A REVIEW ON EFFECT OF MACHINING PARAMETERS FOR END MILLING OPERATION

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Abstract: End milling is widely accepted material removal process. The process is used to manufacture component with complicated shapes and profiles. During machining the material is removed by end milling cutter. During the machining the material is removed by end milling cutter. In end milling operation surface finish and material removal rate are two major problems. The quality is measure in terms of surface roughness and productivity is measure in terms of material removal rate. Surface roughness defines the quality since it greatly influence the performance of the mechanical part as well as production. The material removal rate and the surface roughness is depend on various parameters like spindle speed, depth of cut, feed rate, vibrations, and tool geometry. But the most affecting parameters are spindle speed, depth of cut, and feed rate.

Keywords: End milling Machining Parameters, surface roughness, material removal rate.

I. INTRODUCTION

Milling is a fundamental machining process which is used to produce flat and complex shapes with the use of multi – point cutting tool which is called milling cutter and the cutting edges are called teeth. The axis of rotation of the cutting tool is perpendicular to the direction of feed and either parallel or perpendicular to the machined parts. The machine that performs this operation is called milling machine. The cutter is a cutting tool with sharp teeth in the milling machine. The cutter rotates at a high speed and because of the multiple cutting edges it removes metal in the form of chip at very fast rate.

End milling is the most common metal removal operation which is widely used in a variety of manufacturing industries due to its ability to produce the complex surfaces with reasonable accuracy and surface finish. The Computer Numerical Controlled milling machine is a unique adaptation in the field of manufacturing because of the flexibility and versatility. In end milling operation surface finish and material removal rate are two major problems. The quality is measure in terms of surface roughness and productivity is measure in terms of material removal rate. Surface roughness defines the quality since it greatly influence the performance of the mechanical part as well as production. It is a very complex problem in machining and depends on the machining methods as well as machining factors employed each time. The following factors have significant impact in cutting processes,

- Cutting conditions (cutting speed, feed rate, depth of cut)
- Process kinematics
- Cutting tool form and material
- Mechanical properties of processed material
- Vibrations in the machine tool system

Material removal rate (MRR) is another important problem that defines the productivity. It is an important control factor of machining operation and the control of machining rate is also critical for production planners. MRR is a measurement of productivity & it can be expressed by analytical derivation as the product of the width of cut, the feed velocity of milling cutter and depth of cut.MRR indicates processing time of the workpiece, which greatly influences production rate and production cost.

II. LITRETURE REVIEW

Thakre [1] studied the effects of various cutting parameters such as spindle speed, feed rate, and depth of cut and coolant flow on surface roughness using L9 standard orthogonal array. The study was conducted on 1040 MS material in vertical milling using carbide inserts. The study indicated that coolant flow is the most significant parameter in controlling the surface roughness followed by spindle speed.

` Chahal [2] conducted end milling operation for hardened die steel H-13 with solid carbide four flute end mill tool. The input machining parameters like spindle speeds, feed rate, depth of cut were evaluated to study the effect of different process parameters on surface roughness using L-9 standard orthogonal array. Their study revealed that feed is most important parameters while milling hardened die steel.

Singh et al. [3] investigated the influence of cutting parameters on surface roughness and material removal rate during milling of EN 24 steel. The control parameters such as speed, feed, and depth of cut were selected for the study. A total of 27 experimental runs were conducted using an orthogonal array, and ideal combination of controllable factor level was determined for the surface roughness and material removal rate. The result showed that feed rate is most affecting parameter in milling of EN 24 steel.

Durukbasa et al. [4] studied the effects of tip radius of the tools on the machined surface quality. Taguchi, design of experiments method, was used to determine the optimum processing parameters like cutting speed and depth of cut. To obtain high surface quality for the end milling process of AISI H13 hot work steel the coating material was added with different tool radius. The study indicated that coating type is the most effective parameter for the surface roughness.

