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A REVIEW ON STUDIES OF PARAMETRIC ANALYSIS DURING TURNING

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Abstract- The surface finish of a turned surface is an important response parameter. In order to get desired quality for surface finish of machining parts, proper selection of turning parameters is essential. This paper review the studies related to the investigation of the effect of different turning parameters on surface roughness. Most of the studies revealed that spindle speed, feed rate and depth of cut are the primary factors which affect the surface roughness. The effect of different turning parameters was analyzed by using various designs of experiments such as Factorial design, Taguchi's approach, Response surface methodology (RSM) etc. The parameter which affected surface roughness the most was spindle speed/feed rate, as determined by most of the researchers. It was also revealed that depth of cut had not a major role to play in affecting surface finish. In addition, some studies also investigate the influence of the type of cutting tool, cutting fluids, workpiece material etc. on surface roughness, cutting force, material removal rate etc. during turning.
Keywords: Turning parameters, Surface Roughness, Design of experiments.

1. INTRODUCTION

Manufacturing processes are mainly focused on quality of workpiece, dimensional accuracy, surface finish, life of cutting tool, production rate and economy of machining process. Turning is machining process carried out on a lathe machine in which unwanted material is removed by using a tool bit which is advanced into the rotating work causing the cutting action [1]. Turning provides the power to turn the workpiece and to feed to the cutting tool at specific rate and depth of cut. Therefore three cutting parameters namely spindle speed, feed rate and depth of cut are primary factors in a turning operation. Other process parameters include tool material, workpiece material, tool geometry, tool setup, tool wear, environmental condition etc. which are the secondary factors in a turning operation [2].

The purpose of turning operation is to produce low surface roughness or high surface finish. Surface roughness describes the geometry of the machined surfaces and it is the measure of the quality of a product [3]. Material removal rate (MRR), cutting force, power consumption etc are other output characterstics/responses in the turning operation.

A statistical model is required for the selection of input parameters in some systematic way to get the output response by using the experimental methods. An experimental program recognizes the major factors that affect the outcome of the experiment. The next thing is the number of levels for each of the factors. The experiments are repeated with a particular set of levels for all the factors [4]. Design of experiment is to get maximum information about a system with minimum number of well designed experiments such as factorial design, Taguchi design, Response surface methodology etc [5]. The full factorial design consist of two or more factors, each with discrete possible levels in which one factor varies at a time and performs experiments for all levels [6]. Taguchi method is the use of parameter design, which is an engineering method for product and process design that focus on determining the parameter settings producing the best levels of a quality characteristic with minimum variation. Taguchi design provides efficient method for designing processes that operate consistently over a variety of conditions [7]. Response surface methodology is to find the optimum response and to understand how the response changes in a given direction by adjusting the design variables [8]. Various researchers had developed a plot of experiments using different design of experiment techniques.

2. LITERATURE REVIEW

Many researchers have worked on turning of different types of steel for evaluating the response. Most of the published studies show the effect of process parameters like cutting speed, feed rate and depth of cut on surface roughness. Table 1 shows the classification of different studies and their key findings.

Routara et al. [9] had optimized cutting conditions on surface roughness of EN8 steel during CNC turning. Mathematical models were developed using response surface methodology on the basis of experimental results. It was found in the study that surface roughness decreases with increase in spindle speed and depth of cut but increases with increase in feed rate.

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Abhang et al. [10] had analyzed the effect of cutting parameters on surface roughness by turning steel alloy (EN-31) by using tungsten carbide inserts. The feed rate, depth of cut and lubricant temperature were Organised by Society of Materials & Mechanical Engineers (SOMME) in collaboration with Shaheed Udham Singh College of Engg. & Tech. Tangori, Mohali, Punjab (India) varied to observe the effect on responses by using the systematic procedure of Taguchi parameter design. It was found from the study that lubricant temperature and feed rate were the main parameters that influence the surface roughness.

Rao et al. [11] had analyzed surface roughness of steel (AISI 1050) turned under different cutting parameters. L_{27} design of Taguchi method was used for the experiments. The study revealed that feed rate was the most significant factor for both the cutting forces as well as surface roughness.

Rajasekaran et al. [12] had studied the influence of cutting parameters on carbon fiber reinforced polyester resin when carrying out turning operation. The cutting tool used was cubic boron nitride (CBN). The result of this study revealed that the feed plays a primary role in deciding the surface roughness followed by cutting speed. But depth of cut did not make any significance for this particular case.

