Journal of Advances in Science and Technology
Vol. 13, Issue No. 01, (Special Issue) March-2017, ISSN 2230-9659

Process Optimization for Milling Operation - A Review

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Abstract – Milling is the machining process which improves dimensional accuracy and surface quality. In this present review work input parameters are cutting speed, feed rate, depth of cut, coolant flow, tool size, width of cut, nose radius, tool diameter, and radial rake angle. Techniques used to optimize process parameters are Taguchi optimization technique with orthogonal array used for design of experiment, response surface methodology and artificial neural network. Response surface methodology (RSM) approach is the procedure for determining the relationship between various process parameters with the various machining criteria and exploring the effect of these process parameters on the coupled responses. An Artificial Neural Network (ANN) is an information processing paradigm that is inspired by the way biological nervous systems, such as the brain processes information. This study provides a review on optimization of machine parameters by different techniques.

Keywords: Milling Process, Surface roughness, Material removal rate, Optimization, Taguchi Methodology, Response Surface Methodology, Artificial neural network.

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INTRODUCTION

Milling is the process of machining flat, curved, or irregular surface by feeding the work piece against a rotating cutter containing a number of cutting edges.

Milling is the fundamental machining operation among several industrial CNC (Computer Numerical Control) machining processes. For metal removal operation end milling and face milling is mostly used. The end milling operation is associated with surface roughness and material removal rate because of some requirements such as machining efficiency, high quality surfaces, dimensional accuracy, and the process reliability [1]. End milling and face milling are broadly used in variety of manufacturing industries including automotive sectors, aerospace, where quality is vital factor in the production of slots, pockets, and precision moulds and dies [2]. CNC machine tools require less operator inputs, provide greater improvement in productivity and increase the quality of the machined part.

CNC the abbreviation for Computer Numeric Control is used for that type of systems which controls the functions of a machine tool using coded instructions processed by a computer. The application of CNC to a manual machine allows its operation to become fully automated. Combining this with the use of a part program enhances the ability of the machine to perform repeat tasks with high degrees of accuracy. Preparatory functions, called G codes, are used to locate the geometry of tool movements and operating state of the machine controller; functions such as linear cutting movements, drilling operations and specifying the units of measurement [3]. They are normally programmed at the start of a block. Miscellaneous functions, called M codes, are used by the CNC to command on/off signals to the machine functions. The functions allocated to lower M code numbers are constant in most CNC controls, although the higher M code number functions can vary from one make of controller to the next. For success of the manufacturing organization finding the optimum balance between higher production rate and improve the quality is most important.

Productivity can be interpreted in terms of material removal rate in the machining processes and quality represents product characteristics as desired by the customers which will give competitive edge over the competitors [4]. The Taguchi method is a powerful experimental design tool uses simple, effective and systematic approach for deriving of the optimal machining parameters in lower time. For the milling operation different cutting tools are used to remove extra material from work piece such as carbide end mill tool (coated/uncoated), HSS tool etc.

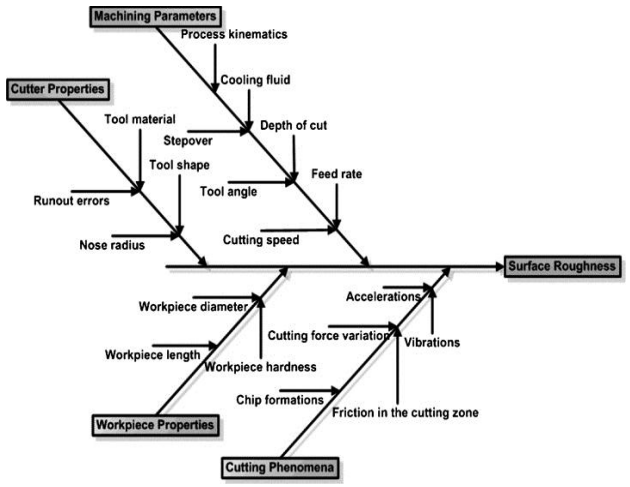

Fig.1 Fish bone diagram showing parameters that affect on surface roughness [1]

A. Slot Milling

Slot milling operation is a type of milling process in which for slot milling operation end milling cutter is used. In T-Slot milling operation T shape type end mill cutter is used. As shown in figure no. 2 the slot milling operation is done by feeding work piece against the tool with axial depth of cut. Also the work piece is cut into two parts by slotting operation using different types of cutter. Therefore slot milling operation is widely used in machining processes.