Rawangwong et al. [5] conducted face milling operation for semi-solid AA 7075 using carbide tool with twin cutting edges.The input variable parameters like spindle speeds, feed rate, depth of cut were evaluated to study the effect of different process parameters on surface roughness using factorial design. Their study revealed that the most affecting factors for the surface roughness were feed rate and speed, while depth of cut unaffected the surface roughness.

Maiyar et al. [6] investigated the parameter optimization of end milling operation for Inconel 718 super alloy with multi –response criteria based on the Taguchi orthogonal array with the gray relational analysis. They perform nine experimental runs based on an L9 orthogonal array of taguchi method. Cutting speed, feed rate and depth of cut are optimized with response parameters as surface roughness and material removal rate. The study reveals that gray relational analysis is an effective optimization tool for machining Inconel 718 alloy in end milling.

Akhtar et al. [7] reported three important aspects of surface integrity of mechanical part as surface roughness, micro-hardness, and residual stresses. Milling of super alloy GH4169/Incone718 carried out using coated cemented carbide and coated carbide inserts. The better surface integrity obtained at minimum cutting feed, speed and minimum depth of cut. Their results elaborate carbide insert produce better surface integrity of the finished part whereas ceramic inserts generates very high surface tensile stresses and poor surface finish.

Reddy et al. [8] explained the effect of process parameter cutting speed, feed rate and depth of cut on surface roughness and delamination damage on glass fiber reinforced polymeric composite (GFRP) during end milling. The Taguchi method and ANOVA technique was used for the experimentation. The results from ANOVA method shows that the cutting speed and depth of cut are the most significant factors that affects the surface roughness. The artificial neural network technique is also applied to compare the predicted values with the experimental values.

Pang [9] reported the application of Taguchi optimization methodology in optimizing the cutting parameters of end milling process for machining the halloysite nanotube with aluminium reinforced epoxy hybrid composite material under dry condition. The cutting parameters like speed, feed and depth of cut are chosen for evaluation and response factors to be measured are the surface roughness and cutting force. The results showed that Taguchi method is best method for determining the best combination for machining parameters which provide the optimal machining response conditions for lowest surface roughness and lowest cutting force.

Sukumar et al. [10] studied the optimal combination of influential factors in the milling process using Taguchi method. The milling operation performed on Al 6061 material, according to Taguchi orthogonal array (L16) for various combinations of speed, feed and depth of cut. Also Artificial Neural Network (ANN) model developed and trained with full factorial design. Their results showed that both Taguchi method and ANN found different sets of optimal combinations but the confirmation test shows that both got almost same surface roughness values.

Kuram and Ozcelik [11] conducted micro milling operation for aluminium material with ball nose end mill.The input machining parameters like spindle speeds, feed rate, depth of cut were evaluated to study the effect of different process parameters on surface roughness, tool wear and cutting forceusing Taguchi method. Cutting tools and workpiece surfaces were inspected via scanning electron microscope for adhesion and abrasion wear mechanisms during micro-milling of aluminum.

Ji et al. [12] studied two process electric discharge(ED) milling and mechanical grinding to machine SiC, ceramic. The effect of tool polarity on the machining characteristics such as material removal rate (MRR), tool wear ratio (TWR), and surface roughness (SR) studied. Also the effects of pulse on-time, pulse off-time, discharge current and open voltage on MRR, TWR, and SR studied with Taguchi experimental design.

Rao et al. [13] investigated the effect of speed, feed and depth of cut on surface roughness of MWCNT reinforced epoxy component. Taguchi method was used to design of experiment (DOE) and optimization. The ANOVA technique was also employed to find out most significant cutting pararameter for surface roughness. Their results revealed that the Depth of cut is most significant factor.

Dhiman and Gupta [14] conducted face milling operation on SS202 material. The input machining parameters like spindle speed, depth of cut and feed rate were selected to study the effect of different process parameters on material removal rate and surface roughness using Taguchi methodology. Analysis of Variance (ANOVA) technique was employed to analyze the effect of milling parameters on material removal rate and surface roughness.

