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REVIEW ARTICLE

IMPLEMENTING TAGUCHI OPTIMIZATION METHOD IN TURNING – A REVIEW

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ABSTRACT

In highly competitive manufacturing industries nowadays, the general manufacturing problem can be described as the achievement of a predefined product quality with given equipment, cost and time constraints. Unfortunately, for some quality characteristics of a product such as surface roughness it is hard to ensure that these requirements will be met. To achieve these goals, one of the considerations is by optimizing the machining parameters such as the cutting speed, depth of cut, feed rate. Recently, alternative to conventional techniques, evolutionary optimization techniques are the new trend for optimization of the machining parameters. The present work is an effort to review the literature on optimizing these machining parameters in turning processes. The objective of this review is to study the effect of cutting speed, feed, and depth of cut on surface roughness and cutting forces in dry, wet and MQL type turning by employing Taguchi optimization techniques. Present work concludes that Taguchi technique is widely used in optimizing the turning operation and MQL turning can be alternative to dry and wet turning.

INTRODUCTION

The modern industry technology is advancing towards the automation and to fulfill the technological needs engineers should be ready to achieve product of good surface finish, economic production, less wear of cutting tool with optimizing the use of resources (Thamizhmanii and Hasan, 2006). One of the most important, vital and widely used manufacturing processes in engineering industries is metal cutting which is defined as metal removal of chips from job to achieve the desired product of appropriate shape, size and surface roughness (Anil Gupta *et al*., 2011). In metal cutting most regularly used method is turning in which a cutting tool does metal removal by giving feed in a parallel direction to the axis of rotation (Abhang and Hameedullah, 2010). Stainless steels are used to fabricate chemical and food processing equipment, pressure vessels, cryogenic vessels as well as machinery parts requiring high corrosion resistance. Stainless steels are characterized by a high work hardening rate and low thermal conductivity, They are generally regarded as more difficult to machine than carbon and low alloy steels on account of their high strength, high work hardening tendency and poor thermal conductivity. Problems such as poor surface finish and high tool wear are common in stainless steel. Work hardening is recognized to be responsible for the poor machinability of austenitic stainless steels.

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In addition, stainless steel material bond very strongly to the cutting tool during cutting and when chip is broken away, it may bring with it a fragment of the tool, particularly when cutting with cemented carbide tools. During the machining of stainless steel cutting force variation is also much more obvious than those when machining unalloyed steel (Ihsan Korkut *et al*., 2004). Carbide cutting tools are very popular in metal cutting industry for the cutting of various hard materials such as, alloy steels, die steels, high speed steels, bearing steels, white cast iron and graphite cast iron. In the past few decades there had been great advancements in the development of these cutting tools. Coating is also used on cutting tools to provide improved lubrication at the tool/chip and tool/work piece interfaces and to reduce friction, and to reduce the temperatures at the cutting edge.

During machining, coated carbide tools ensure higher wear resistance, lower heat generation and lower cutting forces, thus enabling them to perform better at higher cutting conditions than their uncoated counterparts. The use of coated tools are becoming increasingly demanding among the other tool materials. More than 40% of all cutting tools are coated in modern industry (Harsh Y Valera and Sanket N Bhavsar, 2014). Cutting forces are the background for the evaluation of the necessary power machining. They are also used for dimensioning of machine tool components and the tool body. They influence the deformation of workpiece machined, its dimensional accuracy, chip formation and machining system stability (Aouici and Yallese, 2013).

