A Review-Optimization of Machining Parameters in Turning Operation by Employing Taguchi Method

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Abstract— This paper deals with literature review on optimization of independent process parameters like cutting speed, feed rate, depth of cut, tool nose radius, cutting environment, tool tip temperature, etc. which affect desired response parameters or characteristics like cutting forces, material removal rate, surface roughness, power consumption. Different optimizing tools or techniques like Taguchi’s design approach, Taguchi grey relational analysis, Analysis of variance (ANOVA) are reviewed to investigate their effectiveness in optimization and finding significant factors in turning operation.

Key words: Turning, optimization, cutting forces, Taguchi’s approach, grey relational analysis, ANOVA

I. INTRODUCTION

Turning is the process in which a single point cutting tool is held parallel to the surface of rotating work piece in which certain feed and depth of cut is provided to the cutting tool to penetrate in the work piece to cause the material removal with the help of friction force. Higher material removal rate (MRR), lower cutting forces, higher surface finish, and lower power consumption are desired by industry to cope up with the mass production without sacrificing product quality in shorter time and low cost. So, in today’s rapidly changing scenario of manufacturing industries, use of optimization techniques in metal cutting processes is essential for a manufacturing unit to respond effectively to severe competition and increasing demand of quality products in the market [2]. For optimization of turning operations, it is desired to determine the cutting parameter more efficiently. There are several methods for optimization of turning operations like Taguchi’s approach, grey relational analysis etc. As a result, from the practical viewpoint, the parameter design of the Taguchi method seems to be the most suitable approach to determine the optimal cutting parameters for turning operations in machine shop. So, selection of appropriate process parameter plays very vital role in the effectiveness, efficiency and overall economy of manufacturing by machining to achieve the desired objectives.

Taguchi’s approach can analyze and provide optimum parameters for a given set of independent parameters and a response variable. If there are multiple response variables for the same set of independent variables, the methodology provides a different set of optimum operating conditions for each response variable. For example, in machining, optimum condition for minimizing cutting forces need not be the same as for minimizing surface roughness. In such conditions, obtaining a solution that gives the best possible surface finish at the lowest possible cutting forces are necessary in some instances. In such circumstances, the Taguchi method may not provide appropriate solution. In a complex and multivariate system such as machining, the relationships between various factors are unclear. Such systems often are called grey that give poor, incomplete, and uncertain information. To solve such kind of problem, the grey relational analysis is necessary [6].

II. REVIEW OF TAGUCHI METHOD

Genichi Taguchi, a Japanese engineer, formulated the methodology for process or product quality improvement by using scientific and statistical concepts. He developed offline product or design improvement tool after lot of experiments to reduce quality lose in traditionally quality check done in production line or after production. Taguchi facilitates a three stage process: system design, parameter design and tolerance design. System design identifies the working levels of the design parameters, parameter design provides the parameter levels that produce the best performance of the product/process under study. The optimal condition is selected so that the influence of uncontrollable factors (noise factors) causes minimum variation to system performance. The orthogonal arrays, variance and signal to noise analysis are the essential tools of parameter design. Tolerance design is a step to fine tune the results of parameter design by tightening the tolerance of parameters with significant influence on the product Kabra Ashish et al (2013) [8]. This method uses orthogonal array which reduces number of experiments by many times as compare to conventional methods. Nithyanandan T et al (2014) [10] investigated the effects of process parameters on surface finish and material removal rate (MRR) to obtain the optimal setting of these process parameters using Taguchi’s approach. He obtained that cutting speed and depth of cut had significant effect on feed force whereas feed rate and depth of cut were factors that significantly influences on thrust force. The depth of cut and cutting speed had predominant effect on tool wear. Feed rate had less significant effect on tool wear. Mohd. Rafeeq et al. 2014 [11] obtained an optimal setting of turning process parameters (cutting speed, feed rate and depth of cut) resulting in an optimal values of the feed force and radial force when machining EN31B steel with TiC-coated tungsten carbide inserts applying Taguchi’s design approach and the analysis of Variance (ANOVA). S.Shivade et al. 2014 [15] presented the single response optimization of turning parameters for turning of EN 8 steel. Experiments were conducted based on Taguchi’s L9 orthogonal array design. It optimized the surface roughness and tool tip temperature in turning operation using single point carbide cutting tool. The analysis of variance (ANOVA) was employed to analyze the influence of process parameters during turning. Arvind Kumar 2014 [16] optimized selected response parameter, material removal rate, using selected combination of machining parameters by Taguchi.
orthogonal array working on mild steel 1018. This study demonstrated when feasible process parameters were selected, mild steel (1018) could be efficiently turned using coated carbide tool.