Yasiret al. [15] investigated effect of cutting parameters on the surface topography of AISI 316L stainless steel. End milling operation was performed on AISI 316L steel with tungsten carbide tool. The response surface methodology (RSM) technique was used for optimization. The input machining parameters like cutting speeds and feed rate were evaluated. Their study revealed that feed rate is most affecting parameters while milling of AISI 316L steel.

Lakshmi and Subbaiah [16] conducted end milling operation on EN24 grade steel with a hardness of 260 BHN using solid coated carbide tool. Input variables consist of cutting speed (V), feed rate (f) and depth of cut (d).The output variables are surface roughness and Material removal rates. Average surface roughness were modeled and optimized by using RSM method. Their results showed that feed rate is the most affecting parameter on surface roughness followed by cutting speed. However, depth of cut appears to have very little effect over roughness value.

Maurya et al. [17] reported influence of various machining parameters like, tool feed, tool speed, tool diameter and depth of cut on CNC end milling of AL 6351 –T6 material.Taguchi standardL9orthogonal array was chosen for design of experiments and the main influencing factor were determined for each given machining criteria by using Analysis of variance (ANOVA). In their experimental work, they foundorder of significant parameter as tool feed, tool speed,tool diameter,depth of cut.

Patel and Pal [18] employed the Taguchi design method to optimize the surface roughness quality in milling of aluminum.The control parameters were spindle speed, feed rate, and depth of cut. Orthogonal array of L9 and analysis of variance (ANOVA) were carried out to identify the significant factors affecting the surface roughness. The experimental results indicated that the most significant factors affecting the surface roughness of aluminum during milling process were spindle speed followed by feed rate and depth of cut.

Joshi and Kothiyal [19] investigated the impact of various parameters like spindle speed, depth of cut and feed rate on surface finish in end milling of aluminium cast heat-treatable alloy using Taguchi methodology.Experimental plan was performed by a Standard Orthogonal Array. Their results indicated that feed Rate is most influencing factor for modeling surface finish. Also the graph of S-N Ratio indicates the optimal setting of the machining parameter which gives the optimum value of surface finish.

Prajapati et al. [20] conducted face milling operation for aluminium alloy with Carbide end mill tool. Input parameters like feed rate, spindle speed and depth of cut were selected to study impact on surface roughness and material removal rate process by using Taguchi L3 orthogonal array and ANOVA were performed to find out the significance of each of the input parameters. Their results revealed that feed rate is the most affecting parameter for the material rate and spindle speed is most significant factor for surface finish.

Hayajnehet. al. [21] conducted series of experiments to characterize the factors affecting surface roughness for end milling process. The effect of spindle speed, feed rate, depth of cut on surface roughness of aluminium sample was studied. In general the study shows that the cutting feed is the most dominant factor that affects on surface roughness.

Tammineni and Yedula [22] studied the effect of three selective parameters cutting speed, feed and depth of cut on the surface roughness and flatness of Aluminium 1050 during milling operation. Using Box-Behnken design for combination of parameters was considered and experiments were conducted. Surface roughness and flatness were measured and using response surface methodology. it is observed that feed rate is a dominant parameter and the surface roughness increases rapidly with the increase in feed rate and decreases with increase in cutting speed, where as the effect of depth of cut is not regular. In case of flatness significant changes are caused by depth of cut

Kiswantoet. al.[23] studied experimentation on the effect of spindle speed, feed rate and machining time to the surface roughness and burr formation of aluminium alloy in 1100 in micro-milling operation. The micro milling process was performed by three variations of feed-rate and spindle speed in three intervals of machining time. By statistical method, it is found that feed-rate and machining time contribute significantly to surface roughness.

Amalet. al. [24] investigated on machining parameters optimization in end milling of Ti6Al4V using Taguchi method. In this study cutting speed, feed rate, depth of cut and nose radius of milling cutter is selected as input parameters. The responses observed are surface roughness and cutting force. L9 orthogonal array has been selected for the experimentation. Most influencing parameter on surface roughness is feed rate followed by cutting speed, depth of cut & nose radius and on cutting force most influencing parameter is feed rate followed by depth of cut, nose radius & cutting speed.