Turning produces three cutting force components, (the main cutting force i.e. thrust force (F_Z) produces in the cutting speed direction, feed force (F_X) produces in the feed rate direction and the radial force (F_Y) which produces in radial direction and which is normal to the cutting speed). Out of three force components the cutting force (main force) constitutes about 70% to 80% of the total force 'F' and is used to calculate the power 'P' required to perform the machining operation. Power is the product of main cutting force and the cutting velocity and is a better criterion for design and selection of any machine tool (Harsh Y Valera and Sanket N Bhavsar, 2014). Surface roughness plays an important role as it influences the fatigue strength, wear rate, coefficient of friction, and corrosion resistance of the machined components. In actual practice, there are many factors which affect the surface roughness i.e. tool variables, workpiece hardness and cutting conditions. Tool variables include tool material, nose radius, rake angle, cutting edge geometry, tool vibration, tool point angle, etc. In hard turning, surface finish has been found to be influenced by a number of factors such as feed rate, cutting speed, tool nose radius and tool geometry, cutting time, workpiece hardness, stability of the machine tool and the workpiece set up etc.

(Aouici and Yallese, 2013). Highly competitive market requires high quality products at minimum cost. Products are manufactured by the transformation of raw materials. Industries in which the cost of raw material is a big percentage of the cost of finished goods, higher productivity can be achieved through proper selection and use of the materials (Fnides, 2008). To improve productivity with good quality of the machined parts is the main challenges of metal industry; there has been more concern about monitoring all aspects of the machining process. Surface finish is an important parameter in manufacturing engineering and it can influence the performance of mechanical parts and the production costs. The ratio of costs and quality of products in each production phase has to be monitored and quick corrective actions have to be taken in case of deviation from desired output. Surface roughness measurement presents an important task in many engineering applications. Many life attributes can be also determined by how well the surface finish is maintained (Harsh Y Valera and Sanket N Bhavsar, 2014).

EEFECT CUTTING PARAMETERS

In this connection, two important aspects which are widely studied in turning operations are cutting forces and surface roughness of the work-piece. Process parameter optimization is of great significance while looking into the process capability of any machining operation. Cutting forces in turning operations are very important to analysis as a number of factors are influenced by it, namely, surface accuracy, tool wear, tool breakage, cutting temperature, self-excited and forced vibrations, etc. Cutting parameters (Feed rate, Cutting Speed, Depth of Cut, tool geometry and material properties of tool) directly influence the surface finish of machined components. However, among the cutting force, thrust force, and feed force, the former prominently influences power consumption and this work considers only cutting force as one of the endogenous factors. Surface roughness is also a vital measure as it may influence frictional resistance, fatigue strength or creep life of machined components.

As far as turned components are concerned, better surface finish (low surface roughness) is important as it can reduce or even completely eliminate the need of further machining (Raoa *et al*., 2013). Many researchers have found that surface roughness has bearing on heat transmission, ability to hold lubricant, surface friction, wearing etc. Despite the fact that surface roughness plays a very important role in the utility and life of a machined component due to its dependence on several process parameters and numerous uncontrollable factors machining process has no complete control over surface finish obtained. So, the venture of controlling process parameters so as to produce best surface finish is an on-going process varying from various materials to tool combinations and the machining conditions. Literature is very rich in terms of turning operation owing to its importance in metal cutting.

The three important process parameters in this research are speed, feed and depth of cut. Surface roughness of a turned work-piece is dependent on these process parameters and also on tool geometry such as nose radius, rake angle, side cutting edge angle and cutting edge. In addition, it also depends on the several other exogenous factors as work piece and tool material combination and their mechanical properties, quality and type of the machine tool used, auxiliary tooling, and lubricant used, and vibrations between the work piece, machine tool and cutting tool (Dogra *et al*., 2011). The cutting fluids are used in machining processes to improve the characteristics of tribological processes, which are always present on the contact surfaces between tool and workpieces. Due to several negative effects, a lot has been done in the recent past to minimize or even completely avoid the use of cutting fluids (Ross, 1996). Minimum quantity of lubrication (MQL) in machining is an alternative to completely dry or flood lubricating system, which has been considered as one of the solutions for reducing the amount of lubricant to address the environmental, economical and mechanical process performance concerns (Heinemann *et al*., 2006). MQL refers to the use of cutting fluids of only a small amount, flow rate in the range 50–500 ml/h. The minimum quantity lubricants have the advantages of advanced thermal stability and lubricating (Davim *et al*., 2007).

