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FLANK WEAR MONITORING DURING END MILLING FOR AISI 1025 STEEL

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Abstract: From experimental tests in end milling on AISI-1025 steel, it has been found that the flank wear is the prominent wear under normal cutting conditions. Hence, the standard criterion that determines significant flank wear of an end mill is used to set the corresponding threshold values for the cutting force signal in the tool condition monitoring system. The primary objective of this research is to monitor tool wear during end milling of AISI-1025 steel, using tool maker's microscope. The results of the tool wear on the end mill cutter; with and without tool condition monitoring system have been analyzed. The results provide rich information for tool wear in end milling operation, hence is considered for tool condition monitoring system and a suitable criterion for AISI 1025 steel is decided.

Keywords: CNC Milling, Flank Wear, Taguchi method, Tool wear criteria.

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INTRODUCTION

In present time the technology of CNC vertical milling machine has been improved significantly to meet the advance requirements in various manufacturing fields, especially in the precision metal cutting industry. This experiment gives the effect of different machining parameters (spindle speed, feed, and depth of cut) and one geometric parameter rake angle of end mill tool on tool life. The demand for high quality and fully automated production focus attention on the surface condition of the product, surface finish of the machined surface is most important due to its effect on product appearance, function, and reliability. For these reasons it is important to maintain consistent tolerances and surface finish. Among several CNC industrial machining processes, milling is a fundamental machining operation. End milling is the most common metal removal operation encountered. It is widely used in a variety of manufacturing industries. The quality of the surface plays a very important role in the performance of milling as a good-quality milled surface significantly improves fatigue strength, corrosion resistance, or creep life. The surface generated during milling is affected by different factors such as vibration, spindle run–out, temperature, tool geometry, feed, cross-feed, tool path and other parameters. During finish milling, the depth of cut is small. Technological parameter range plays a very important role on surface roughness. In end milling, use of high cutting speed, low feed rate and low depth of cut are recommended to obtained better surface finish for the specific test range in a specified material. Cutting feed is the most dominated factor for surface finish. The most important interactions, that effect surface roughness of machined surfaces, are between the cutting feed and depth of cut, and between cutting feed and spindle speed. Surface Roughness is affected negatively if the applied force is increased. With the more precise demands of modern engineering products, the control of surface texture together with dimensional accuracy has become more important. This experimental investigation outlines the Taguchi optimization methodology, which is applied trice to optimize tool life in end milling operation. The experiment is conducted on a AISI 1025 MS plate the processing of the job is done by High Speed Steel (HSS) end-mill tool of 14 mm diameter under rough milling conditions. The machining parameters evaluated are spindle speed, feed rate, depth of cut and only one geometric parameter is taken into consideration tool rake angle. The experiments are conducted by using Taguchi L9 orthogonal array as suggested by Taguchi and this method is applied.

1. Optimization using Taguchi's Techniques

Optimization, in its broadest sense, can be applied to solve any engineering problem. Some typical applications from manufacturing area indicate the wide scope of the subject [1],

1. Selection of machining conditions in metal-cutting processes for minimum production cost

2. Design of material handling equipment, such as conveyors, trucks, and cranes, for minimum cost

3. Optimal production planning, controlling, and scheduling

4. Optimum design of chemical processing equipment and plants

5. Planning of maintenance and replacement of equipment to reduce operating costs

6. Allocation of resources or services among several activities to maximize the benefit

7. Controlling the waiting and idle times and queueing in production lines to reduce the costs

8. Planning the best strategy to obtain maximum profit in the presence of a competitor.

Genichi Taguchi is a Japanese engineer who has been active in the improvement of Japan's industrial products and processes since the late 1940s. He has developed both the philosophy and methodology for process or product quality improvement that depends heavily on statistical concepts and tools, especially statistically designed experiments. Many Japanese firms have achieved great success by applying his methods. Barker [2] reported that since 1983, after Taguchi's association with the top companies and institutes in USA (AT & T Bell Laboratories, Xerox, Lawrence Institute of Technology (LIT), Ford Motor Company etc.), his methods have been called a radical approach to quality, experimental design and engineering.

