Modeling and Optimization of CNC Turning Parameter using Taguchi Method

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Abstract— In modern competitive world the ultimate goal of manufacturing industries, is to manufacture products at low cost and high quality in short time. Automated and flexible manufacturing systems are employed for that purpose along with CNC machines that are capable of achieving high quality and very low processing time. Metal cutting process is one of the complex process which has several factors contributing towards the quality of the finished product. Turning is one of the most common methods for cutting and especially for machining cast parts. Furthermore, in order to produce any product with high cutting performance, selection of proper cutting parameter is very important. To select the cutting parameters, several mathematical models based on statistical techniques and neural networks have been developed to establish a relation between cutting parameters and cutting performance. The objective of this paper is to review of application of Taguchi method and other statistical method for optimization of turning Parameters to meet the customers' demands.

Key words: Power Optimization, CNC Turning, Taguchi Technique, Cutting Parameters, MRR, Design of Experiments (DOE), Surface Roughness (SR)

I. Introduction

Every manufacturing industry aims at producing a large number of products with in relatively lesser time. But it is felt that reduction in manufacturing time may cause severe quality loss. In order to embrace these two conflicting criteria, it is necessary to check quality level of the item either on-line or off-line. Metal cutting is widely used manufacturing processes in engineering industries and in today's manufacturing scenario, optimization of metal cutting process is essential for a manufacturing unit to respond effectively to highly competitive environment in the market and increasing demand of quality which has to be achieved at minimal cost.

As flexibility and adaptability needs growing in the manufacturing industries, computer numerical control systems were introduced in metal cutting processes that provided automation of processes with very high accuracies and repeatability. Because of high cost of numerically controlled machine tools compared to their conventional machines, there is an economic need to operate these machines as effectively as possible in order to obtain the require payback. Product quality, productivity and cost management became an important goal in manufacturing industries. Quality of a product can be described by various quality attributes. The attributes may be quantitative or qualitative.

This requires optimization of parameters Optimization is to seek identification of the best parametric combination for the said manufacturing process. If the problem is related to a single quality attribute, then it is called single objective (or response) optimization. If more than one attribute is in consideration it is very difficult to select the optimal setting which can achieve all quality requirements simultaneously. Otherwise optimizing one quality feature may lead severe quality loss to other quality characteristics which may not be accepted by the customers.

II. Taguchi's Approach

It is a statistical methods developed by Genichi Taguchi to improve the quality of manufactured goods, and more recently also applied to engineering [3] biotechnology [4], marketing and advertising It includes both upstream and shop-floor quality engineering [5]. Upstream methods efficiently use small-scale experiments to reduce variability and remain cost-effective, and robust designs for large-scale production and market place. Shop-floor techniques provide cost-based, real time methods for monitoring and maintaining quality in production [6]. Traditional experimental design methods are very complicated and difficult to use. Additionally, these methods require a large number of experiments when the number of process parameters increases. In order to minimize the number of tests required, Taguchi experimental design method, a powerful tool for designing high-quality system, was developed by Taguchi. This method uses a special design of orthogonal arrays to study the entire parameter space with small number of experiments only [7]. In this design analysis each factor is evaluated independent of all other factors [8] Taguchi approach to design of experiments in easy to adopt and apply for users with limited knowledge of statistics, hence gained wide popularity in the engineering and scientific community. [9]

Quality is often approached to as conformance to specifications. However, Taguchi proposes a different view of quality as one that relates it to cost and loss in money, not just to the manufacturer at the time of production but to the consumer and to the society as a whole. According to Taguchi (2005), Loss is usually thought of as additional manufacturing cost incurred upto the point the product is shipped.

In case of machining, the energy consumed or the power demand varies because of noise variables which are classified as inner, outer and between product noises. To minimize the effects caused by these noise variables, some countermeasures may be considered. The most important is by design which involves 1) system design 2) parameter design and 3) tolerance design.