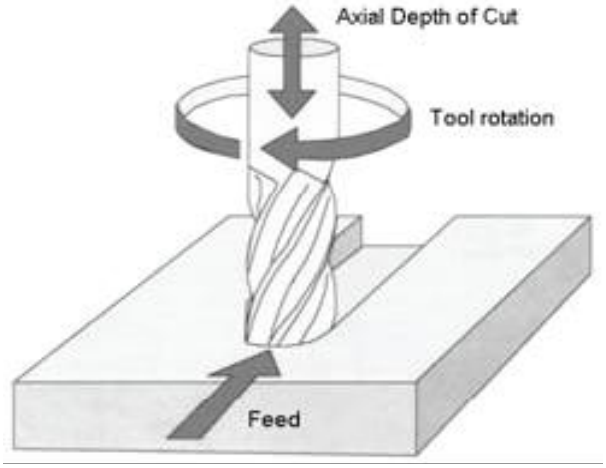

Fig.2 Slot milling operation [3]

So that understand the mechanism included in milling process, study effect of milling process parameters and optimize for enhancement of output variables.

LITERATURE REVIEW

The literature review focuses on study done on related journal papers and articles. The literature covers the Milling process related to input parameters and machining parameters on output response parameters using optimization techniques.

B. Singh et al. [1] did experimental work on Optimization of input process parameters in CNC Milling machine of EN24 steel. The experiment is conducted on VMC by using input parameters as cutting speed, feed rate and depth of cut with help of carbide end mill tool on EN24 steel material face milling operation was done. Taguchi method with L9 orthogonal array is used for optimizes process or output parameters such as surface roughness and material removal rate by using Minitab 15 software. It is found that for the experiment 27 work piece materials are taken with three cutting tools to analyse tool life. By analysis this experiment the feed rate has effect on the tool life and the contribution for feed rate, cutting speed and depth of cut was 57.17%, 29.85% and 0.003%, respectively for material removal rate.

M. Y. Kumar et al. [2] did study on Cutting parameters optimization in milling of P-20 tool steel and EN31B. The experiment is conducted on VMC by using input parameters as cutting speed, feed and depth of cut on P20 tool and EN31B as a work piece material. By using cemented carbide inserts face milling operation was done. Taguchi methodology with ANOVA and CADD software is used to optimise the output parameters such as Stress, strain and displacement torque.

M. T. Hayajneh et al. [3] did experimental work on a study of effects of machining parameters on the surface roughness in the end milling process. The experiment is conducted on VMC by using input parameters as speed, feed and depth of cut on Aluminium material. By using Carbide inserts the face milling operation was done. Regression analysis with ANOVA is used to study output parameters such as tool life, surface roughness, cutting forces and energy consumption. In this paper 84 specimen for cut in which 60 samples are used to built up regression model using training set and 24 samples are used to flexibility and validity of regression model using testing set.

A. A. Thakare et al. [4] did experimental work on optimization of milling parameters for minimizing surface roughness using taguchi`s approach. For the experimentation VMC was used with carbide end mill cutter to perform end milling operation on 1040 MS material. Taguchi methodology using Minitab15 software is used to optimize process parameters such as surface roughness using input parameters as cutting speed, feed, depth of cut and coolant flow. Pie charts are also used for analysis. By the analysis this paper optimal solution for minimizing the surface roughness value is spindle speed 2500 rpm, feed of 800 mm/min, depth of cut 0.8 mm and coolant flow 30 lit/min. Surface roughness was mainly controlled by coolant flow.