Makadia et al. [13] had analyzed the effect of turning parameters such as feed rate, tool nose radius, cutting speed and depth of cut on surface roughness of steel (AISI 410) by using response surface methodology and (3^4) full factorial design of experiments. The study revealed that the main factor influencing the surface roughness was feed rate, followed by the tool nose radius and cutting speed. Surface roughness had not significantly affected by the depth of cut.

Fatima et al. [14] had investigated the effects of three different cutting fluids (urea based cutting fluid, coolant based cutting fluid and motor oil based cutting fluid) on tool tip temperature while turning of mild steel (AISI 1008). It was found that the maximum temperature reduction was obtained with urea based cutting fluid because formation of urea based cutting fluid in itself was an exothermic reaction.

Lavanya et al. [15] had optimized the process parameters in turning of steel (AISI 1016) using Taguchi method and ANOVA analysis. It was concluded that speed had a greater influence on the surface roughness followed by feed rate and depth of cut had least influence on surface roughness.

Sahijpaul et al. [16] had analyzed the effect of cutting speed, feed rate, depth of cut, cutting fluid concentration and two cutting fluids on surface roughness of EN8 steel during turning. Design of experiments, custom design method, analysis of variance, leverage plot was applied to optimize the surface roughness. The analysis revealed that feed rate was the most significant factor and the value of surface roughness did not significantly differ for the two different cutting fluids.

Saraswat et al. [17] had investigated the effect of cutting speed, feed rate and depth of cut on the surface roughness of medium carbon steel (EN9) when turned with HSS tool. Taguchi method by minimizing S/N ratio was used to optimize the cutting parameters. It was found that feed rate was the most significant factor for surface roughness, followed by spindle speed, and depth of cut.

Patel et al. [18] had analyzed dry and wet cutting on surface roughness and cutting force while turning of medium carbon steel (EN9) with carbide tool. Full factorial parameter design was used to optimize a design for performance. Constant cutting speed, side rake angle, feed rate and depth of cut are the process parameters and the result revealed that side rake angle is the most significant parameter for surface roughness and cutting force.

Abhang et al. [19] [2014] had analyzed effect of machining parameters such as cutting speed, feed rate, depth of cut, tool nose radius and lubricant on surface roughness. The experiment was done in dry, wet and minimum quality of cutting fluid (boric acid mixed with base oil SAE-40) while turning steel (EN-31). The result revealed that with increase in feed rate followed by depth of cut, the surface roughness increases but with increase in cutting speed and tool nose radius, the surface roughness decreases. Moreover it was found that performance of steel turning with minimum quality of cutting fluid was better than dry and wet turning.

Aouici et al. [20] had investigated surface roughness, cutting force, specific cutting force and power in hard turning of steel (AISI D3). By using 3^3 full factorial design approaches, it was found that cutting force was affected mostly by feed rate followed by depth of cut; surface roughness was highly influenced by feed rate; power was highly influenced by feed rate followed by depth of cut. By using RSM, the optimum cutting condition was determined and the result revealed that better surface roughness and minimum cutting forces were obtained at lower depth of cut value, higher cutting speed and by limiting feed rate (0.12 and 0.13 mm/rev).

Bhardwaj et al. [21] had investigated the influence of cutting speed, feed rate, depth of cut and nose radius on surface roughness during wet turning of steel (EN 353) using tungsten carbide insert. RSM was used and the result revealed that the surface roughness decreases with increase in speed and nose radius, but increases with increase in feed.

Senthikumar et al. [22] had studied the effect of machining parameters on flank wear, surface roughness and material removal rate by using response surface methodology. Turning was performed on medium carbon steel (AISI 1045) by using uncoated cemented carbide tool insert. The result revealed that the main significant factor that affects the flank wear and surface roughness was feed rate, and for material removal rate, it was cutting speed.

Shihab et al. [23] had investigated the effect of cutting parameters on the cutting temperature while hard turning of alloy steel (AISI 52100). CCD (Central Composite Design) based on RSM (Response Surface Methodology) was used to model the relationship between cutting parameters and performance characteristics. It was found that the Organised by Society of

Materials & Mechanical Engineers (SOMME) in collaboration with Shaheed Udham Singh College of Engg. & Tech. Tangori, Mohali, Punjab (India) cutting temperature was highly affected by feed rate and cutting speed.

Srithar et al. [24] had analysed the process parameters in machining of steel (AISI D2) by coated carbide insert. The parameters varied for the experiment were cutting speed, feed and depth of cut. The result of this study revealed that the feed rate was highly controlled parameters, which influence the surface roughness parameters and the increase of cutting speed decreases the surface roughness.