A. Parameter Design

This is used to reduce the influence of sources of variation. It is the most important step in developing stable and reliable products or manufacturing processes. With this technique, we find a combination of parameter levels that are capable of damping the influences of noise signals and also allow achieving the desired quality characteristics.

Most important in applying design of experiments is to select objective quality characteristics with the intention of designing a process that is reliable to wide range of performance conditions but at lowest price. The quality characteristics in case of machining can be surface roughness, tool wear, energy consumption, and lot more. This work focuses on energy as the quality characteristic and as smaller-the-better characteristic with an ideal target being zero [Ross, 1996].

III. Literature Review

[10] They investigated the multi-response optimization of the turning process for an optimal parametric combination to yield the minimum cutting forces and surface roughness with the maximum material-removal rate (MRR) using a combination of a Grey relational analysis (GRA) and the Taguchi method. The objective functions were selected in relation to the parameters of the cutting process: cutting force, surface roughness and MRR. The Taguchi approach was followed by the Grey relational analysis to solve the multi-response optimization problem. This shows that a proper selection of the cutting parameters produces a high material-removal rate with a better surface roughness and a lower cutting force. The Grey-based Taguchi method was applied for the multiple performance characteristics of turning operations. A grey relational analysis of the material-removal rate, the cutting force and the surface roughness obtained from the Taguchi method reduced from the multiple performance characteristics to a single performance characteristic which is called the grey relational grade. The optimization of the complicated multiple performance characteristics of the processes can be greatly simplified using the Grey-based Taguchi method.

[11] This paper emphasis on selection of cutting tool, work tool material & geometry, selection of various process and performance parameters after parameter selection aims to study various techniques for the optimization. The process and machining parameters for the performance characteristics of turning operation on CNC using different grades of Tungsten Carbide and with varying properties and surface roughness testing of work piece material is to be carried out after machining. After testing optimization and the Effect of cutting parameters on surface roughness of different selected geometry on EN-24 alloy steel by using Taguchi Analysis Statistical Software is being compared. On comparing the calculated values of MRR for three specimen of same material (EN-24) machined with different grades of tool, observed that specimen B (uncoated), C (TNMG) has the maximum value of MRR which fulfil the condition. Most defects in turning are inaccuracies in a feature's dimensions or surface roughness. There are several possible causes for these defects, including incorrect cutting parameters, dull cutting tool, and unsecured work piece.

[12] This paper presents how to utilize Taguchi methods to optimize surface roughness, tool wear and power required to perform the machining operation in turning metal matrix composites (MMC). The cutting parameters are analyzed under varying cutting speed, feed rates and cutting time. The settings of turning parameters were determined by using Taguchi's experimental design method. From the analysis, the conceptual signal-to-noise(S/N) ratio approach, analysis of variance (ANOVA) provides a systematic and efficient methodology for the optimization of cutting parameters. It shows that surface roughness, tool wear and power required can be improved significantly for turning MMC.

[13] This paper elaborates the Taguchi robust parameter design for modeling and optimization of surface roughness in dry single-point turning of cold rolled alloy steel 42CrMo4/AISI 4140 using TiN-coated tungsten carbide inserts was presented. Three cutting parameters, the cutting speed (80, 110, 140 m/min), the feed rate (0.071, 0.196, 0.321 mm/rev), and the depth of cut (0.5, 1.25, 2 mm), were used in the experiment. Each of the other parameters was taken as constant. The average surface roughness (Ra) was chosen as a measure of surface quality. The experiment was designed and carried out on the basis of standard L27 Taguchi orthogonal array. The surface roughness was most affected by cutting speed. The impact of feed rate was somewhat smaller, while the influence of depth of cut was least pronounced. On the other side, in qualitative terms, the influence of feed rate and depth of cut on the surface quality was opposite in relation to cutting speed. In fact, while the increase of cutting speed caused better surface quality, the increase of feed rate and depth of cut led to the decrease of surface quality.

