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A Review on Optimization Method for Machining Parameters Using DOE

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Abstract – The design of experiments is a powerful approach to improve product design or process performance. This procedure constitutes a systematic method for the planning of experiments, collection and analysis of data with near-optimum use of available resources. It is used to investigate the variables affecting the product design and process performance, systematically. On the basis of planning, the design of experiments includes several techniques, such as, factorial design, Taguchi method, response surface methodology, grey Taguchi etc. In the past, numerous researchers extensively used statistical design of experiments to investigate the effect of machining conditions on responses and to optimize the machining parameters for achieving the desire response i.e minimum surface roughness, minimum tool wear, maximum metal removal rate etc. in metal machining a brief discussion in this regard has been presented in this review paper.

Keywords - Design of Experiments, Taguchi, Response Surface Methodology, Grey Relation Analysis.

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I. INTRODUCTION

Manufacturing is the process of converting raw materials into finished products. Among various manufacturing processes, the machining is considered to be quite important. In fact majority of the finished products require machining at some stage during their production, ranging from relatively rough or no precision work, such as cleanup of casting or forgings, to high precision work. Now-a-days, due to global competitiveness, manufacturing industries are more concerned about the quality of their products. The industries focus on producing high quality products in time at minimum cost. The quality of the machined surface is greatly influenced by the cutting conditions such as tool geometry, tool material, machining process, types of chip form, work piece material, tool wear and vibration during machining. In order to produce parts with the desired surface finish at low production cost, the machining parameters should be selected properly. However, proper selection of cutting conditions and parameters for achieving a desired quality is not an easy task, because the mechanism behind the machining is very dynamic, complicated and process dependent. To overcome the limitations a number of studies have been conducted to investigate and formulate the effect of machining parameters for prediction of responses and obtain the optimal machining parameters. This paper present a review of past literature of in the field of metal machining using design of experiments such as Taguchi methodology, factorial design, response surface methodology, grey Taguchi etc.

2. DESIGN OF EXPERIMENTS

The design of experiments is a powerful approach to improve product design or process performance. This procedure constitutes a systematic method for the planning of experiments, collection and analysis of data with near-optimum use of available resources. It is used to investigate the variables affecting the product design and process performance, systematically.

On the basis of planning, the design of experiments includes several techniques, such as, factorial design, Taguchi method, response surface methodology etc. The general steps followed for the development of prediction models using design of experiments are given as:

1. Experimentation and data collection according to design matrix.
2. Regression analysis for the development of prediction model.
3. Checking the adequacy of the developed model using analysis of variance.

4. Elimination of insignificant terms from the models using backward/forward/manual elimination method.

5. Final surface roughness prediction model

ANOVA is commonly used to perform test for (i) significance of the regression model, (ii) significance on individual model coefficients, and (iii) lack-of-fit of model. This analysis is based on two assumptions, (a) The variables are normally distributed, and (b) homogeneity of variance. Significant violation of either assumption can increase the chances of committing error.

3. LITERATURE REVIEW

In the recent past, many studies have been reported on the investigation of the effect of cutting parameters on surface roughness and the development of surface roughness prediction model in turning of non ferrous metals using design of experiments. A brief review of the research in the relevant area is given below.