Comparative investigation of dry and wet turning is studied by selecting cutting velocity of 190, 220, 240 and 260 m/min, feed rate of 0.14 mm/rev and depth of cut of 0.5 and 1.0 mm on AISI 1050 steel using coated carbide tool, it is found that cutting speed did not show a significant effect on surface roughness for both dry and wet machining conditions. The cutting fluid enabled in reducing the main cutting force due to improved and intimate chip-tool interaction (Yahya Isik, 2010). By selecting cutting speed of 252, 273 and 306 m/min, Feed rate of 0.2, 0.35 and 0.5 mm/rev and depth of cut as 0.5, 0.75, 1 mm in the dry and wet turning process of AISI 422 stainless steel the it is observed that dry machining achieved the appropriate surface quality at higher cutting speed and less feed rate speed but result are increase of the temperature and high cutting forces (Galanis *et al*., 2008). In plain turning of AISI-1040 steel with cutting velocity of 64, 80, 110 and 130 m/min, Feed rate of 0.10, 0.13, 0.16 and 0.20 mm/rev and depth of cut of 1.0 mm it is found that in MQL turning dimensional accuracy improved mainly due to reduction of wear and damage at the tool tip (Dhar *et al*., 2006).

In the comparative performance of MQL and dry turning of AISI-1040 steel with Cutting velocity of 72, 94, 139 and 164 m/min, Feed rate of 0.10, 0.13, 0.16 and 0.20mm/rev and depth of cut of 1.5 mm it is investigates that MQL reduced the cutting forces by about 5–15% (Dhar *et al*., 2007). The overall performance of the cutting tools during minimal cutting fluid application was found to be superior to that compared to dry turning and conventional wet turning on the basis of parameters such as cutting force, temperature and surface finish (Vikram Kumar and Ramamoorthy, 2007). Speed, feed and depth of cut are three important process parameters which prominently affect cutting forces and surface roughness (Raoa *et al*., 2013). The regeneration methods of used cutting fluids would also provide various advantages such as reducing cutting the fluids cost, disposals cost of used cutting fluids and nearly eliminating environmental pollution (Çakīr and Yardimeden, 2007).

It has been established that ecology-friendly vegetable-based oils could successfully replace petroleum-based mineral oils as cutting fluids. With slight modifications and deliberate but careful alterations in some of the components of such oils, even better performing cutting fluids could be obtained (Sharafadeen Kunle Kolawole and Jamiu Kolawole Odusote, 2013). The overall results are Increases in feed rate and cutting depth affect the surface quality negatively, while the increase of nose radius affects it positively (Yahya Isik, 2007).

TAGUCHI METHOD

Main concern is to achieve improved quality and economic productivity with reduced cost and time. It is challenging to acquire good surface finish and less tool wear while working with materials having high strength, corrosive resistance and wear resistance in turning. In order to overcome the above problem, optimized cutting parameters are to be employed (Ranganathan and Senthilvelan, 2010). Various types of optimization techniques are available for optimization of cutting parameter in turning process i.e. Taguchi method, Analysis of variance (ANOVA), Response surface methodology (RSM), Multiple regression analysis, Genetic algorithm(GA), Fuzzy logic, Artificial neural network etc (Saini and Pradhan, 2014).

Amongst the all optimization techniques the Taguchi methods is latest design techniques widely used in industries because it provides simple, systematic and efficient methodology for optimization of machining parameters (Narinder Kumar and Nirpakash Uppal, 2013). Taguchi method has strong statistical background, applied to a wide range of engineering problems where the size of the search space must be reduced and it has potential for savings in experimental time and cost on product or process development and quality improvement (Abhang and Hameedullah, 2012; Benardos and Vosniakos, 2003; Aman Aggarwal and Hari Singh, 2005). According to Taguchi “Quality is the loss imparted to society from the time a product is shipped.” Science experimental procedures are generally expensive and time consuming we need to satisfy the design objective with minimum number of tests (Amitava Mitra, 2008). Taguchi method involves laying out the experimental condition using orthogonal array.

