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

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***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), smoothening 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 301and 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 % R^2 (adj) = 78.5%

For Hollow End Milling Cutter

R_a= 2.84-0.00176 N.

R^2= 98.1 % R^2 (adj) = 96.2 %

For Hollow End Milling Cutter with one damper

R_a= 2.42-0.00148 N.

R^2= 86.7% R^2 (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.

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

where *n* is number of measurements in a trial/row and *yi* 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

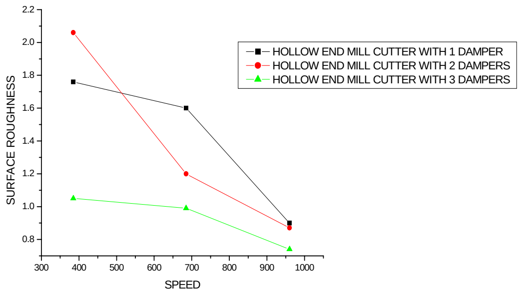

Fig. 4 Variation of Surface roughness with speed

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 Optimial 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

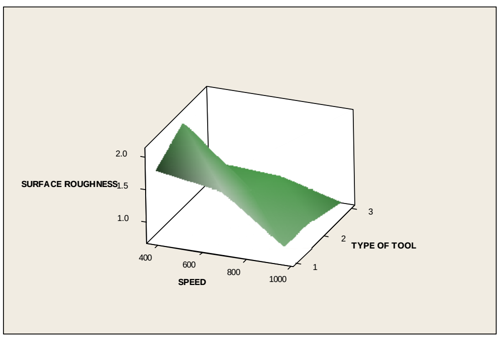

Fig.5 3-D graph showing variation of surface roughness with speed and type of tool

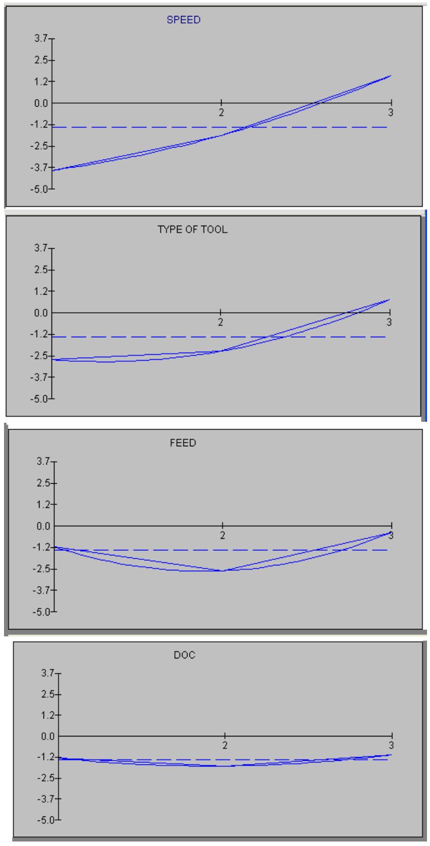

Fig. 6 S/N ratios for surface roughness

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.

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