

Surface Roughness Optimization in End Milling Operation with Damper Inserted End Milling Cutters

Krishna Mohana Rao, G. Ravi Kumar, and P. Sowmya

Abstract—This paper presents a study of the Taguchi design application to optimize surface quality in damper inserted end milling operation. Maintaining good surface quality usually involves additional manufacturing cost or loss of productivity. The Taguchi design is an efficient and effective experimental method in which a response variable can be optimized, given various factors, using fewer resources than a factorial design. This Study included spindle speed, feed rate, and depth of cut as control factors, usage of different tools in the same specification, which introduced tool condition and dimensional variability. An orthogonal array of $L9(3^4)$ was used; ANOVA analyses were carried out to identify the significant factors affecting surface roughness, and the optimal cutting combination was determined by seeking the best surface roughness (response) and signal-to-noise ratio. Finally, confirmation tests verified that the Taguchi design was successful in optimizing milling parameters for surface roughness.

Keywords—ANOVA, Damper, End Milling, Optimization, Surface roughness, Taguchi design.

I. INTRODUCTION

MILLING process is having wider application, but the vibration during the process affects the performance. The key benefit of high speed milling is that a large amount of material can be cut in a short time span with a relatively small tool due to high rotational speed of the tool. This results in a relatively low force, which allows one to mill large and complex thin walled structures from a single block of material, instead of assembling the same structure from several parts. Since the effective use of a milling process also accompanied with vibrations, a mechanism is to think of which can reduce the amount of vibration of tool and its influence on the machining performance. Particularly, in case of end milling cutter the lateral vibration of the tool effects the surface roughness of the component. In the present work an attempt is made to find the influence of insertion of damper (finger) into the tool longitudinally.

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II. LITERATURE REVIEW

Research on structural damping has given a great knowledge in understanding the behaviour of a tool. They investigated this problem and proposed devices to provide damping to the structures. Some of them used tuned mass dampers, liquid dampers, friction dampers, and impact dampers.

Cobb [1] found that impact dampers served better in controlling the vibrations. The types of impact dampers used were a spring/mass liquid impact damper and a tapered impact damper. Keyvanmanesh, Amir [2] developed an algorithm to detect the chatter region based on the information obtained from the cutting tests on different end mills. Similar to the work done by Smith, Kevin Scott, [3], he did a time domain simulation using the values obtained from the dynamic response of the tool to plot the stability lobes. Cook, R. A., Bloomquist, D., Richard, D. S., and Kalajian, M.A [4] developed damping mechanisms to control vibrations on traffic signal structures. They proposed devices to provide damping to the structures.

The research damper model was based on the work done by Slocum, H. Alexander [5] on damping bending in beams. J. Tlusty, K.S. Smith, W. Winfough [6] studied two techniques using end mills in high-speed milling. In the first method, the top speed and power of the spindle are accepted as fixed, and the structural dynamics are manipulated by adjusting the tool length so as to take the advantage of stability lobe effects. Proportional Derivative fuzzy logic controller is designed and implemented by E. Soliman, F. Ismail [7] to suppress chatter in peripheral milling. E.G. Kubica, F. Ismail [8] proposed the maximum quantity of material that can be removed by the milling operation which is often limited by the stability of the cutting process, and not by the power available on the machine.

Delio T., Tlusty J., Smith S. [9] have described a control strategy for chatter suppression by adjusting the spindle speed to operate in high stability lobe. Weck, M., Altintas, Y. Beer, C [10] attempted to assess the merits of using the spindle speed modulation and for that matter any other technique for chatter suppression, one needs to detect the onset chatter reliably. M. Liang, T. Yeap, A. Hermansyah [11] reported a fuzzy logic approach for chatter suppression in end milling processes. Tlusty and Smith [12] suggested the use of stability lobes to select chatter free spindle speeds. Englehardt, R., Lin, S. C.,

Devor, R. E., and Kapoor, S. G. [13] have demonstrated the technique of spindle speed modulation to be very effective in suppressing chatter in milling at regular cutting speeds. Ralston, P.A. & Ward, T.L. [14] proposed the use of spindle speed modulation by adjusting the parameters on-line via feedback control. It was found that the fuzzy logic control approach was well suited for the current investigation. J.Y. Zhu, A.A. Shumsheruddin and J.G. Bollinger [15] developed a fuzzy logic control to control the surface finish by adjusting the feed rate in plunge grinding. K. Nagaya, J. Kobayasi, K. Imai [16] gave a method of micro-vibration control of milling machine heads by use of vibration absorber. An auto-tuning vibration absorber is presented in which the absorber creates anti-resonance state. A method of optimal auto-tuning control is presented in which both principal and higher modal vibrations are suppressed.