Choudhury and Baradie [1] investigated the effects of the main cutting parameters such as cutting speed, feed, and depth of cut, on surface roughness in turning EN 24T steel with uncoated carbide inserts. The first order and second order prediction models were developed in terms of cutting parameters. The first order prediction model is based on 12 experimental data sets (2- level full factorial design with four center points) while second order prediction model makes use of 24 experimental data sets (8 factorial points, 4 center points and 12 star points). The response surface methodology has been used to analyze the effect of cutting parameters on surface roughness. On the basis of statistical analysis the second -order model has been found to be adequate as compared to first order model. Also, the feed has been found to be the most significant cutting parameter for surface roughness. Nian et al. [2] studied the influence of cutting parameters on multiple performance characteristics (tool life, cutting force and surface finish) in turning of S45C steel bars using tungsten carbide tool. The cutting speed, feed and depth of cut were considered as independent cutting parameters. The L_9 orthogonal array based Taguchi method was employed to optimize the cutting parameters for multiple performance characteristics. It has been found that the Taguchi method provides a simple, systematic and efficient methodology for the optimal selection of the cutting parameters. In addition to this, feed has been found most significant parameter that’s affect the surface roughness. Abouelatta et al. [3] developed correlation between surface roughness and cutting tool vibration in turning free cutting steel with cemented carbide cutting tool. A 2-level full factorial design was used to develop surface roughness prediction model in terms of rotational cutting speed, feed rate, depth of cut, tool nose radius, tool overhang, approach angle, work piece length, work piece diameter and machine tool vibration. The prediction model involving both the cutting parameters and the tool vibrations have been found more accurate as compared to those involving the cutting parameters only.

Ghani et al. [4] experimentally investigated the effect of speed, feed and depth of cut on tool life, surface finish and vibration during turning of nodular cast iron using ceramic tool. Total nine experiments were conducted to explore the variation in surface finish of the workpiece due to increased tool wear. Also, the effect of vibration on the flank wear in the direction of main cutting force and radial cutting force has been investigated. The tool life of the alumina ceramic inserts has been found unsatisfactory. On the other hand, variation in surface finish with the progress of the flank wear under all cutting conditions has been found almost constant. Ozel et al. [5] experimentally investigated the effect of cutting edge geometry, workpiece hardness, feed rate and cutting speed on surface roughness and resultant of three components of cutting forces (tangential, radial and feed force). The turning experiments were conducted on AISI H13 steel according to two level full factorial design using cubic boron nitrite inserts. Statistical analysis of variance (ANOVA) was performed to identify statistically significant trends in the measured surface roughness and cutting force data. The first order effects of workpiece hardness, cutting edge geometry, feed rate and cutting speed on surface roughness have been found statistically significant. The interaction term of the edge geometry and the workpiece hardness, the edge geometry and the feed rate, and the cutting speed and feed rate have also been found significant for surface roughness. On the other hand, the effect of cutting-edge geometry, workpiece hardness and cutting speed on cutting force components have been found to be significant. Sahin and Motorcu [6] investigated the effect of cutting parameters (cutting speed, feed rate and depth of cut) on surface roughness in turning of mild steel. Total 18 sets of turning experiments were carried out using TiN- coated carbide tool. The response surface methodology has been used to develop the first order and the second order surface roughness prediction models in terms of cutting parameters. The analysis of models suggests the feed rate has the highest effect on the surface roughness. The surface roughness seems to increase with increase in the feed rate but decreases with increase in the cutting speed and the depth of cut. Singh and Rao [7] studied the effect of cutting conditions on surface roughness in hard turning of the bearing steel (AISI 52100) with mixed ceramic inserts of aluminium oxide and titanium carbonitride. Based on the 3-level full factorial design, total 81 turning experiments were carried out. The surface roughness prediction model was developed in terms of cutting conditions (cutting speed, feed rate, effective rake angle and tool nose radius) using RSM. The feed has been found to be the dominant factor affecting the surface roughness followed by the nose radius, cutting speed and effective rake angle. In addition to this, the effect of interaction terms of the nose radius and the effective rake angle, and feed and nose radius, on surface roughness have also been found significant. Also, the surface roughness tends to increase with increase in feed and effective rake angle while it tends to decrease with increase in the cutting speed and nose radius. Galanis and Manolakos [8] studied the effect of cutting speed, feed rate and depth of cut on surface roughness in turning of AISI 316L stainless steel femoral heads using TiN–Al2O3–TiC-coated carbide cutting tool. The 3-level full factorial design coupled with RSM has been used to investigate the effect of cutting parameter on surface roughness. The second order surface roughness prediction model was developed in terms of cutting parameters. The depth of cut has been found as a main influencing factor affecting the surface roughness. The surface roughness is found to increase with increase in depth of cut and feed rate, but it decreases with increase in the cutting speed. Sahoo and Sahoo [9] investigated the effect of cutting parameters (speed, feed and depth of cut) on surface roughness in turning of D2 steel using TiN coated carbide insert. The surface roughness prediction model has been developed using regression analysis. The L_{27} orthogonal array based Taguchi parameter design and response surface methodology have been used to investigate the effect of cutting parameters. The result reveals the feed to be the most significant parameter followed by the depth of cut. The effect of cutting speed has been found insignificant. The optimum parametric combination for minimum surface roughness is found to be the highest level of cutting speed, lowest level of feed and highest level of depth of cut. Kirby et al. [10] employed L_9 orthogonal array based Taguchi parameter design to make optimal selection of machining parameters for minimum surface roughness during turning of aluminum workpieces. The spindle speed, feed rate, depth of cut and tool nose radius were considered as control parameters. Varying room temperature and more than one insert of the same specification have been treated as noise factors. The confirmation runs have been conducted to verify the results. The minimum surface roughness has been achieved at the combination of highest level of spindle speed, lowest level of feed, lowest level of depth of cut and highest level of nose radius.