P. Kumar et al. [5] did the experimental work on optimization of process parameters for machining of mild steel EN18 by response surface methodology.

The experiment was conducted on VMC by using input parameters such as speed, feed and depth of cut. By using RSM with ANOVA analysis, output parameters as MRR and Ra are measured. The experiment was performed in constant coolant flow using face milling operation. Minitab software was used with objective to minimise Ra and maximise MRR of Mild steel EN18. The polynomial model is formulated and the interaction of parameters by using central composite design is evaluated.

R. Noorani et al. [6] did the experimental work on improving surface roughness of CNC milling machined aluminium samples due to process parameter variation. The experiment was done on VMC using input parameters such as spindle speed, feed rate, depth of cut and tool size on Aluminium alloy 6061 work piece material using carbide end mill. End milling operation was done on AL6061 to optimize the surface roughness. Classical / analytical / statically design of experiment (DOE) using Minitab software. DOE helps to improve the quality of design and processes by statistical analysis and minimise the effect of variability on process or product performance. From this paper two factors highly responsible for the Ra are feed rate and tool size.

S. Moshat et al. [7] did the experimental work on optimization of CNC end milling process parameters using PCA based Taguchi Method. The experiment was done on VMC by using input parameters as spindle speed, feed rate, and depth of cut. By using CVD coated carbide tool end milling operation was done on aluminium work piece. PCA based Taguchi method was used to optimize Ra and MRR by using Minitab software. The work has been found efficient for solving multi-attribute decision making problem, i.e. for multi-objective product as well as process optimization for continuous quality improvement.

A.V. Vishnu et al. [8] did experimental work on optimization of different process parameters of Aluminium alloy 6351 in CNC Milling using Taguchi method. The experiment was done on VMC by using input parameters such as spindle speed, feed, depth of cut, and coolant flow. By using uncoated carbide insert face milling operation was done on Aluminium alloy 6365. Taguchi robust design methodology is used to optimize surface roughness using Minitab 16 software. Analysis of variance suggests that coolant flow is the most significant factor for the surface roughness followed by feed rate, whereas, depth of cut and cutting speed appear to have very little effect over roughness value. An increment of feed rate and coolant Flow will result in better surface quality in terms of roughness.

A. Choubey et al. [9] did experimental work on optimization of process parameters of CNC Milling machine for Mild Steel using Taguchi design and S/N Analysis. The experiment was performed on VMC by using input parameters speed, feed, depth of cut and width of cut. By using HSS drilling tool, drilling finishing operation was done on Mild steel material. Taguchi methodology was used to optimize output parameters such as Ra and MRR using Minitab 16 software. This paper has discussed the feasibility of machining Mild Steel by CNC finishing machine with a HSS Tool. The signal to noise ratio has been used to determine the main effects significant factors and optimum machining condition to the performance of finishing operation in mild steel based on the results presented here in, we can conclude that, the spindle speed of finishing machine tool mainly affects the SR. The feed rate largely affects the MRR.

A. Joshi et al. [10] did the experimental work on experimental investigation of machining parameters of CNC Milling by Taguchi method. The experiment was performed on VMC by using input parameters such as speed, feed and depth of cut. The face operation was done by using HSS tool on Aluminium cast heat-treatable alloy. Taguchi methodology was used to optimize MRR using Minitab 15 software. It was found that conceptual S/N ratio and Pareto ANOVA approaches for data analysis draw similar conclusion and the depth of cut is the most dominant factor for material removal rate out of others two factors, i.e. spindle speed and feed rate.