Ashish Kabra et al (2013) [8] analyzed the surface roughness, feed force and radial force in CNC turning process using Taguchi method. The study was focused on the determination of optimum condition of process parameters (cutting speed, feed rate, depth of cut) to get best surface roughness feed and radial forces in turning EN-19 alloy steel in CNC turning. Vikas B. magdum et al. 2013 [14] carried out optimization and evaluation of machining parameters for turning on EN8 steel on Lathe machine. This study investigated the use of tool materials and process parameters for machining forces for selected parameter range and estimation of optimum performance characteristics. Kapil Sharma et al. 2013 [19] described a review of basic terms and visualizations of the major components of the cutting tool geometry in orthogonal turning process. The parameters like rake angle, depth of cut, feed rate, temperature and cutting speed were taken into account so as to predict their effects on tool life. Their influences on cutting forces and tool geometry had also been referred.

C.J. Rao et al. 2013 [21] reported the significance of influence of speed, feed and depth of cut on cutting force and surface roughness while working with tool made of ceramic with an Al2O3+TiC matrix (KY1615)and the work material of AISI 1050 steel (hardness of 484 HV). Experiments were conducted using Johnford TC35 Industrial type of CNC lathe. Taguchi method (L27 design with 3 levels and 3 factors) was used for the experiments. Analysis of variance with adjusted approach had been adopted. Mahendra Korat et al. 2012 [12] studied to optimize the effects of cutting parameters on surface finish and MRR of EN24/AISI4340 work material by employing Taguchi techniques. The orthogonal array, signal to noise ratio and analysis of variance (ANOVA) were employed to study the performance characteristics in turning operation. Five parameters were chosen as process variables: Speed, Feed, Depth of cut, Nose radius, Cutting environment (wet and dry). Krishankant et al. 2012 [18] described an optimization of turning process by the effects of machining parameters applying Taguchi methods to improve the quality of manufactured goods, and engineering development of designs for studying variation. EN24 steel was used as the work piece material for carrying out the experimentation to optimize the Material Removal Rate. The metal removal rate was considered as the quality characteristic with the concept of "the larger-the-better". There were three machining parameters i.e. Spindle speed, Feed rate, Depth of cut for Taguchi orthogonal array designed with three levels of turning parameters with the help of software Minitab 15.

Aman Aggarwal et al (2009) [7] used Taguchi method in CNC machining process for an optimal setting of parameters (cutting speed, feed rate, depth of cut, nose radius and cutting environment) resulting in optimal values of the feed and radial forces during machining P-20 tool steel with TiN coated tungsten carbide inserts. Aman Aggarwal et al. 2008 [13] presented the effects of cutting speed, feed rate, depth of cut, nose radius and cutting environment in CNC turning of AISI P-20 tool steel. Design of experiment techniques, i.e. response surface methodology (RSM) and Taguchi’s technique had been used to accomplish the objective of the experimental study. L27 orthogonal array and face centered central composite design had been used for conducting the experiments. Singh H, Kumar P (2006) [3] applied Taguchi’s parameter design approach for optimal setting of process parameters (cutting speed, feed rate & depth of cut) resulted in optimal value of cutting force during machining EN24 alloy steel with TiC coated carbide insert.

A. Methodology
Taguchi’s approach is useful in obtaining the optimum level of control parameters. This approach provides the facility of not performing many experiments as it has Orthogonal Array (OA) of limited set of well balanced experiments.

Various steps in Taguchi method are:
- **Step 1** To identify the quality characteristics or objective function to be optimized and process parameters. Brainstorming, Flow charting, Cause-effect diagrams are the suggested methods used for determining which parameter to include in an experiment.
- **Step 2** To identify the levels of control factors or process parameters. The total degrees of freedom of experiment are a direct function of total number of trials. If the number of levels of a parameter increases, the DOF of the parameter will also increase as the DOF of a parameter is the number of levels minus one. So, increasing the number of levels for a parameter increases the total degree of freedom in the experiment which in turn increases the total number of trials.
- **Step 3** Selection of orthogonal array (OA): When a particular OA is selected for an experiment, the following condition must be satisfied:

\[
\text{Total degree of freedom of an OA} \geq \text{Total DOF required for parameters and interactions.}
\]

\[
\text{Total degree of freedom of an OA} = N - 1
\]

Where, \(N\) is number of trials.

Degree of freedom for interactions of parameters is product of degree of freedom of individual parameters.

The standard two-level and three-level arrays are:
- Two level arrays: \(L_4, L_8, L_{12}, L_{16}\)
- Three-level arrays: \(L_9, L_{18}, L_{27}\)

The subscript in the array shows the number of trials in that array.