Singh et. al.[25] carried out optimization of end milling process for die steel by using response surface methodology. In this study the approach was for determination of best cutting parameters leading to maximum material removal rate in machining die steel on vertical milling centre. Spindle speed (N), Feed Rate (F) and Depth of Cut (DC) are the considered machining parameters. The effect of machining parameters on material removal rate is evaluated and the optimum cutting condition for maximizing the material removal rate is determined using Minitab Software.

Kannanet. al. [26] investigated on selection of machining parameters in face milling operations for copper work piece material usingResponse surface methodology and genetic algorithm. This work shows the parameters influence on material removal rate and surface roughness. The milling parameters selected are spindle speed, feed rate & depth of cut. The hybridisation of Response surface methodology with genetic algorithm is carried out to get best results of surface roughness and material removal rate.

Raj et. al. [27] investigated on optimisation of milling parameters of EN8 using Taguchi methodology. In this experimental investigation the machining performance with various cutting speed, feed and depth of cut using side and face milling cutter was observed. Surface roughness where investigated using Taguchi design of experiments and analysis of variance (ANOVA). The result of the experiments indicates cutting speed play a dominating role in surface roughness in milling process.

Rawangwong et al. [28] investigated optimum cutting conditions in face milling operation for aluminum semi-solid 2024 using carbide tool for surface roughness. The controlled factors were speed, feed rate and depth of cut in which the depth of cut was not over 1 mm. For this experiment, they have used factorial design method and the result showed that the factors effected of surface roughness was the feed rate and the speed while the depth of cut did not affect with the surface roughness.

Sheth and George [29] done experimental investigation and prediction of flatness & surface roughness during face milling operation of wrought cast steel grade B material. The machining parameters selected were spindle speed, feed rate and depth of cut while the response factors selected were flatness and surface roughness. Full factorial design method has been used for experimentation and ANOVA has been carried out to know significance of input parameter. The result shows that to achieve better quality more focus should be made on proper selection of spindle speed and feed while the influence of depth of cut is very less.

Kumar et. al. [30] studied optimization of machining parameters in end milling of Al 2024-SiCp metal matrix composite using Taguchi method for surface roughness. In this study four machining parameters as spindle speed, feed rate, depth of cut and number of flutes were taken in the experiment. The experiment was designed and carried out on the basis of standard L27 Taguchi orthogonal array. the results shows that increase in spindle speed, decrease in feed rate and decrease in depth of cut and less flutes will decrease the surface roughness within specific test range.

Shokrani et al. [31] carried out a study for effect of liquid nitrogen coolant on the surface roughness of Inconel 718 in CNC milling. A series of experiments were carried out using PVD TiAlN coated solid carbide end mills to investigate effects of cryogenic cooling on the machinability of Inconel 718 in comparison with dry machining. The results revel that cryogenic cooling has resulted in 33% reduction in surface roughness.

Aggarwal and Sharma [32]carried outoptimization of machining parameters in end milling of AISI H11 steel alloy by Taguchi based grey relational analysis. The machining parameters considered are cutting speed, feed and depth of cut while the response parameters selected were surface roughness and material removal rate. Design of experiments based on Taguchi grey relational analysis with L27 orthogonal array has been used to carry out experimentation. The results show that cutting speed is the significant machining parameter for surface roughness, and material removal rate. Out of remaining two feed rate is identified as second most influencing parameter where as depth of cut has least influence on surface roughness and material removal rate.

Nimase and Khodke [33] studied the effect of machining parameters on surface roughness of Al-7075 alloy in end milling. The machining parameters taken into consideration were spindle speed, feed rate and depth of cut. Eight experimental runs based on an L8 orthogonal array of Taguchi design method are employed.In this research S/N ratio analysis for smaller the better characteristics is used to obtain lower surface roughness. From the results of ANOVA, it is concluded that spindle speed and feed rate are the most significant factors affecting the response.