Johnson et al. [25] had studied the cutting parameters and fluid application parameters while turning of Oil Hardened Non Shrinkable Steel (OHNS) using carbide tool insert. An effort was made to reduce the quality of usage of cutting fluid using Taguchi technique. The results were compared with dry turning and conventional wet turning under similar cutting conditions and it was found that the minimal cutting fluid application enhanced the cutting performance by improving surface finish compared to dry and wet turning. It was also seen that the feed rate had significant influence on surface roughness.

Elmunafi et al. [26] had evaluated the performance of Minimal Quality Lubrication (MQL) using caster oil as cutting fluid. Stainless steel (AISI 420) bar was turned with coated carbide tool under different cutting parameters. The study revealed that the technique was able to increase the tool life of coated carbide cutting tools compared to dry cutting.

Gaur et al. [27] had optimized the cutting forces while turning of 20MnCr5 alloy steel using Taguchi approach. L_9orthogonal array was implemented on process parameters namely, cutting speed, feed rate and depth of cut. It was found in the study that feed rate was the most influencing factor followed by depth of cut and cutting speed.

Sohrabpoor et al. [28] had studied the effect of various lubrications and machining parameters on tool wear and surfaceroughness in turning of steel (AISI 4340). Four strategies of lubrication namely dry, air cool, wet and MQL was carried under three different regimes and this study revealed that MQL strategy ensures lowest surface roughness and tool wear. L_{27} orthogonal array design of experiments was used and the ANOVA results demonstrated that cutting speed and feed rate were the most important factor rather than the others.

Kajal et al. [29] had studied the CNC turning parameters for surface roughness of EN345 steel using Taguchi method.Single point cutting tool was used for the turning operation. It was found in the study that cutting speed was the most significant factor followed by feed rate for surface roughness. Depth of cut was the least influencing factor for the same.

Azam et al. [30] had studied the effect of machining parameters (feed rate, speed and depth of cut) on surface roughness while turning high strength low alloy steel (AISI 4340). A series of test using RSM has been employed to develop a relationship between surface roughness and machining parameters. The result revealed that feed rate was the most influencing parameter on surface roughness.

Ranganath et al. [31] had scrutinized the effect of cutting speed, feed rate and depth of cut on surface roughness while turning of EN8 steel with uncoated carbide insert. Design of experiment was conducted using Response surface methodology (RSM) and the model was developed in the form of multiple regression equation. It was found during the study that cutting speed is the most influencing process parameter.

Gupta et al. [32] had investigated the effect of cryogenic coolant used as cutting fluid compared to that of dry machining with respect to tool wear i.e crater and flank wear, surface roughness, cutting forces and cutting temperature by turning of medium carbon steel (AISI 1040). The result revealed that the use of cryogenic coolant increases the performance as compared to dry machining.

Khan et al. [33] had studied the effect of cutting speed, feed rate and rake angle on cutting forces, tool temperature and work specimen temperature while turning AISI 1045 steel. Design of experiment was conducted in which 20 experiments were designed. The result revealed that with increase in cutting speed, force decreases. Bigger rake angle of tool tends to increase the temperature but decrease the cutting forces. Higher feed rate results in higher cutting force and high temperature.

Sathiyaraj et al. [34] had investigated the effect of cutting speed, feed rate and depth of cut on surface roughness of EN8 medium carbon steel by using tungsten carbide tipped tool. Taguchi design was implemented to find various levels of chosen parameters and optimum range was found by statistical analysis. It was concluded in the result that cutting speed was the most affecting factor for surface roughness followed by feed rate and depth of cut.

Debnath et al. [35] had analysed the effect of various cutting fluid levels and cutting parameters on surface roughness on mild steel bar. Result was proved using Taguchi orthogonal array that the feed rate was most influential factor.

Zerti et al. [36] had evaluated the optimization for minimum technological parameters such as surface roughness, tangential forces, specific cutting forces and cutting power durning dry turning of AISI D_3 steel. Major cutting edge angle, cutting insert nose radius, cutting speed, feed rate and depth of cut were the input cutting parameters. A Taguchi L_{18} orthogonal array was used and it was found that feed rate and cutting insert nose radius were the main influencing factors on surface roughness.