Eriksson L. et. al. [3] pointed out that the key element for achieving high quality and low cost is parameter design & optimization. Through parameter design, levels of product and process factors are determined, such that the product's functional characteristics are optimized and the effect of noise factors is minimized.

Singh H. et. al. [4] applied Taguchi's technique for optimizing surface finish, tool wear, cutting force and power consumed in turning operations for machining En24 steel with titanium carbide-coated tungsten carbide inserts. The success of many applications has demonstrated the power of Taguchi's overall approach. It is also worth mentioning that many of the specific statistical techniques he has proposed for implementing robust parameter design have generated a great deal of controversy. However, most commentators agree that Taguchi's loss function concept represents a solid contribution. Furthermore, there is general agreement that off-line experiments during the product or process design stage are of great value and the methodology is based on solid engineering principles. Reducing quality loss by designing the products and processes to be insensitive to variations in noise variables is a novel concept to statisticians and quality engineers.

Gupta et. al. [5] investigated the application of Taguchi method with logical fuzzy reasoning for multiple output optimization of high speed CNC turning of AISI P-20 tool steel using TiN coated tungsten carbide coatings. The machining parameters (cutting speed, feed rate, depth of cut, nose radius and cutting environment) are optimized with considerations of the multiple performance measures (surface roughness, tool life, cutting force and power consumption). Taguchi's concepts of orthogonal arrays, signal to noise (S/N) ratio, ANOVA have been fuzzified to optimize the high speed CNC turning process parameters through a single comprehensive output measure (COM).

They investigated the following results related to combination of parameters multi-response problem and response and multi-response optimization analysis

(1) The factor/level combination S3F2D2N3E3 for surface roughness, S1F1D1N2E3 for the tool life, S1F1D1N2E3 for power consumption and S2F1D1N2E3 for cutting force are the recommended optimum parameters, for high speed CNC turning when all four responses are considered independently.

(2) In the multi-response problem, all the four responses tool life, power consumption, cutting force and surface roughness were simultaneously considered, and S2F1D1N2E3 was the recommended optimum condition as per the hybrid Taguchi-fuzzy approach.

(3) It can be concluded that middle level of cutting speed (160 m/min) and nose radius (0.8 mm) and lower level of feed (0.1 mm/rev) and depth of cut (0.2 mm) yield the optimal result. Cryogenic environment is the most favorable condition out of three cutting environments.

(4) Both single response and multi-response optimization analysis proved that cryogenic machining environment E3 is favorable in increasing tool life and reducing surface roughness, cutting force and power consumption compared to wet (conventional coolant ILO cut 154 Indian Oil recommended for CNC machine) and dry machining.

They also presented the use of fuzzy logics to the Taguchi method in optimization of the high speed CNC turning with multiple performance characteristics. A fuzzy reasoning of the multiple performance characteristics has been performed by the fuzzy logic unit. As a result, four performance characteristics namely surface roughness, tool life, cutting force and power consumption can be improved. It can be concluded that the optimization methodology developed in this study is useful in improving multiple performance characteristics in high speed CNC turning.

Cicek A. & Kivak T. [6] investigated the application of Taguchi method for Surface roughness and roundness error in drilling of AISI 316 stainless steel. In his study, the effects of deep drilling parameters on surface roughness and roundness error were investigated in drilling of AISI 316 austenitic stainless steel with M35 HSS twist drills. In addition, optimal control factors for the whole quality were determined by using Taguchi technique. Two cutting tools, cutting speeds and feed rates were considered as control factors, and L8 (23) orthogonal array was determined for experimental trials. Multiple regression analysis was employed to derive the predictive equations of the surface roughness and roundness error achieved via experimental design. Minimum surface roughness and roundness error were obtained with treated drills at 14 m/min cutting speed and 0.08 mm/rev feed rate. Confirmation experiments showed that Taguchi method precisely optimized the drilling parameters in drilling of stainless steel.

Moshat S. & Datta S. [7] investigated the Optimization of CNC end milling process parameters using PCA-based Taguchi method. To optimize aforesaid quality attributes in a manner that these multi-criterions could be fulfilled simultaneously up to the expected level. This invites a multi-objective optimization problem which has been solved by PCA based Taguchi method. To meet the basic assumption of Taguchi method; in his work, individual response correlations have been eliminated first by means of Principal Component Analysis (PCA). Correlated responses have been transformed into uncorrelated or independent quality indices called principal components. Finally Taguchi method has been adapted to solve this optimization problem.