Depending on the number of levels in the parameters and total DOF required for the experiment, a suitable OA is selected. Then, interactions to orthogonal array (matrix formation) are done. An OA has several columns to which various parameters and their interactions are assigned.
- **Step 4** Experiments and Data Collection: The experiment is done for each trial conditions of the OA array. Each experiment at a trial condition is repeated in order to reduce chance of error owing to noise factors. Randomization should be carried to reduce bias in the experiment.
- **Step 5** Data Analysis: There are many methods that have been suggested by Taguchi for analyzing the data such as ANOVA, S/N ANOVA, plot of
average responses etc. In plot of average responses at each level of parameter indicates the trend. It is the pictorial representation of the effect of a parameter on the response variable. Similarly ANOVA for OA is conducted in the same manner as other experiments. A standard ANOVA is conducted on raw data which identified the significant parameters.

- **Step 6** Determine Prediction of the mean and Confidence level. In prediction of mean and confidence intervals are the two optimization methods in which the optimum value lies, or lies between these two and confidence interval value is always less than the predicted value. Then the value which will satisfy this condition is the optimum value.

- **Step 7** The last step is confirmation experiment. The confirmation experiment is the final step in verifying the conclusions from the previous round of experimentation. The optimum conditions are set for the significant parameters and a selected number of tests are run under constant specified conditions. The average of the confirmation experiment results is compared with the anticipated average based on the parameters and levels tested. The confirmation experiment is a decisive step and is highly recommend verifying the experimental conclusions.

### III. RESULT ANALYSIS

Various literature studies concluded optimal combination of process parameters for a specific response characteristics in different working condition. I Meddour et al. 2014 [5] demonstrated that the force components were significantly influenced by depth of cut, followed by feed rate. The tool nose radius influences only the thrust force. The best surface roughness was obtained by using small feed rate and large nose radius. Nithyanandhan.T et al. 2014 [10] obtained that cutting speed and depth of cut had significant effect on feed force whereas feed rate and depth of cut were factors that significantly influences on thrust force. The depth of cut and cutting speed had predominant effect on tool wear. Feed rate had less significant effect on tool wear. Mohd. Rafeeq et al. 2014 [11] reported the effects of cutting parameters on the feed and radial force. The experimentally investigated Statistical results(at a 95% confidence level) showed that the depth of cut, and feed rate in affecting the variation of feed and radial forces were significantly larger as compared to the contribution of spindle speed. S.Shivade et al. 2014[15] remarked that for surface roughness the most significant factors were speed then followed by depth of cut and for tool tip temperature the most significant factor were depth of cut followed by speed. Arvind Kumar et al. 2014 [16] showed that the feed rate had an impetus effect on material removal rate. The analysis of material removal rate further confirmed such results. This study concluded the following effect of work piece material: It was noted that mild steel (1018) with hardness rate (107.5 - 172.5 HV), tensile strength (345 - 580 MPa), and density (7861.093 kg/m3) was difficult to machine. Effect of tool material: The coated carbide turning tool had a high elastic modulus. This leads to the more efficient turning of work material as compared to the tool material. Effect of cutting speed, feed rate and depth of cut: Surface roughness increased when feed rate increased, however cutting speed also the influencing parameter followed by depth of cut. Ashish Kabra et al. 2013 [8] The results were analyzed using analysis of variance technique (ANOVA) and prediction models were developed with the help of regression analysis method using Minitab-16 software. Results showed that depth of Cut represented the largest influence on surface roughness, feed and radial forces followed by feed rate, and finally Cutting Speed.

Vikas B. magdum et al. 2013[14] reported the level of parameters at designated levels as A2 (tool material - carbide), B2 (cutting speed- 384), C1 (depth of cut-0.5mm). D1 (feed rate-0.065mm/rev.) were the best combination to get minimum thrust force Z and A2 (carbide tool),B2 (cutting speed-384), C1 (depth of cut -0.5mm). D1 (feed-0.065mm/rev.) were the best combination to get minimum thrust force Z in turning of EN 8 bar. Kapil Sharma et al. 2013 [19] found that the cutting force decreases as the tool rake angle increases. With increase in feed rate, this tends increase in cutting force. The increase in absolute value of negative tool rake angle and cutting speed these results in the decrement of tool chip friction. The tool tip temperature increased with an increase in cutting speed.