Xiao et al. [37] had analyzed the effect of cutting parameters (spindle speed, feed rate and depth of cut) on surface roughness. The experiments were carried out in hard turning of AISI 1045 steel. Taguchi orthogonal design was used to design the optimization experiment and ANOVA was exploited Organised by Society of Materials & Mechanical Engineers (SOMME) in collaboration with Shaheed Udham Singh College of Engg. & Tech. Tangori, Mohali, Punjab (India) to study the effect of machining parameters on surface roughness. The result revealed that feed rate had the great effect on the surface roughness as compared to the spindle speed and depth of cut.

Bhaduria et al. [38] had investigated the effect of cutting speed, feed rate and depth of cut to get better surface finish of 45C8 steel. Taguchi method was used to find out the optimal combination. The result of the study was found that feed was the most significant factor that contribute maximum to the surface roughness.
Rashid et al. [39] had investigated the effect of feed rate, depth of cut and linear cutting speed on surface roughness of AISI 4340 steel by using CBN cutting tool. L_{16} orthogonal array was used with individual combination of cutting parameters. This study revealed that the lower feed rate provided an improved machined surface roughness.
Zerti et al. [40] had studied the Taguchi design of experiments for optimization and modeling of surface roughness. The dry turning operations were performed on $X_{210}Cr_{12}$ steel and L_{18} orthogonal array was developed. The result of the study proved that the best surface roughness was obtained by using small feed rate and large nose radius.

Table 1: Classification of different studies and their key findings

Researchers	Year	W/P Material	Cutting Parameters	DOE	Key Findings
Routara et al.	2012	EN8 Steel	Spindle speed Feed rate Depth of cut	RSM	Surface roughness decreases with increase in Spindle speed and depth of cut but increases with increase in feed rate.
Abhang et al.	2012	EN31 Steel	Feed rate Depth of cut Lubricant Tem	Taguchi Design	Lubricant temperature and feed rate was the main parameters that influence surface roughness.
Rao et al.	2013	AISI 1050 Steel	Cutting speed Feed rate Depth of cut	Taguchi Design	Feed rate was the most significant factor for both the cutting forces as well as surface roughness.
Rajasekaran et al.	2013	Carbon fiber reinforced polyester	Cutting speed Feed rate Depth of cut	Taguchi Design	Feed plays a primary role in deciding the surface roughness followed by cutting speed,
Makadia et al.	2013	AISI 410 Steel	Feed rate Nose radius Cutting speed Depth of cut	RSM	Main factor influencing the surface roughness was feed rate, followed by the tool nose radius and cutting speed.
Fatima et al.	2013	AISI 1008 Steel	Cutting Fluids	Customized Exp. Design	Maximum temperature reduction was obtained with urea based cutting fluid.
Lavanya et al.	2013	AISI 1016 Steel	Cutting speed Feed rate Depth of cut	Taguchi Design	Speed had a greater influence on the surface roughness followed by feed rate and depth of cut.
Sahijpaul et al.	2013	EN8 Steel	Cutting speed Feed rate Depth of cut	Custom design method ANOVA	Feed rate was the most significant factor and the value of surface roughness did not significantly differ

			Cutting Fluids	Leverage plot	for the two different cutting fluids.
Saraswat et al.	2014	EN9 Steel	Cutting speed Feed rate Depth of cut	Taguchi Design	Feed rate was the most significant factor for surface roughness, followed by spindle speed, and depth of cut.
Patel et al.	2014	EN9 Steel	Side rake angle Feed rate Depth of cut	Full Factorial Design	Side rake angle is the most significant parameter for surface roughness and cutting force.
Abhang et al.	2014	EN 31 Steel	Cutting speed Feed rate Depth of cut Nose radius Lubricant	Variance Technique F-Test	With increase in feed rate followed by depth of cut, the surface roughness increases but with increase in cutting speed and tool nose radius, the surface roughness decreases. Minimum quality of cutting fluid was better than dry and wet turning.