Bhushan et al. [11] experimentally investigated the influence of cutting parameters on surface roughness of workpiece and wear rate of tool. The cutting speed, depth of cut and feed rate have been considered as cutting parameters. A total of 64 turning experiments were conducted on two different materials, the 7075 Al alloy and the10 wt.% SiC particulate metal-matrix composite using both the tungsten carbide and the polycrystalline diamond (PCD) inserts. It has been observed that the surface roughness on the turned Al alloy is less as compared to the turned Al alloy composite, machined under the same machining conditions with both the inserts. Also wear of the tungsten carbide and the PCD inserts has been found less for Al alloy as compared to that for Al alloy composite. Chen et al. [12] analyzed the effect of cutting conditions on tool vibrations and surface roughness in precision turning of A6061-T6 material using diamond cutting tool. The spindle speed, feed rate, depth of cut and status of lubrication were considered as cutting conditions. The empirical models for tool vibrations (longitudinal and transverse) and surface roughness have been developed using a D - optimal design based on the response surface methodology. The results reveal that the spindle speed and the feed rate have the greatest influence on the longitudinal vibration amplitude while the feed rate and the cutting depth have been found most significant parameters affecting the transverse vibration amplitude. In addition to this, the minimum surface roughness has been obtained at high spindle speed, low feed rate and low depth of cut with lubrication. Mansour and Abdalla [13] analyzed the effect of machining parameters (cutting speed, feed rate and axial depth of cut) on surface roughness in end milling of EN 32 steel with coated tungsten carbide inserts. For this purpose, total 24 machining experiments were performed to collect the set of data for surface roughness values. The first order and second order surface roughness prediction models were developed in terms of machining parameters using RSM. The analysis of both the models indicates that the surface roughness increases with increase in feed and axial depth of cut while it decreases with increase in cutting speed. Ghani et al. [14] analyzed the effect of cutting parameters on surface roughness and cutting force in end milling of AISI H13 hardened steel with TiN coated carbide inserts using L_{27} orthogonal array based Taguchi approach. The cutting speed, feed rate and depth of cut were considered as cutting parameters. The pareto analysis of variance (ANOVA) has been employed to evaluate the percentage contribution of each cutting parameter on surface roughness and cutting force. An attempt has also been made to optimize the cutting parameters for minimum surface roughness and cutting force. The results show that the optimal combination of cutting parameters for low resultant cutting force and good surface finish is obtained at high cutting speed, low feed rate and small depth of cut. The feed has been found to be the most significant parameter affecting the cutting force while cutting speed appears to have dominating effect on surface roughness.