J.C. Ziegert, C. Stanislaus, T. Schmitz, R. Sterling [17] found that the limiting chatter-free depth of cut in milling is dependent on dynamic stiffness of the tool or spindle system. A method for increasing the dynamic stiffness by providing additional damping is demonstrated. N.H. Kim, K.K. Choi, J.S. Chen, Y.H. Park [18] proposed a continuum-based shape design sensitivity formulation for a frictional contact problem with a rigid body using mesh less method.

T. Schmitz, J.C. Ziegert, C. Stanislaus [19] Charles Stanislaus predicted that the stable cutting regions are a critical requirement for high-speed milling operations. Sridhar, R., Hohn, R. E., and Long, G. W. [20] presented the first detailed mathematical model with time varying cutting force coefficients. E. Budak, Y. Altintas [21] derived the finite order characteristic equation for the stability analysis in milling. M.Alauddin, M.A.EL Baradie, M.S.J.Hashmi [22] has revealed that when the cutting speed is increased, productivity can be maximized, and surface quality can be improved. According to M. Hasegawa, A. Seireg, R.A. Lindberg [23] surface finish can be characterized by various parameters such as average roughness (Ra), smoothing depth (Rp), root mean square (Rq), and maximum peak-to-valley height (R t).

EI-Baradie [24] and B.P. Bandyopadhyay and E.H. Teo [25] have shown that by increasing cutting speed, the productivity can be maximized, and the surface quality can be improved simultaneously. According to Gorlenko [26] and Thomas [27], surface finish can be characterized by various parameters. Krishna Mohana Rao, P.Ravi Kumar [28] experimentally analyzed the influence of cutting parameters on the roughness of the surface produced.

In the present paper an attempt is made to study the roughness of the surface produced on the aluminium work piece with end milling cutters with three different dampers inserted.

III. EXPERIMENTAL SETUP

A. Cutting Tools

To experimentally test the performance of the damper insert, two end mills are designed. The tool is made of high-speed steel with 19.05mm outer diameter, 125mm length, and

has 3 cutting flutes. The tools had an internal blind hole of 9.5mm diameter with a length of 105 mm. Testing was performed on the solid and hollow end mills, and later the dampers were inserted into the hollow tool, and the tests were repeated. The damper insert had fingers and was constructed from a 9.5 mm diameter tungsten carbide blank.

As shown in fig. 1 to 3 tools with one, two, three dampers is chosen, so that different interactions between independent variables could be effectively investigated. The diameter of the damper insert was such that the solid portion provided a light press fit into the tool body.



Fig. 1 Hollow milling cutter with one and two dampers



Fig. 2 Hollow milling cutter with one and two dampers



Fig. 3 Hollow milling cutters with three dampers

B. Machining Conditions and Experimental Design

The independent variables in the study are cutting speed, feed rate, depth of cut and the number of dampers or fingers. The last variable is introduced in to the experiment since the vibrations generated by varying the number of dampers could affect the resulting surface finish since the natural frequencies are expected to be modified. The dependent variable is the resulting first cut surface finish. An $L_9 (3^4)$ Taguchi orthogonal array was used as the experimental design .The levels of parameters investigated are given in Table I.

TABLE I
 LEVELS OF MACHINING PARAMETERS

Levels(3)/ Factors(4)	Level 1	Level 2	Level 3
Speed (rpm)	385	685	960
Type of tool	SOLID	HOLLOW	ONE DAMPER
Feed (mm/rev)	29	29	29
Depth of cut (mm)	0.5	0.5	0.5

C. Work piece Materials and Cutting

Aluminium of 50mm X 15mm was used as a work piece material. The milling experiments were carried out on a vertical milling machine equipped with a maximum spindle speed of 985 rpm. The milling process was interrupted after every experiment. This basic design makes use of up to four control factors, with three levels each.

IV. UNITS

A. Regression Analysis

The surface roughness values R_a is measured on surf test SJ 301 and values are given in Table II. Mathematical models for cutting parameters such as cutting speed, feed rate, depth of cut and cutting tools were obtained from regression analysis using MINITAB 14 statistical software to predict Surface Roughness. The following notation is used in mathematical models:

N: cutting speed, R_a : Surface Roughness.