[14] This paper discusses an investigation into the use of Taguchi Parameter Design for optimizing surface roughness generated by a CNC turning operation. This study utilizes a standard orthogonal array for determining the optimum turning parameters, with an applied noise factor. Controlled factors include spindle speed, feed rate, and depth of cut; and the noise factor is slightly damaged jaws. The noise factor is included to increase the robustness and applicability of this study. After experimentally turning sample workpieces using the selected orthogonal array and parameters, the results of this study indicate that t Feed rate had the highest effect on surface roughness, spindle speed had a moderate effect, and depth of cut had an insignificant effect. This would indicate that feed rate and spindle speed might be included alone in future studies while The noise factor, "damaged" and new chuck jaws, was not found to have a statistically significant effect here, although the inclusion of this noise could still help make this experiment robust.

[15] This paper outlines an experimental study to optimize the effects of cutting parameters on surface finish and MRR of EN24/AISI4340 work material by apply Taguchi techniques. The orthogonal array, signal to noise ratio were employed to study the performance characteristics in turning operation. Five parameters Speed, Feed, Depth of cut, Nose radius, cutting environment (wet and dry) were considered as process variable. Taguchi's L18 Orthogonal Array (OA) was employed for experimentation plan Optimal cutting parameters for, minimum surface roughness (SR) and maximum material removal rate were obtained to increase machine utilization and decrease production cost in an automated manufacturing environment.

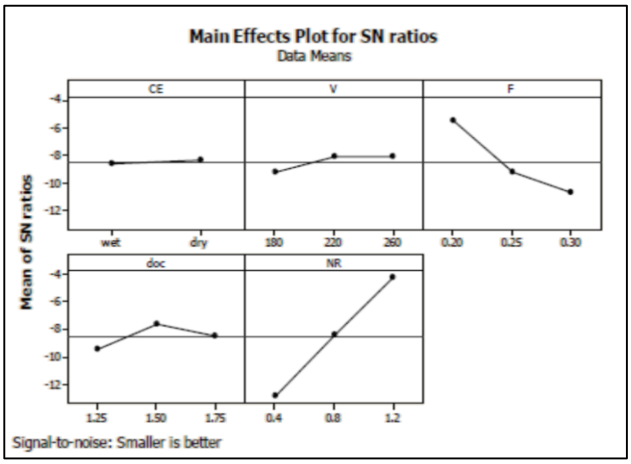

Fig. 1: Effects of Process Parameters on Surface Roughness

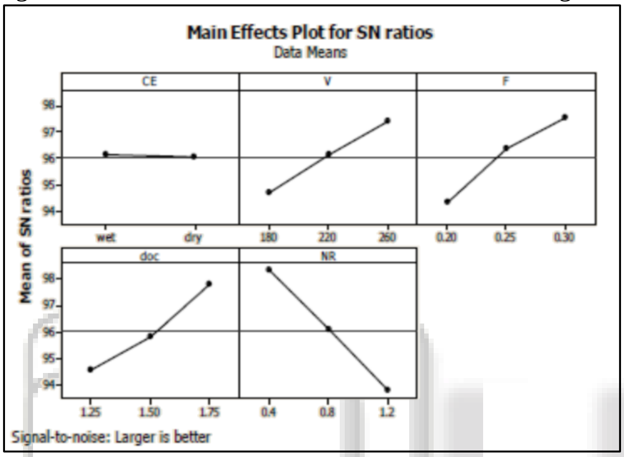

Fig. 2: Effects of Process Parameters on MRR

Experimental result using Taguchi approach suggests that nose radius is the most significant factor and cutting environment is most in significant factor for both surface roughness and MRR. ANOVA (S/N Data) results shows that nose radius, depth of cut, feed rate, cutting speed and coolant condition affects the material removal rate by 40.68 %, 20.96 %, 20.53 %, 14.88 % and0.023 % respectively.