It is a specially constructed table which ensures that experiment design is both straight forward and consistent. By adopting this method number of analytical exploration needed to get the required design is significantly reduced. Hence testing time and experimental cost both are reduced. Orthogonal array provides much reduced variance for the experiment resulting optimum setting of process control parameter. It is carried in three step approach i.e. system design, parameter design, tolerance design. In system design, scientific and engineering principles are used to generate a prototype of the product that will encounter functional requirements. Parameter design is to optimize the settings of process parameter values for enlightening performance characteristics. And in tolerance design, tolerances are set around the target a value of the control parameter identified in the parameter design phase and is done only when the performance variation attained by the settings identified in the parameter design stage is unacceptable (Davis and John, 2013). Taguchi method is a powerful tool for design of experiments (DOE) which serves as a basis for optimization of various engineering processes.

It is an important tool to identify the critical parameters and also predict optimal settings for each process parameter. This methodology has been widely adopted in the experimental design related to a large variety of machining processes (Thakur *et al*., 2009; Dewangan *et al*., 2013). By this method the product quality is defined in terms of loss function (S/N ratio), due to deviation of the product's functional characteristics from its desired target value. Taguchi method uses a special design of orthogonal arrays (OA), where the experimental results are transformed into signal-to-noise (S/N) ratio as the measure of the quality characteristic. An OA is a small fraction of full factorial design and assures a balanced comparison of levels of any parameter or interaction of parameters. The columns of an OA represent the experimental parameters to be optimized and the rows represent the individual trials (combinations of levels). Traditionally, data from experiments are used to analyze the mean response. Taguchi method estimates the effects of factors on the response mean and variation. In Taguchi method the mean and the variance of the response (experimental result) at each parameter setting in OA are combined into a single performance measure known as the signal-to-noise (S/N) ratio.

The S/N ratio is a quality indicator by which the experimenters can evaluate the effect of changing a particular experimental parameter on the performance of the process. Depending on the criterion for the quality characteristic to be optimized, the S/N ratio characteristics can be divided into three stages: smaller-the-better, larger-the better, and nominal-the-better. Regardless of the category of the performance characteristic, the larger S/N ratio corresponds to the better performance characteristic. Therefore, the optimal level of the parameter is the level with the highest S/N ratio. The optimal parameter levels are determined using the analysis of means (ANOM) and analysis of variance (ANOVA). A confirmation experiment is the final step in Taguchi method and it is used to verify the optimal combination of the parameter settings. There are some studies regarding optimization of cutting parameters based on cutting force in turning operation using Taguchi method (Singh *et al*., 2005; Petropoulos *et al*., 2005 and Phadke, 1989).

The optimal level for a process parameter is the level, which results in highest value of S/N ratio in the experimental region. The original Taguchi method is applied to optimize a single quality characteristic. However, most of the processes have several performance characteristics and hence there is a need to obtain single optimal process parameters setting. Several modifications are suggested to the original Taguchi optimization technique for multi-performance characteristics optimization (Jeyapaul *et al*., 2005).

IMPLEMENTING TAGUCHI METHOD IN TURNING

In the detailed experimental investigation in hard turning of X38CrMoV5-1 (50 HRC) steel with CBN tool the effects of cutting speed, feed rate and depth of cut on the cutting force components and the surface roughness parameters are studied. A three-factor, three-level factor technique can be employed easily to develop a mathematical model for predicting surface roughness parameters and cutting force components of cutting conditions during the turning operation (Aouici and Yallese, 2013). Taguchi method with L27 design is applied in order to optimize cutting parameters based on cutting force in a longitudinal turning of an alloy steel EN24 in which cutting speed, feed and depth of cut are considered as control factors with three levels and response factor is feed force (Singh and Kumar, 2006).