Wathore and Adwani [34] investigated optimum cutting parameters for end milling of H13 Die steel using Taguchi based grey relation analysis. In this work Taguchi L9 orthogonal array with grey relational analysis is used. Surface roughness and material removal rate are optimized considering the characteristics namely cutting speed, feed rate & depth of cut. Analysis of variance shows that depth of cut is the most significant machining parameter followed by cutting speed, affecting selected response characteristics i.e. surface roughness and material removal rate.

Kumbhar et. al. [35] carried out multi objective optimisation of machining parameters in CNC end milling. This study was carried out using Taguchi methodology and grey relational analysis. Surface roughness and material removal rate were selected as response parameters and cutting speed, feed rate and depth of cut were selected as machining parameter. Experiments were performed using Taguchi's L9 orthogonal array. From the experimental result it has been observed that depth of cut is most significant factor followed by feed and cutting speed.

Malvade and Nipanikar [36] carried out optimisation of cutting parameters of end milling on VMC using Taguchi method. In this study the milling of OHNS steel material is carried out using high speed steel tool material. The milling parameters taken into consideration are speed, feed & depth of cut while the response parameters were material removal rate and surface roughness. The Taguchi's L16 orthogonal array has been selected for experimentation. The analysis reveals that, in general depth of cut significantly affects MRR and speed significantly affects the surface roughness.

Jatin and Sharma [37] studied effect of machining parameters on output characteristics of CNC milling using Taguchi optimisation technique. The effect of different machining parameters such as cutting speed, feed and depth of cut on surface roughness in end milling has been studied. The L9 orthogonal array has been selected for experimentation. The study shows that feed rate and cutting speed are most dominant factor than the depth of cut for surface finish. High cutting speed and low feeds gives best surface finish; depth of cut should be low but not so low that it will lead to vibration of tool.

Kumar and Paswan [38] carried out optimization of cutting parameters of AISI H13 with multiple performance characteristics. In this study the effect of three input process parameters speed, feed and depth of cut are seen on AISI H13 steel. The response parameters were considered are surface roughness and tool wear. The experiments were carried out using design of experiments by response surface methodology. The study shows that surface roughness is increased with increase in feed and depth of cut while it is decreased when spindle speed is decreased and tool wear is minimum when spindle speed is less.

Prajina [39] carried out multi response optimization of CNC end milling using response surface methodology and desirability function. In this work, second-order quadratic models were developed forcutting forces, surface roughness and machining time; considering the spindle speed, feed rate, and depth of cut and immersion angle as thecutting parameters using central composite design. It is found that feed has significant effect on cutting force and it has to be kept minimum for least force and better surface finish and machiningtime. Cutting speed has significant effect on machining time and surface roughness.Speed has to be kept maximum for combined optimization of forces, roughness andmachining time. With less power good surface finish is obtained at minimum time ifcutting speed is kept maximum and depth of cut minimum.

Shelar and Shaikh [40] carried out cnc milling operation AISI 316 stainless steel.In this work three levels and three parameters are considered; and L27 orthogonal array was carried out by using two different insert coatings. For the experimentation the wet conditions is taken. The machining parameters such as cutting speed (m/min), feed rate (mm/min),depth of cut (mm) and responsive output parameters such as Surface Roughness, material removal rate, dimensional accuracy and flatness was selected.

Subramanian and Veerapriya [41] Investigated the effect of process parameters in AISI 4340 /EN24 High tensile steel in a milling machine by using ball end mill cutter. The input parameters are the spindle speed, angle and depth of cut is varied to study their effect on material removal rate and surface roughness. The experiments are conducted using one factor at a time of approach. Results were investigated by using Taguchi method.