For Solid End Milling Cutter

$$R_a = 2.93 - 0.00178 N.$$

$$R^2 = 89.2 \% \quad R^2 (\text{adj}) = 78.5\%$$

For Hollow End Milling Cutter

$$R_a = 2.84 - 0.00176 N.$$

$$R^2 = 98.1 \% \quad R^2 (\text{adj}) = 96.2 \%$$

For Hollow End Milling Cutter with one damper

$$R_a = 2.42 - 0.00148 N.$$

$$R^2 = 86.7\% \quad R^2 (\text{adj}) = 73.5\%$$

Where N is speed in RPM.

This data has to be changed.

In multiple linear regression analysis, R^2 is value of the correlation coefficient and should be between 0.8 and 1. In

this study, results obtained from surface roughness were in good agreement with regression models ($R^2 > 0.80$) i.e surface roughness measurements matched very well with the experimental data.

B. Analysis of S/N

There are several S/N ratios available depending on type of characteristic: lower is better (LB), nominal is best (NB), or higher is better (HB) .Smaller is better S/N ratio was used in this study because less surface roughness was desirable. Quality characteristic of the smaller is better is calculated in the following equation.

$$\eta = -10 \log \left[\frac{1}{n} (\sum_{i=1}^n y_i^2) \right] \quad (1)$$

where n is number of measurements in a trial/row and y_i is the i th measured value in a run/row. The S/N ratio values calculated by taking equation (1) into consideration and are listed in Table II.

Figures 4 and 5 show the variation of surface roughness with speed and type of tool. Figure 6 showed the main effects plot for S/N ratios. The level of a factor with the highest S/N ratio was the optimum level for responses measured. The results of ANOVA are summarised in Table III. Table IV gives the optimised conditions of machining.

TABLE II
 EXPERIMENTAL RESULTS FOR DIFFERENT DAMPERS

run	1	2	3	4	R_a Sample 1	R_a Sample 2	S/N Ratio (η)
1	1	1	1	1	1.76	1.76	-4.911
2	1	2	2	2	2.05	2.06	-6.278
3	1	3	3	3	1.05	1.05	-0.424
4	2	1	3	1	1.6	1.6	-4.083
5	2	2	3	1	1.2	1.2	-1.584
6	2	3	1	2	0.99	0.99	0.087
7	3	1	3	2	0.9	0.9	0.915
8	3	2	1	3	0.87	0.87	1.209
9	3	3	2	1	0.74	0.74	2.615

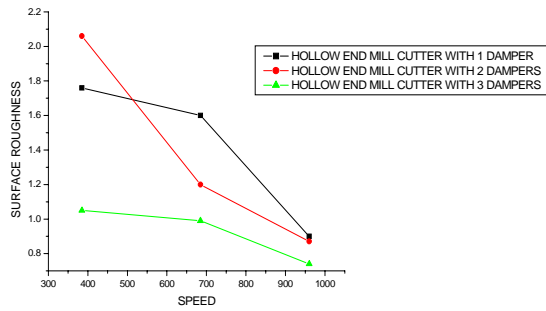


Fig. 4 Variation of Surface roughness with speed

TABLE III
 SUMMARY OF ANOVA RESULTS

COL#/Factor	DOF	SUM OF SQUARES (S)	VARIANCE(V)	Pure sum(S')	Percent P(%)
SPEED	2	45.582	22.791	45.582	60.943
TYPE OF TOOL	2	21.004	10.502	21.004	28.082
FEED	2	7.519	3.759	7.519	10.052
DOC	2	0.689	0.344	0.689	0.921

TABLE IV
 OPTIMUM CONDITIONS AND PERFORMANCE

COL#/Factor	DOF	SUM OF SQUARES (S)	VARIANCE(V)	Pure sum(S')	Percent P(%)
SPEED	2	45.582	22.791	45.582	60.943
TYPE OF TOOL	2	21.004	10.502	21.004	28.082
FEED	2	7.519	3.759	7.519	10.052
DOC	2	0.689	0.344	0.689	0.921