Considering cutting forces and surface roughness as output parameters the Taguchi L27 OA is applied for optimization of cutting parameters for three factors three levels i.e. speed of 50, 75, 95 m/min, feed of 0.05, 0.10, 0.15 mm/rev and depth of cut of 0.25, 0.50, 0.75 mm in dry turning of AISI 1050 steel [8]. In dry turning mild steel using high speed steel cutting tool effect of cutting factors on surface roughness (Ra) and cutting force (Fc) are studied using analysis of variance (ANOVA) by selecting three factor and three level i.e. speed of 228, 360, 450 rpm, feed of 0.11, 0.18, 0.75 mm/rev, depth of cut of 0.25, 0.50, 0.75 mm (Rodrigues and Kantharaj, 2012). Taguchi L9 OA is applied to optimize the cutting parameters in dry turning of S235 G2T steel using three factors three level of cutting parameters i.e. cutting speed of 78.54, 142.94, 314.16 m/min; feed of 0.049, 0.107, 0.214 mm/rev and depth of cut of 1.75, 3.50, 7.00 mm, it is investigated that depth of cut contributes 60.63% for main cutting force and 70.18% for feed force, followed by the feed contributes 36.96% for main cutting force and 22.08% for feed force. The cutting speed has smaller effect with contribution of 1.77% for main cutting force and 5.88% for feed force (Miroslav and Radovanović, 2012).

Taguchi method is employed in the comparative performance of dry and wet turning with three-level L27 orthogonal array and three factors i.e. cutting speed of 54, 150 m/min, feed rate of 0.11, 0.22, 0.33 mm/rev, and depth of cut of 0.50, 1.00, 1.50mm, it is observed that dry turning produces better dimensional accuracy compared to that produced and no considerable difference in surface roughness is produced by dry and flood turning (Rafai and Islam, 2010). In the MQL and wet turning processes of AISI 1045 work material with the objective of suggesting the experimental model in order to predict the cutting force and surface roughness the measured data were analyzed by regression analysis and verification experiments were conducted to confirm the results. From the experimental results and regression analysis, this research project suggested the experimental equations, proposed the optimal cutting parameters, and analyzed the effects of cutting parameters on surface roughness and cutting force in the MQL and wet turning processes (Young Kug *et al*., 2010). The Taguchi method and factorial design employed to addresses the results and analysis from the experiments of turning aluminum material by adopting L9 orthogonal array. It is observed that effect of MQL is better than the others but not so significant but it needs further research (Jong-Yun Jung and Xiangyu Hou, 2006).

Conclusion

Steel material has various industrial applications so details analysis machining with steel has to be carried out of in order to achieve the good surface quality. Machining with coated carbide tool provide various advantages i.e. reduced cutting forces, high wear resistance, improved lubricating effect, reduce friction, reduced temperatures at the cutting edge etc. Effect main cutting force and thrust force has to be evaluate properly in the machining process because they influence the deformation of workpiece machined, its dimensional accuracy, chip formation and machining system stability. machining with cutting fluid and cutting without fluid has several positive and negative effect hence switching from fluid cutting or dry to MQL cutting will best solutions for reducing the amount of lubricant to address the environmental, economical and mechanical process performance concerns. MQL refers to the use of cutting fluids of only a small amount, flow rate in the range 50–500 ml/h.

A review of literature shows that large number research has been perform to find the effect of cutting parameters on surface quality and cutting forces in machining selecting various combination of cutting parameters. From the various cutting parameters speed, feed rate and depth of cut has strong effect on machining outputs i.e. surface quality, cutting forces etc. Review of literature also gives importance of implementing Taguchi method for optimizing the cutting parameters in the turning process. Extensive research show effect and contribution each cutting parameters on cutting forces, surface roughness in different cutting environments. Still there is some contradiction in order to predict the effect cutting parameters on cutting forces, surface roughness. MQL turning is better than dry and wet turning but further research is needed to remove the contradiction.

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