Zhang et al. [15] analyzed the effect of machining conditions on surface roughness during CNC face milling of aluminum using coated carbide inserts. The spindle speed, feed rate and depth of cut have been considered as control factors while operating chamber temperature and the tool wear have been considered as noise factors. The optimum conditions for minimum surface roughness have been obtained using L_9 orthogonal array based Taguchi methodology. The ANOVA has also been carried out to identify the significant factors affecting surface roughness. Finally, confirmation experiments have been carried out to verify the results. The results indicate that spindle speed and feed rate have a major impact on surface roughness in comparison to the depth of cut. In addition to this, one of the noise factors (tool wear) has been found to be statistically significant. The results obtained after the conformation runs indicate the ability of the Taguchi method to obtain the optimum cutting conditions for minimum surface roughness with minimum experimentations. Kopac and Krajnik [16] employed L_{18} orthogonal array based Taguchi method to optimize flank milling parameters for multi performance characteristics (cutting force, surface roughness and metal removal rate). The milling experiments were conducted on Al alloy 5083 using coated carbide inserts. Coolant application, number of flutes, cutting speed, feed rate, axial depth of cut and radial depth of cut have been considered as milling parameters. The results indicate that the flank milling with two or three flutes is superior to four-fluted tool. Also, it has been found the reduced feed rates appear to improve the process performance and tool life while maximal cutting speed does not yield optimal performance.

Nouari et al. [17] experimentally investigated the effect of machining parameters on tool wear, hole diameter deviations and surface roughness during the dry drilling of aluminum alloy 2024 using coated tungsten carbide drill, uncoated tungsten carbide drill and HSS drill. The drilling experiments were performed on rigid instrumented drilling bench. The result shows that minimum hole deviation and minimum surface roughness has been achieved with in terms of maximum and minimum hole diameter deviations and surface roughness are obtained for the uncoated and coated tungsten carbide drills. The HSS tool is found not suitable for dry machining of aluminum alloy 2024. The cutting speed has been found most significant parameter that affects the surface roughness, tool wear and hole deviation during the dry drilling of aluminum alloy A2024. C.C. Tsao [18] used Taguchi methodology to investigate the effect of drilling parameters on thrust force and surface roughness during the drilling of quality associated with core drill in drilling of carbon fibre reinforced plastic (CFRP) laminate. The grit size of diamond, thickness, feed rate and spindle speed have been considered as drill parameters. The ANOVA has also been used to investigate most significant parameter that affect the thrust force and surface roughness during the drilling process. The result indicates that the thickness and feed rate have been found most significant parameters that affect the surface roughness and thrust force. It has also been found through conformation runs that Taguchi methodology is a effective tool for the evaluation thrust force and surface roughness (errors within 10%) during drilling of composite material. Mohan et al, [19] used Taguchi methodology to investigate the effect of drilling parameters and workpiece parameters on peel up and push down delamination factor during the drilling of glass fibre reinforced plastic (GFRP) composite laminates. The speed, feed rate, drill size have been considered as drilling parameters and thickness of glass fibre reinforced plastic has been considered as workpiece parameter. The signal-to-noise ratio is used to investigate the effect of parameters on peel up and push down delamination factor during drilling.An attempt has also been made to optimize the parameters for minimum delamination. The specimen thickness and cutting speed have been found significant effect on peel up delamination, on the other hand the specimen thickness and feed have been found significant effect on push down delamination. Hsu and Tsao [20] used Grey-Taguchi methodology based on Taguchi methodology and grey relation grade for multi response optimization of drilling parameters during the drilling of carbon fiber-reinforced plastic (CFRP) using candlestick drill. The ANOVA analysis has also been carried out to investigate the most significant drilling parameter. The Surface roughness and MRR have been considered as responses while feed rate spindle speed and drill diameters have been considered as drilling parameters. The feed rate and drill diameter have been found most significant parameters that affect the responses. On the other hand spindle speed has been found insignificant parameter during the drilling of CFRP. Ahamed et al. [21] experimentally investigated the effect of drilling parameters on surface roughness and tool wear during the drilling of hybrid Al-5%SiCp-5%B4Cp metal matrix composites with HSS drills. An attempt has also been carried out to optimize the drilling parameters for minimum surface roughness and minimum tool wear. The cutting speed and feed have been considered as drilling parameters. Characterization of tool wear and surface integrity are also carried out using SEM. The result reveals that tools wear increases with increase in cutting speeds. The cutting speed has been found most significant parameter that affects the surface roughness. The surface roughness increases with increase in cutting speed. The minimum surface roughness and minimum tool wear have been achieved at lower level of feed and lower level of cutting speed during the drilling of Al-5%SiC-5% B4C composites with HSS tool.