Predicted Optimal S/N value from ANOVA = 5.024

Predicted Surface roughness value Corresponding to S/N = 5.024 is 0.56

Experimental surface roughness value = 0.7

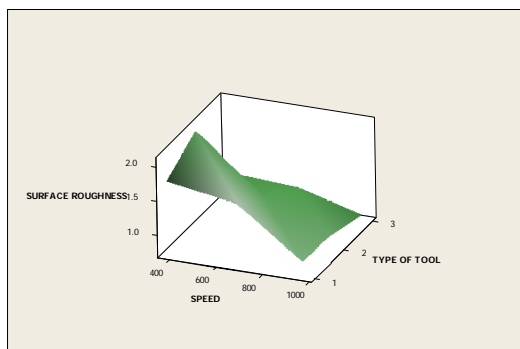


Fig.5 3-D graph showing variation of surface roughness with speed and type of tool

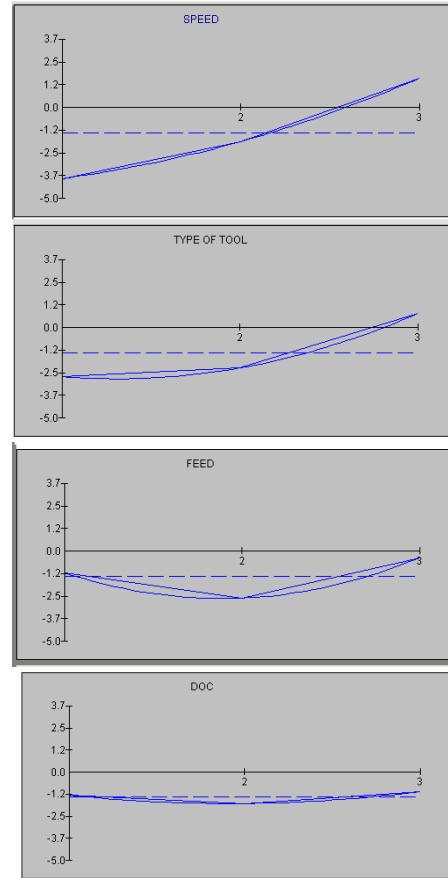


Fig. 6 S/N ratios for surface roughness

V. CONCLUSION

The experimental results indicate that in this study the effects of spindle speed and type of tool on surface were larger than depth of cut and feed for milling operation.

The surface finish achievement of the confirmation runs under the optimal cutting parameters indicated that of the parameter settings used in this study, those identified as optimal through Taguchi parameter design were able to produce the best surface roughness in this milling operation.

The optimal levels for the controllable factors were spindle speed 960 rpm, feed rate 29 mm/rev, depth of cut 0.5 mm for hollow milling cutter with 2 dampers.

Compared with the experiment results, the optimal surface roughness of the 9 confirmation samples 0.7 μm . which was very close to the smallest value optimal value of surface roughness 0.56 μm by ANOVA.

REFERENCES

- [1] Cobb, W. T., "Design of Dampers for Boring Bars and Spindle Extensions," *Master's Thesis*, Mechanical Engineering, University of Florida, Gainesville, FL, 1989.
- [2] Keyvanmanesh, Amir, "Evaluation of Chatter Detection and Control System," *Master's Thesis*, Mechanical Engineering, University of Florida, Gainesville, FL, 1990.
- [3] Smith, Kevin Scott, "Chatter, Forced Vibrations, And Accuracy In High-Speed Milling," *Master's Thesis*, Mechanical Engineering, University of Florida, Gainesville, 1985.