2. Materials and Methods

Experiment is divided into three main phases. These three phases are the planning phase (design of experiments, experimental data consideration and machine, machine tool and work material used) the conducting phase (experimentation), the analysis phase. Following are the planning phase input parameter and there levels.

3.1 Design of Experiments

Experiments are designed with the help of using Taguchi L9 orthogonal array. The software used for DOE (Design of experiment) is Minitab15.

Table 2.1.1: Process Parameters and their levels

Factors	Parameters	Level 1	Level 2	Level 3
A	Spindle Speed in RPM	600	800	1000
B	Feed in mm/min	50	100	150
C	Axial depth of Cut in mm	0.1	0.2	0.3
D	Rake Angle in Degree	10	15	20

As per Taguchi experimental design philosophy (table 2.1.1) a set of three levels assigned to each parameter has two degrees of freedom (DOF). Here we have four parameters with three levels. This gives a total of 8 DOF for four parameters selected in this work. The nearest three level orthogonal array available satisfying the criterion of selecting the OA is L9 (table 2.1.2) having 8 DOF [8].

Table 2.1.2: Taguchi's L9 standard orthogonal array

Expt. No.	1 V	2 Fr	3 Dp	4 γ	Response (Raw Data)				S/N Ratio
1	1	1	1	1	1	$Y1_1$	$Y1_2$	$Y1_3$	$Y1_4$
2	2	1	2	2	2	$Y2_1$	$Y2_2$	$Y2_3$	$Y2_4$
3	3	1	3	3	3	$Y3_1$	$Y3_2$	$Y3_3$	$Y3_4$
4	4	2	1	2	3	$Y4_1$	$Y4_2$	$Y4_3$	$Y4_4$
5	5	2	2	3	1	$Y5_1$	$Y5_2$	$Y5_3$	$Y5_4$
6	6	2	3	1	2	$Y6_1$	$Y6_2$	$Y6_3$	$Y6_4$
7	7	3	1	3	2	$Y7_1$	$Y7_2$	$Y7_3$	$Y7_4$

8	8	3	2	1	3	$Y8_1$	$Y8_2$	$Y8_3$	$Y8_4$
9	9	3	3	2	1	$Y9_1$	$Y9_2$	$Y9_3$	$Y9_4$

R1, R2, R3, R4 represent response values for three repetitions of each trial. The 1's, 2's, 3's and 4's represent levels 1, 2, 3 and 4 of the variables, which appear at the top of the column. Yij are the measured values of the quality characteristic (response). The responses of the experimentation was measured in four terms namely flank wear, face wear, surface roughness and tool life.

3.2 Experimentation

Figure 3.1 shows the experimental setup used in this work

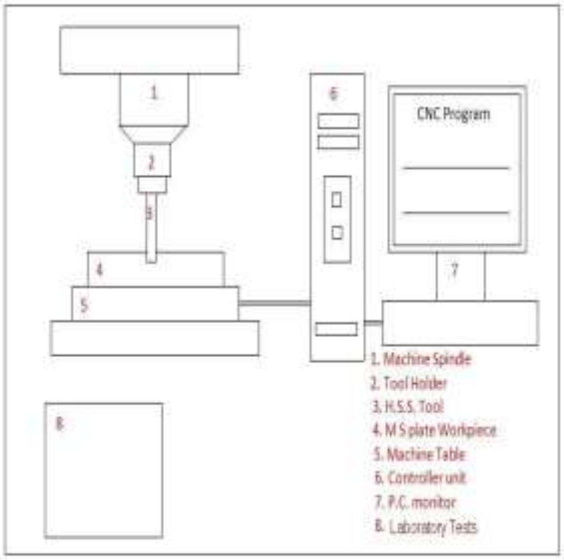

Figure 3.1 Experimental setup

3.3 Analysis of data

The analysis of data is discussed in more details in the results and discussion section.