Prof. V. M. Prajapati et al. [11] did experimental work on study and investigate effects of cutting parameters in CNC Milling process for aluminium alloy 8011h14 through Taguchi design method. The experiment was done on VMC by using input parameters such as spindle speed, feed and depth of cut was applied. The Taguchi methodology by using Minitab 15 to optimize Ra and MR. Carbide inserts was used to perform face milling. It was found that with the L3(9) orthogonal array, a total of 9 experimental runs, covering three main factors each at three levels and two noise factors each at two levels, indicated that the Taguchi parameter design was an efficient way of determining the optimal cutting parameters for surface finish. Feed rate is the most significant factor on MRR. The recommended parametric combination for optimum material removal rate is SS (1800/2000/2200) FR (1500) DOC (0.8). In case of surface roughness, spindle speed is most significant control factor and hence the optimum recommended parametric combination for optimum surface Roughness is SS (2000) FR (1500) DOC (0.6).

G. Guruvalah Naidu et al. [12] did the experimental work on Optimization of process parameters for surface roughness in milling of EN31 steel material using Taguchi robust design methodology. The experiment was performed on VMC by using input

parameters such as speed, feed, depth of cut and coolant flow. By using carbide insert face milling operation was done on EN 31 steel alloy material. The Taguchi methodology was used to optimize output parameter Ra by using Minitab 15. The S/N ratio of predicted value and verification test values are valid when compared with the optimum values. It is found that S/N ratio value of verification test is within the limits of the predicted value and the objective of the work is full filled.

N. Agrawal et al. [13] did experiment on Surface roughness modelling with machining parameters in CNC Milling. The experiment was performed on VMC by using input parameters such as speed, feed, and depth of cut. By using HSS tool grooving operation was done on aluminium material. Multiple regression model with t-test was used to optimize Ra. As the spindle speed increases for lower feed rates, the surface roughness decreases. For higher feed rates, the Ra changes considerably.

P. Maurya et al. [14] study was carried out for Implementation of Taguchi methodology to optimization of CNC End milling process parameters of Al 6351-T6. The experiment was performed on VMC by using input parameters such as tool feed, tool speed, depth of cut and tool diameter. By using carbide insert 3-tools face milling operation was done on AL6351-T6 material. Taguchi methodology with f-test was used to optimize output parameter Ra by using Minitab. In this study the analysis of confirmation experiment and the design of control parameter with their level & four parameters to find the optimal control parameter to minimize the surface roughness that the parameter is Tool feed.

S. Jeyakumar et al. [15] studied the optimization of machining parameters of AL6061 composite to minimize the surface roughness modelling using RSM and ANN. The experiment was performed on VMC, by using input parameters such as cutting speed, depth of cut, and nose radius. By using Tungsten carbide insert in milling operation was one on AL6061 material. RSM and ANN methodology was used to optimize Ra, using MATLAB software. The experimental measurements Ra value is adequate to construct the prediction model for Ra.

V. Pare et al. [16] studied optimization of cutting condition in end milling process with approach of particle swarm optimization. The experiment was performed on VMC by using input parameters such as cutting speed, feed rate, depth of cut, and radial rake angle. By using carbide end milling operation was done on annealed alpha beta titanium alloy material. PSO with genetic algorithm was used to optimize Ra by using MATLAB 10 software. The work can also be extended by taking output variables such as, material removal rate (MRR), production cost, etc., in addition to surface roughness.

From literature review, gaps are found for optimization of limited method of design of experiment (DOE) used for milling process with process variables like, depth of cut, feed, cutting speed for optimum output surface roughness and material removal rate.

SUMMARY OF LITERATURE REVIEW

From above literature review, it is observed that optimum surface finish and material removal rate obtained with process conditions. Taguchi method is used for experiment is best to optimize quality characteristics. ANOVA is best analysis of variance. For analysis of input parameters we can apply RSM method, ANN method of optimization. Also work piece material such as EN24 steel, P-20 tool steel, EN31B, Aluminium, 1040 MS, Mild steel EN18, AL6061, AL6351, Mild steel, AL8011h14, Aluminium cast heat treatable alloy, EN31csteel alloy, AL6351-T6, Ti-6Al-4v can be used as work piece material. Carbide end mill cutter, carbide inserts (coated/uncoated) and HSS tool is used for machining

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