- [4] Cook, R. A., Bloomquist, D., Richard, D. S., and Kalajian, M.A., "Damping Of Cantilevered Traffic Signal Structures," *Journal of Structural Engineering*, 2001, Vol. 25, pp 1476-1483.
- [5] Slocum, H. Alexander, "Precision Machine Design", *Society Of Manufacturing Engineers*, Dearborn, MI, 1992.
- [6] J. Tlusty, K.S. Smith, W. Winfough, "Techniques for the use of long slender end mills in high-speed machining", *Annals of the CIRP* 25 (1) (1996) 393-396
- [7] E. Soliman, F. Ismail, "Chatter suppression by adaptive speed modulation", *International Journal of Machine Tools & Manufacture* 37 (3) (1997) 355-369.
- [8] E.G. Kubica, F. Ismail, "Active suppression of chatter in peripheral milling", *International Journal of Advanced Manufacturing Technology* 12 (4) (1996) 236-245.
- [9] Delio T., Tlusty J., Smith S. "Use of audio signals for chatter detection and control". *Journal of Engineering for Industry*, 1992, 114: 146-157
- [10] Weck, M., Altintas, Y., Beer, C., "CAD assisted chatter free NC tool path generation in milling", *International journal of machine tools and manufacture*, 1994, 34, 879-891.
- [11] M. Liang, T. Yeap, A. Hermansyah, "A fuzzy system for chatter suppression in end milling", *Proceedings of the Institution of Mechanical Engineers Part B: Journal of Engineering Manufacture* (2004) 403-417.
- [12] S. Smith and J. Tlusty, "Stabilizing chatter by automatic spindle speed regulation", *Annals of CIRP*, 41(1):433-436, 1992.
- [13] Englehardt, R., Lin, S. C., Devor, R. E., and Kapoor, S. G. "A Verification of the Use of Variable Spindle Speed for Vibration Reduction in Face Milling", *Proc. of the 17th NAMRI/SME Conference*, 1989, Vol. 17, pp. 115-122.
- [14] Ralston, P.A. & Ward, T.L. "Adaptive Control of Machine Tools: the past and projected role of Numerical Control Computers". *Computers and Industrial Engineering*, Vol. 14, No. 2, 1988, pp. 85-94.
- [15] J.Y. Zhu, A.A. Shumsheruddin and J.G. Bollinger, "Control of Machine Tools Using the Fuzzy Control Technique", *CIRP Annals - Manufacturing Technology*, Volume 31, Issue 1, 1982, Pages 347-352
- [16] K. Nagaya, J. Kobayasi, K. Imai, "Vibration control of milling machine by using auto-tuning magnetic damper and auto-tuning vibration absorber", *International Journal of Applied Electromagnetics and Mechanics* 16 (1-2) (2002) 111-123.
- [17] J.C. Ziegert, C. Stanislaus, T. Schmitz, R. Sterling, "Enhanced Damping in Long Slender End" *Transactions of the North American Manufacturing Research Institute of SME*, vol. 32 2004 pp. 1-8.
- [18] N.H. Kim, K.K. Choi, J.S. Chen, Y.H. Park, "Meshless shape design sensitivity analysis and optimization for contact problem with friction", *Computational Mechanics* 25 (2/3) (2000) 157-168.
- [19] T. Schmitz, J.C. Ziegert, C. Stanislaus, "A Method for Predicting Chatter Stability for Systems with Speed-Dependent Spindle Dynamics" SME Technical Paper TP04PUB182, *Transactions of the 2004 North American Manufacturing Research Institute of SME*, vol.32 2004 pp. 17-24.
- [20] Sridhar, R., Hohn, R. E., and Long, G. W., 1968, "A General Formulation of the Milling Process Equation—Contribution to Machine Tool Chatter Research—5," *ASME J. Eng. Ind.*, pp. 317-324.
- [21] E. Budak, Y. Altintas, "Analytical prediction of chatter stability in milling-part I: general formulation; part II: application to common milling systems", *Transactions of the ASME, Journal of Dynamic Systems, Measurement, and Control* 120 (1998) 22-36
- [22] M. Alauddin, M.A. El Baradie, M.S.J. Hashmi, "Prediction of tool life in end milling by response surface methodology", Vol 71, 1997, 456-465.
- [23] M. Hasegawa, A. Seireg, R.A. Lindberg, "Surface roughness model for turning", *Tribology International*, December Vol, 1976, 285-289.
- [24] M.A. El-Baradie, "Surface roughness model for turning grey cast iron 1154 BHN", *Proc. IMechE*, 207, 1993, pp 43-54.
- [25] B.P. Bandyopadhyay and E.H. Teo, "Application of factorial design of experiment in high speed turning", *Proc. Man-Int. Part 4, Advances in Materials & Automation*, Atlanta, GA, USA, ASME, NY, 1990, 3-8.
- [26] O.A. Gorlenko, "Assessment of surface roughness parameters and their interdependence", *Precis. Eng.*, 3 (1981) 2.
- [27] T.R. Thomas, "Characterisation of surface roughness", *Precis. Eng.*, Vol. 3, 1981.
- [28] Krishna Mohana Rao, P. Ravi Kumar, "Surface roughness analysis in milling" *World Academy of Science, Engineering and Technology*, Issue 59, November 2011



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