Aouici et al.	2014	AISI D3 Steel	Cutting speed Feed rate Depth of cut	RSM	Better surface roughness and minimum cutting forces were obtained at lower depth of cut value, higher cutting speed and by limiting feed rate
Bhardwaj et al.	2014	EN 353 Steel	Cutting speed Feed rate Depth of cut Nose radius	RSM	Surface roughness decreases with increase in speed and nose radius, but increases with increase in feed.
Senthikumar et al.	2014	AISI 1045 Steel	Cutting speed Feed rate Depth of cut	RSM	Main significant factor that affects the flank wear and surface roughness was feed rate, and for material removal rate, it was cutting speed.
Shihab et al.	2014	AISI 52100 Steel	Cutting speed Feed rate Depth of cut	RSM	Cutting temperature was highly affected by feed rate and cutting speed.
Srithar et al.	2014	AISI D2 Steel	Cutting speed Feed rate Depth of cut	Customized Exp. Design	Feed rate was highly controlled parameters, which influence the surface roughness parameters.
Johnson et al.	2014	OHNS	Cutting speed Feed rate	Taguchi	Minimal cutting fluid application enhanced the cutting performance by improving surface finish. Feed rate

		Steel	Depth of cut Cutting Fluids	Design	had significant influence on surface roughness.
Elmunafi et al.	2015	AISI 420 Steel	Cutting Fluids	Customized Exp. Design	MQL technique was able to increase the tool life of coated carbide cutting tools compared to dry cutting.
Gaur et al.	2015	20MnCr5 alloy steel	Cutting speed Feed rate Depth of cut	Taguchi Design	Feed rate was the most influencing factor followed by depth of cut and cutting speed.
Sohrabpoor et al.	2015	AISI 4340 Steel	Lubricants Cutting speed Feed rate Depth of cut	Taguchi Design	MQL strategy ensures lowest surface roughness and tool wear. Cutting speed and feed rate were the most important factor rather than the others.
Kajal et al.	2015	EN 345 Steel	Cutting speed Feed rate Depth of cut	Taguchi Design	Cutting speed was the most significant factor followed by feed rate for surface roughness.
Azam et al.	2015	AISI 4340 Steel	Cutting speed Feed rate Depth of cut	RSM	Feed rate was the most influencing parameter on surface roughness.
Ranganath et al.	2015	EN8 Steel	Cutting speed Feed rate Depth of cut	RSM	Cutting speed is the most influencing process parameter.
Gupta et al.	2015	AISI 1040 Steel	Cutting fluids	Customized Exp. Design	Use of cryogenic coolant increases the performance as compared to dry machining.
Khan et al.	2015	AISI 1045 Steel	Cutting speed Feed rate Rake angle	Taguchi Design	With increase in cutting speed, force decreases. Bigger rake angle of tool tends to increase the temperature but decrease the cutting forces. Higher feed rate results in higher cutting force and high temperature.
Sathiyaraj et al.	2015	EN8 Steel	Cutting speed Feed rate Depth of cut	Taguchi Design	Cutting speed was the most affecting factor for surface roughness followed by feed rate and depth of cut.
Debthnath et al.	2016	Mild steel	Cutting speed Feed rate Depth of cut	Taguchi Design	Feed rate was most influential factor for surface roughness.

			Cutting fluids		

Zerti et al.	2016	AISI D3 Steel	Major Cutting edge angle Nose radius Cutting speed Feed rate Depth of cut	Taguchi Design	Feed rate and cutting insert nose radius were the main influencing factors on surface roughness.
Xiao et al.	2016	AISI 1045 Steel	Spindle speed Feed rate Depth of cut	Taguchi Design	Feed rate had the great effect on the surface roughness as compared to the spindle speed and depth of cut.
Bhaduria et al.	2016	45C8 Steel	Cutting speed Feed rate Depth of cut	Taguchi Design	Feed rate was the most significant factor that contribute maximum to the surface roughness.
Rashid et al.	2016	AISI 4340 Steel	Linear cutting speed Feed rate Depth of cut	Taguchi Design	Lower feed rate provided an improved machined surface roughness.
Zerti et al.	2017	X210Cr12 Steel	Cutting speed Feed rate Depth of cut Nose radius	Taguchi Design	Best surface roughness was obtained by using small feed rate and large nose radius.

3. SUMMARY

Most of the researchers had taken cutting speed, feed rate and depth of cut as process parameters. In some cases other parameters were also considered such as rake angle, noise radius, cutting fluids, workpiece materials etc. The output parameters which were considered mostly are surface roughness, cutting force etc. For response optimization various techniques such as Taguchi approach, analysis of variance, response surface methodology, regression analysis, factorial method etc were applied by various researchers. It was found that for surface roughness the most significant parameters are speed, feed rate & nose radius and least significant parameter is depth of cut.

4. FUTURE SCOPE

From the above discussion, problem statement can be stated as, to find the effect of turning parameters on a response parameter of some specific grade steel. Cutting tool can be selected according to the workpiece and the experiments can be performed under different environmental conditions. For optimization, a specific technique can be employed to determine the best combination of process parameters.

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