Vijay and Krishnraj [42] conducted end milling operation forTi-6Al-4V.The input machining parameters like spindle speeds, feed rate, depth of cut were evaluated to study the effect of different process parameters on surface roughness and cutting force.The optimization procedure includes the application of Taguchi method and ANOVA for designing of experiment and for validating experimental results. The optimum process parameters for end milling Ti-6Al-4V to reduce cutting force are cutting feed 0.01, speed 40m/min, and axial depth of cut 2 and for surface roughness cutting feed 0.01mm, speed 60m/min, and axial depth of cut 2.5mm.

Shaik and Srinivas [43] reported the influence of machining process variables like feed, cutting speed and axial depth of cut on the output parameters such as surface roughness and amplitude of tool vibration levels in Al-6061. With the use of experimental result analysis and mathematical modeling, correlations between the cutting process conditions and process outputs are studied in detail. The cutting experiments are planned with response surface methodology (RSM) using Box-Behnken design (BBD).

Balasubramanyam et al. [44] investigated the effect of process parameters on surface roughness in end milling process. The machining parameters such as helix angle of cutting tool, spindle speed, feed rate, and depth of cut were selected. Central composite rotatable second order response surface methodology was employed to create a mathematical model and the adequacy of the model was verified using analysis of variance. The experiments were conducted on stainless steel SS 202 by carbide end mill cutter. The surface roughness is minimum when the helix angle and feed rate are respectively at their middle value and maximum when helix angle and feed rate at their lower limits .The increase in helix angle resulted in increased surface roughness for all the levels of depth of cut The surface roughness is better only at low feed and high depth of cut.

Anwar and Khan [45] investigated the effect of the end milling machining parameters on the surface roughness of the EN 31 steel. Nine experimental runs based on an orthogonal array of Taguchi method are performed and it is subsequently applied to determine an optimal end milling parameter combination. Surface roughness is selected as the quality target. The end milling machining parameters considered are rotational speed, feed rate and depth of cut. The feed rate is found to be the most dominant parameter for surface roughness of EN 31 steel. Present study shows that high spindle speed with small feed rate produce better surface finish and the effect of depth of cut is found to be negligible. Taguchi method is used to obtain the optimal combination of end milling parameters.

CONCLUSIONS:

This paper represents the comprehensive review of the effect of machining parameters on end milling operation. The review reveals that the most influencing process parameters on response variables such as surface roughness and material removal rate are cutting speed, feed and depth of cut. The Taguchi’s parametric design method is efficient technique to analyze the optimal combinations of machining parameters for lowest surface roughness and material removal rate. ANOVA is an effective technique for analysis of process parameters and response variables. Following are some of the important conclusions that can be drawn on the basis of above study.

- Surface roughness has a considerable influence on the performance of machined part. All the process parameters have a significant impact on surface characteristics of the finished part.
- In end milling operation increase in cutting speed, decrease in feed rate and increase depth of cut decreases the surface roughness.
- The surface roughness mostly affected by feed rate. Surface roughness increases with increase in feed rate and vice versa. The effect of cutting speed and depth of cut is least significant as compare to feed rate.
- High cutting speed and low feed rate gives best surface roughness.
- Constant cutting speed has no effect on the surface roughness but when feed rate is varied the roughness get changed.
- Besides from feed rate, depth of cut and cutting speed; cutting tool tip radius is observed to be an important parameter to study the surface quality of machined component. This provides the relationship between the tool wear mechanism of tools and surface quality.
- Material removal rate basically depend upon the feed rate, spindle speed, tool diameter and depth of cut. It is important output characteristic in milling or every machining process because MRR has direct relation with the production. And quick and high production is the need of modern production system.
- Milling is use in high speed machining in the modern industry and for higher production there is the necessity of high MRR
- The most significant parameter for material rate is feed rate and depth of cut out. High cutting speed, high depth of cut and high feed rate leads to higher value of material rate.
- The Material removal rate increases as the level of depth of cut and feed rate increase.
- The cutting speed has less significant on material removal rate.
- Some of the areas which are required to be investigated further are chip morphology effect of coolant, effect of type of cutting inserts on various responses during end milling.
- There is lot of scope in study tool wear, tool life, cutting force and flatness during milling operation

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