the deviation as shown in Figures 7-8. The results show a high correlation between the both.

**Figure-7.** Measured Fx values compared with the predicted Fx values.**Figure-8.** Measured Fy values compared with the predicted Fy values.**Figure-9.** Measured Fz values compared with the predicted Fz values.



CONCLUSIONS

Based on the results it can be concluded the followings:

1. The results show a high correlation between the experiment forces with the predicted ones.
2. Increasing the cutting speed with maintain the feed rate and the depth of cut with the minimum values will affect positively on the cutting forces.
3. The most effective factor on all cutting forces is the feed rate
4. The neural network (NN) method gave a high accuracy with low deviation from the measured values

REFERENCES

- [1] Adesta, E., Al Hazza, M., Riza, M. and Agusman, D. 2010. Tool life estimation model based on simulated flank wear during high speed hard turning. *European Journal of Scientific Research*, 39(2), 265-278.
- [2] Babu, G.B., Selladurai, V., Shanmugam, R. "Analytical Modeling of Cutting Forces in End Milling Operation on AluminumSilicon Carbide Particulate Metal Matrix Composite Material Using Response Surface Methodology." *ARPN Journal of Engineering and Applied Science*, 2008 Vol. 3, pp. 5-18.
- [3] Budak, E. 2006. Analytical models for high performance milling. Part I: Cutting forces, structural deformations and tolerance integrity. *International Journal of Machine Tools and Manufacture*, 46(12), 1478-1488.
- [4] Chandrasekaran, M., Muralidhar, M., Krishna, C. M. and Dixit, U. S. 2010. Application of soft computing techniques in machining performance prediction and optimization: a literature review. *The International Journal of Advanced Manufacturing Technology*, 46(5-8), 445-464.
- [5] Chen W (2000) Cutting forces and surface finish when machining medium hardness steel using CBN tools. *Int J Mach Tools Manuf* 40:455-466
- [6] Daud, R., Hasfa, N.K., Tomadi, S.H., Hassan, M.A., Kadirgama, K., Noor, M.M., and Rejab, M.R.M. "Prediction of Chatter in CNC Machining based on Dynamic Cutting Force for Ball End-Milling." *International Multi Conference of Engineers and Computer Scientists* 2009. (March 18 - 20, 2009, Hong Kong), 2009 Vol. II IMECS 2009.
- [7] Ekanayake, R.A. and Mathew, P. "An Experimental Investigation of High Speed End-Milling." 5th Australasian Congress on Applied Mechanics (August 2007-Sydney), 2007 pp. 45-49.
- [8] Kondayya, D. and Krishna, A. G. 2012. An integrated evolutionary approach for modelling and optimisation of CNC end milling process. *International Journal of Computer Integrated Manufacturing*, 25(11), 1069-1084.
- [9] Lai, H.L. "Modelling Cutting Forces in End Milling Operations." *Tamkang Journal of Science and Engineering*, 2000 Vol. 3 pp. 15-22.
- [10] Mahesh, G., Muthu, S., & Devadasan, S. R. (2015). Prediction of surface roughness of end milling operation using genetic algorithm. *The International Journal of Advanced Manufacturing Technology*, 77(1-4), 369-381.
- [11] Patwari, M. A., Amin, A. N. and Faris, W. F. 2009. Prediction of tangential cutting force in end milling of medium carbon steel by coupling design of experiment and response surface methodology. *Journal of Mechanical Engineering*, 40(2), 95-103.
- [12] Raju, K. V. M. K., Janardhana, G. R., Kumar, P. N. and Rao, V. D. P. (2011). Optimization of cutting conditions for surface roughness in CNC end milling. *International journal of precision engineering and manufacturing*, 12(3), 383-391.
- [13] Raksiri, C. and Parnichkun, M. "Geometric and Force Errors Compensation in A 3-axis CNC milling machine." *International Journal of Machine Tools and Manufacture*, 2004 Vol. 44, pp. 1283-1291.
- [14] Sivarao, S., Fairuz, D. and Ahmad, K. 2010. Investigation of Tangential Force, Horsepower and Material Removal Rate Associating HAAS CNC Milling, Al6061-T6511 Work Material & TiAlN Coated End Mill Tool. *International Journal of Basic and Applied Sciences*, 10(4), 23-28.
- [15] Sivarao, S., Fairuz, D. and Ahmad, K. 2010. Investigation of Tangential Force, Horsepower and Material Removal Rate Associating HAAS CNC



Milling, Al6061-T6511 Work Material and TiAlN Coated End Mill Tool. International Journal of Basic and Applied Sciences, 10(4), 23-28.

- [16] Sutherland, J. W. and DeVor, R. E. 1988. A dynamic model of the cutting force system in the end milling process. Diss. Abstr. Int., 49(1), 293.
- [17] Zain, A. M., Haron, H. and Sharif, S. 2010. Prediction of surface roughness in the end milling machining using Artificial Neural Network. Expert Systems with Applications, 37(2), 1755-1768.