4. Observation Recorded:

For recording the observations during experimentation, data consideration is most important. As per Taguchi philosophy the L9 standard orthogonal array was selected to investigate the effect of process parameters on the flank wear, face wear, tool life, surface roughness and material removal rate.

It is very complex to measure and monitor tool uniform flank wear (section 2.4.1) during the experimentation. When the tool was in uniform wear stage, this time is important for the tool life estimation. At a particular time the uniform wear must be taken into consideration. So before going to final experimentation the preliminary experimentation was done to find out the time of flank wear for 14 mm H.S.S. end mill tool machined on AISI 1025 steel workpiece.

The preliminary observations on the basis of preliminary experimentation are taken to judge the exact experimentation time and to find the other aspects where the maximum tool wear occurs. The flank wear is checked after every 20 minute interval of time during machining. As per the flank wear criteria discuss in 2.4.1, the tool life is estimated in this time zone. According to the flank wear criteria for end milling tool, the desired flank wear 0.5 mm was acceptable. The table 4.1 shows parameters decided for the experimentation and there levels and the units of these values are converted as per the input system of CNC program (Appendix III). Table 4.2 shows the observation recorded for flank wear.

Table 4.1 Preliminary parameter level taken for the experimentation

Parameters	Level 1	Level 2	Level 3
Spindle Speed in rpm	600	800	1000
Feed in mm/min	50	100	150
Axial depth of cut in mm	0.1	0.2	0.3
Rake Angle in Degree	10	15	20

5. Results and discussion:

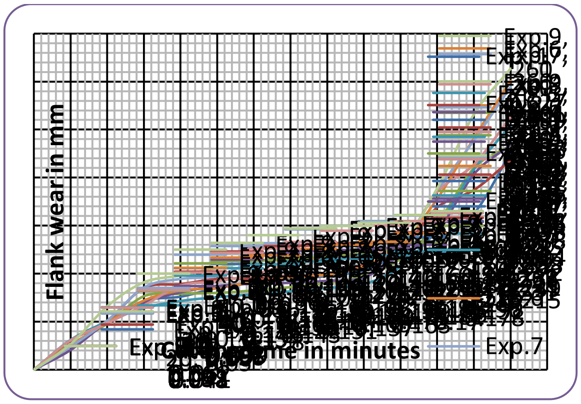

Figure 4.1 Flank wear measurement in 20 minutes time interval

From figure 4.1 it will be observed that the rapid initial flank wear is pointed out at time interval of 0 to 60 minutes, whereas it is uniform during time interval of 70 minute to 180 minute and a rapid catastrophic wear is observed after 180 minutes. The wear is uniform in between 70 to 180 minutes. By observing the values of flank wear in table 4.2 at 180 minute the maximum flank wear was pointed out to be 0.25 mm. So the desired flank wear criteria is 0.25 mm is considered and acceptable. For all experiments the flank wear is measured after 180 minutes.

The experimental results show the variation in flank wear with respect to time. The rapid initial flank wear is pointed out at time interval of 0 to 60 minutes, whereas it is uniform during time interval of 70 minute to 180 minute and a rapid catastrophic wear is observed after 180 minutes. The wear is uniform in between 70 to 180 minutes. This gives the information about setting exact time for experimentation on HSS end mill tool worked on AISI 1025 MS plate. The experimentation also shows the variation in flank wear with respect to cutting speed.

6. Conclusion

The cutting speed, feed rate and depth of cut are the most important machining parameters whereas rake angle is a very important geometric parameter in order to minimize the tool wear to the greater extent. As per the handbook recommendation the parameters which cause the tool wear is directly proportional to tool life are studied and optimized for better results.

Design of experiment methodology proposed by Taguchi and the results of the experiments are analyzed from this, it is conclude that

- Established the best optimum combination of geometric and machining parameters.
- Estimate the response under the optimum condition.

- The optimum condition was identified by studying the effects of each of the parameters on the response variables. It indicates the general trends of influence of each parameter. The knowledge of contribution of individual parameters is a key in deciding the nature of control to be established.

Finally it is concluded that the flank wear criteria as per handbook and tool catalog book. In the literature for a particular work material operating on a particular operation, a flank wear criterion is not cleared. So there is a possibility to find out the exact flank wear criteria for a particular work material.

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