Cicek et al. [22] used Taguchi methodology based on L8 orthogonal array to investigate the effects of drilling parameters on surface roughness and roundness error during the drilling of AISI 316 austenitic stainless steel with M35 HSS twist drills. An attempt has also been made to optimize the drilling parameters for minimum surface roughness.

The two cutting tools, cutting speeds and feed rates have been considered as control factors. Multiple regression analysis has also been carried out to develop prediction models. Minimum surface roughness and roundness error is obtained at 14 m/min cutting speed and 0.08 mm/rev feed rate. Khan et al, [23] used Taguchi methodology to investigate the effect of drilling parameters on hole size deviation during the drilling of acrylic sheet. An attempt has also been made to optimize the drilling parameters for minimum hole deviation. The cutting speed, feed rate, and point angle has been considered as drilling parameters. The cutting speed has been found main influencing factor that affect the hole size deviation followed by feed. Tool angle has been found most complex factor. As the cutting speed increase the hole size deviation also increases. The minimum hole size deviation has been obtained at lower level of cutting speed and higher level of feed rate. Bahce and Ozel [24] investigated the effect of build up edges produce during the drilling on the cutting edges and the effect of drilling parameters on surface roughness during the drilling of Al 5005 alloy on CNC milling machine using Taguchi methodology. The rotation speed, feed rate, drill diameter and point angle have been considered as drilling parameters. An attempt has also been made to optimize the drilling parameter (cutting speed, feed) for minimum axial force during the drilling of mild steel using Taguchi methodology. The results reveal that the proper selection of process parameter requires for proper machining characteristics. The feed has been found most significant parameters for axial force with 64.72 percentage contribution followed by cutting speed (33.38%). Shunmugesh et al. [25] used grey relation analysis with L27 orthogonal array based Taguchi methodology for multi response optimization during the drilling of composite material. The surface roughness and delamination of hole have been considered as response while spindle speed, tool point angle and feed rate have been considered as process parameters. The first order prediction models have also been developed for surface roughness and delamination in terms of process parameters. An attempt has also been made to investigate the effect of drilling parameters on surface roughness and delamination of holes. The result reveals that spindle speed has been found main significant parameter that affects the surface roughness followed by feed rate and point angle. For delamination, the spindle speed has been found most significant parameter.

Tamilselvan and Raguraj [26] used Taguchi methodology to investigate the effect of drilling parameters on thrust force, overcut, taper and circularity of the hole during the drilling of Ti-TiB composite produced by three processes of powder metallurgy namely, spark plasma sintering, hot isostatic pressing and vacuum sintering process. The Analysis of Variance (ANOVA) have also been employed to investigate the effects of parameters on response and estimation of percentage contribution. The spindle speed, feed rate, process, and drill material have been considered as process parameters. The results show that spindle speed and feed rate have been found most significant parameters that affect the dimensional accuracy of the produce hole, on the other hand, the spindle speed and feed rate affects the thrust force. Also, as the spindle speed increases, the thrust force and over cut decreases.

4. CONCLUSION

This paper presented a review of past literature related to application of design of experiment for the modeling and optimization of machining parameters during machining. The review of literature shows that various design of experiments techniques like Taguchi, factorial design, RSM, grey Taguchi etc. have been successfully applied in the past for optimization of the various machining parameters and for the development of prediction models. This review shows that design of experiment is a efficient tool for optimal settings of process parameters. The Taguchi methods and response surface methodology are robust design techniques widely used in industries for making the product/process insensitive to any uncontrollable factors such as environmental variables.

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