[16] In this paper author focused to manufacture products at low cost and high quality in short time. Automated and flexible manufacturing systems are employed for that purpose along with CNC machines that are capable of achieving high accuracy and very low processing time. Furthermore, in order to produce any product with high cutting performance, proper cutting parameters have to be selected. To select the cutting parameters Taguchi's technique is being used. Experiment was conducted on a CNC lathe with cutting speed, feed rate and depth of cut as process parameters and energy consumption was measured. The S/N ratio was computed for each trial and plotted for each factor as shown in the fig 3.

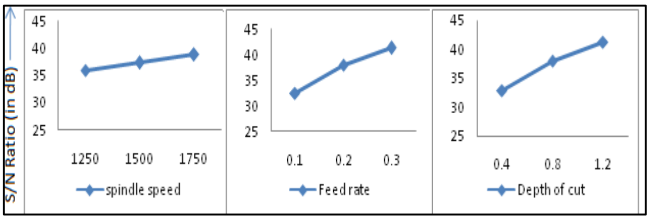

Fig. 3: S/N ratios for three factors

It is seen from the plot that the variations are more for feed rate and depth of cut. The data were analyzed and appropriate process parameters were selected for minimum energy consumption. Using experimental data, both power and energy are compared with material removal rate which shows that, as material removal rate increases power demand increases and energy consumption decreases.

[17] This paper entitled experimental study of roughness characteristics of surface profile generated in CNC turning of AISI 1040 mild steel and optimization of machining parameters based on genetic algorithm. The three level rotatable central composite designs are employed for developing mathematical models for predicting surface roughness parameters. Response surface methodology is used in analyzing the effect of process parameters on different surface roughness parameters. The experimentation is carried out considering three machining parameters, viz., depth of cut, spindle speed and feed rate as independent variables and three different roughness parameters, viz., centre line average roughness, root mean square roughness and mean line peak spacing as response variables. For prediction of roughness

Parameters within the selected experimental domain, the quadratic models are developed and these are used as the objective function for optimization. It is seen that the surface roughness parameters R_a, R_q and R_{sm} decrease with increase in depth of cut and spindle speed but increase with increase in feed an attempt has also been made to optimize the cutting parameters using genetic algorithm to achieve minimum surface roughness.

[18] This paper involves an investigation of identifying the optimized parameters in CNC turning of martensitic stainless steel. The optimization technique used are Response surface methodology, and Genetic algorithm. These optimization techniques are very helpful in identifying the optimized control factors with high level of accuracy. A detailed study on the surface roughness of the martenstic stainless steel (SS40). The detailed study and the optimization procedure has been made to study the effect of speed, feed and depth of cut while machining which would help in real practice. The machining parameter ranges were analyzed and then the experimentation was carried out according to the optimization approaches. The results obtained from RSM indicate that selected parameters (speed, feed, depth of cut) significantly affect the response (surface roughness). The Best ranges obtained by using the genetic algorithm approach are Cutting velocity (speed) -119.93 m/min, Feed-0.15 m/min and Depth of cut -0.5mm. Hence the Optimal surface roughness from GA is 0.74 microns.

[19] This paper elaborate Taguchi method through a case study in straight turning of mild steel bar using HSS tool for the optimization of process parameters. Influences of turning process variables on surface Roughness mild steel have been studied in this research. Lathe used in turning of work piece is Centre Lathe, with 03Phase induction motor a/c and work piece AISI 1040 MS bars of diameter 25mm and length 45mm. The machining variables included cutting speed, feed rate and depth of cut. The variables affecting the Surface Roughness significantly were identified using ANOVA technique. Results show that cutting speed and depth of cut were significant variables to the SR of mild

steel. Surface roughness decreases with increase in spindle speed. SR increases with increase in depth of cut.