C.J. Rao et al. 2103 [21] indicated that it was feed rate which had significant influence both on cutting force as well as surface roughness. Depth of cut had a significant influence on cutting force, but had an insignificant influence on surface roughness. The interaction of feed and depth of cut and the interaction of all the three cutting parameters had significant influence on cutting force, whereas, none of the interaction effects were having significant influence on the surface roughness produced. If power consumption minimization was to be achieved for the best possible surface finish, the most recommended combination of feed rate and depth of cut was also determined. Mahendra Korat et al. 2012 [12] showed that nose radius, depth of cut ,feed rate, cutting speed and coolant condition affected the material removal rate by 40.68 % ,20.96 % , 20.53 % , 14.88 % and0.023 % respectively and nose radius, feed rate, depth of cut, cutting speed and coolant condition affected the surface roughness by 65.38 % ,25.15 % , 3.06 % , 1.41 % and 0.09 % respectively. ANOVA suggested the nose radius and cutting environment were the most significant factors for both surface roughness and MRR.

Raju Shrihari Pawade et al. 2011 [6] applied Taguchi grey relational analysis to experimental results in order to optimize the high-speed turning of Inconel 718 with consideration to multiple performance characteristics. Cutting force components and the surface roughness of the machined components were selected as quality targets. The feed rate showed strongest correlation to cutting forces and surface roughness.

L. B. Abhang et al. 2011 [20] used grey relational analysis for optimizing turning process (cutting speed, feed rate, tool nose radius and concentration of solid –liquid lubricant) for the workpiece surface roughness and chip thickness. It was found that the lubricant type had most significant factor followed by feed rate, cutting speed, and tool nose radius. It was showed that the performance characteristics of the turning process such as surface roughness and chip thickness was improved simultaneously.
by using the method proposed by this study. Aman Aggarwal et al. 2009 [7] found that the percent contributions of depth of cut, cutting environment and feed rate in affecting the variation of feed and radial forces were significantly larger (at 95% confidence level) as compared to the contribution of cutting speed. The percent contribution of nose radius in affecting radial force was significantly much larger compared to feed force.

Gopalsamy et al. 2009 [17] described experimental investigations carried out for machinability study of hardened steel and to obtain optimum process parameters by grey relational analysis. An orthogonal array, grey relations, grey relational coefficients and analysis of variance (ANOVA) were applied to study the performance characteristics of machining process parameters such as cutting speed, feed, depth of cut and width of cut with consideration of multiple responses, i.e. volume of material removed, surface finish, tool wear and tool life. Tool wear patterns were measured using optical microscope and analyzed using scanning electron microscope and X-ray diffraction technique. Chipping and adhesion were main causes of wear. The optimum process parameters were calculated for rough machining and finish machining using grey theory and results were compared with ANOVA. Aman Aggarwal et al. 2008 [13]applied Taguchi’s technique as well as 3D surface plots of RSM which revealed that cryogenic environment was the most significant factor in minimizing power consumption followed by cutting speed and depth of cut. The effects of feed rate and nose radius were found to be insignificant compared to other factors.

Aman Aggarwal et al. 2005 [9] attempted to review the literature on optimizing machining parameters in turning processes by various conventional techniques include geometric programming ,goal programming , sequential unconstrained minimization technique, dynamic programming etc. and latest techniques include fuzzy logic , scatter search technique , genetic algorithm , Taguchi technique and response surface methodology. A review revealed that successful industrial applications of design of experiment based approaches for optimal setting of process variables. Taguchi methods and response surface methodology (RSM) used in industries for making product insensitive to any uncontrollable factors such as environment variable.

C.L. Lin 2004 [4] applied Taguchi method with grey relational analysis for optimizing turning operations with multiple performance characteristics. Tool life, cutting force, and surface roughness were important characteristics and the cutting parameters including cutting speed, feed rate, and depth of cut were optimized in the study. A grey relational analysis of the tool life, cutting force, and surface roughness obtained from the Taguchi method was converted into optimization of the multiple performance characteristics into optimization of a single performance characteristic called the grey relational grade. As a result, optimization of complicated multiple performance characteristics was greatly simplified through this approach. It was shown that the performance characteristics of the turning operations such as tool life, cutting force, and surface roughness were improved together by using the method proposed by this study.

IV. CONCLUSIONS

Review of various latest optimizing techniques such as Taguchi’s approach, grey relational analysis shows significant effect of process parameters i.e. depth of cut, feed rate, cutting speed etc. on performance characteristics like cutting forces, surface roughness, tool flank wear. Literature review concludes by all above discussed optimization techniques that for feed and radial forces most significant factors are depth of cut, cutting environment followed by feed rate then cutting speed. Tool nose radius is significant factor for radial force not for feed and thrust forces. For material removal rate (MRR) most significant factor are depth of cut, feed rate, and speed. Cryogenic environment for turning has remarkable effect on power consumption, surface roughness, and chip thickness. By grey relational environment it is found that significant factor for surface roughness is feed rate then depth of cut and cutting speed.

REFERENCES