[20] Authors investigated the machining parameters affecting the roughness of surfaces produced in hard turning process for three different materials like EN8 steel, Aluminium alloy and Copper alloy under dry conditions. Three parameters were selected for study: cutting speed, feed and material hardness. For the three materials like Aluminium alloy, copper alloy and EN8 steel impact of increase in feeds versus decrease in cutting speeds with constant depth of cut adopted to analyze the influence of these parameters on the generated surface roughness. Regression analysis using MINITAB software for all the three material turning operation data mining was used to create model for the prediction of the average surface roughness (R_a) in terms of cutting speed, feed and material hardness and 67.2% of R2 and 47.52% of R2(adj) were obtained. The investigations of this study indicate that the cutting parameters like cutting speeds and feeds are the primary influencing factors, which affect the surface finish when machining with new tool inserts. The results indicate that feed is the dominant factor affecting the surface roughness, followed by cutting speed and hardness of the material.

[21] they have analyzed the surface roughness produced by turning process on hard martensitic stainless steel by Cubic Boron Nitride cutting tool. The experiments were designed using various operating parameters like cutting speed, feed rate and depth of cut. These operating parameters are predominantly used in carrying out the experiments. Low surface roughness was produced at cutting speed of 225 m/min with feed rate of 0.125 mm/rev and 0.50 mm depth of cut (doc). However, moderate cutting speed of 175 m/min under above feed rate and doc is an ideal operating parameters taking flank wear in to account. All experiment data were obtained on AISI 440 C hardened steel having hardness between 45 to 55 HRC. The surface roughness was measured using Mitutoyo SJ 400 make. The work piece material was received as 1000 mm length bar having 50 mm diameter. This was cut to 350 mm length. The followings conclusions were drawn based on experiments conducted on hard AISI 440 C stainless steel. 1. The surface roughness was 23 microns at high cutting speed of 225 m/min with feed rate of 0.125 and 0.50 mm doc. This may be ideal cutting speed to operate. 2. However, operating at 175 cutting speed with 0.125 feed rate and doc of 1.00 mm may be more suitable taking the flank wear in to consideration.

[22**]** they optimization of machining parameters in turning of AISI 202 austenitic stainless steel using CVD coated cemented carbide tools. During the experiment, process parameters such as speed, feed, depth of cut and nose radius are used to explore their effect on the surface roughness (Ra) of the work piece. The experiments have been conducted using full factorial design in the Design of Experiments (DOE) on Computer Numerical Controlled (CNC) lathe in the Experimental the machining process was studied under DOE whereby the factorial portion is a full factorial design (24) with all combinations of the factors at two levels. Cutting tests were carried out on 10 hp CNC lathe machine under dry conditions. The machining process on CNC lathe is programmed by speed, feed, and depth of cut. In total 16 work pieces (Φ25 mm x 70mm) are prepared. These work pieces cleaned prior to the experiments by removing 0.5mm thickness of the top surface from each work piece in order to eliminate any surface defects and wobbling. They find 57.59% contributed by the feed on surface roughness. In order to obtain a good surface finish on AISI 202 steel, higher cutting speed, lower feed rate, lower depth of cut.

IV. Conclusions

The developed models according to Taguchi methodology using MINITAB are reasonably accurate and can be used for prediction within limits. Taguchi gives systematic simple approach and efficient method for the optimum operating conditions.

Results show that cutting speed and depth of cut were significant variables to the Surface roughness(SR) of mild steel. Surface roughness decreases with increase in spindle speed. SR increases with increase in depth of cut. With the increase in feed rate the surface roughness also increases & as the cutting speed decreases the surface roughness increases.

On the flank wear result, cutting speed has significant effect on tool wear. The depth of cut has also had effect on flank wear. It is clear that by reducing the depth of cut, the flank wear can be controlled.

The MRR is increased by increasing any of the process parameters. With the increase in cutting speed the MRR increases & as the feed rate increases the MRR also increases. The feed rate has significant influence on both the Cutting force and Surface roughness. Depth of cut has a significant influence on cutting force, but negligible influence on surface roughness.

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