Effect of various process parameters on Surface roughness in CNC turning: A Review

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Abstract--- 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. This paper aims at presenting the review on various methodologies and practices that are being employed for the prediction of surface roughness. The objective of this research is to analyze the effects of machining parameters on surface roughness quality.

I. INTRODUCTION

Now-a-days, due to the growing demand of superior quality components for its functional aspect, surface roughness of a machined part plays a significant role in the modern manufacturing process. A good quality machined surface appreciably improves fatigue strength, corrosion resistance and creep life. Surface roughness also influences some functional characteristics of parts, such as, contact causing surface friction, wearing, light reflection, heat transmission, ability of distributing and holding a lubricant, load bearing capacity coating etc. Consequently, the desired finish surface is generally specified and the appropriate cutting parameters are preferred to attain the required quality. Selection of appropriate machining parameters is an important step in the process planning of any machining operation. The present method of selection of machining parameters mainly depends either on previous work experience of the process planner or thumb rule or any machining data hand book. But it is a known fact that the machining parameters obtained from these resources are far from the optimal parameters and may be very much useful for theoretical investigations. The surface roughness of any manufacturing process has become critical because of increased quality demands. Sometimes, even if the dimensions of the component are well within the dimensional tolerances, still there are possibilities of rejecting the component for the lack of required surface finish. Surface roughness is an important measure of the quality of a product and also greatly influences the production cost. Production of required surface finish on a component is mainly dependent on many parameters such as cutting speed, feed, depth of cut, tool nomenclature, cutting force, rigidity of the machine and so on.

II. TURNING

Turning is a form of machining, a material removal process, which is used to create rotational parts by cutting away unwanted material. Turning is a machining process in which a cutting tool, typically a non-rotary tool bit, describes a helical tool path by moving more or less linearly while the workpiece rotates. The tool's axes of movement may be literally a straight line, or they may be along some set of curves or angles, but they are essentially linear.

III. CUTTING PROCESS PARAMETER FOR TURNING APPLICATIONS

1) Cutting Speed:
   The cutting speed of a tool is the speed at which the metal is removed by the tool from the workpiece. In a lathe it is the peripheral speed of the workpiece past the cutting tool expressed in m/min.
2) Feed:
   The feed of a cutting tool in a lathe is the distance the cutting tool advances for each revolution of the spindle and workpiece. Increased feed reduces the cutting time. However increased speed greatly reduces the cutting tool life. Coarser feeds are used for roughing and fine feeds for finishing cuts.
3) Depth of Cut:
   The depth of cut is the perpendicular distance measured from the machined surface to the uncut surface of the workpiece. The depth of cut varies inversely as the cutting speed.[24]
4) Tool Nose radius:
   Tool Nose radius is the curvature of the tool tip. It provides strengthening of the tool nose and better surface finish. Smaller radii produce smoother surface finish.
5) Tool Life:
   Tool life generally indicates the amount of satisfactory performance or service rendered by a fresh tool or a cutting point till it is declared failed. Excessive cutting speeds cause a rapid failure of the cutting edge of the tool. The nose radius is a key factor in many turning operations and one that needs consideration as the right choice affects cutting edge strength to surface finish of the component.[22]
6) Surface Roughness:
   Surface roughness, often shortened to roughness, is a measure of the texture of a surface. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small the surface is smooth. Roughness is typically considered to be the high frequency, short wavelength component of a measured surface.
7) Surface roughness is affected by cutting speed, feed, depth of cut and tool geometry. Surface roughness is directly dependent on square of the feed and inversely proportional to the nose radius of the tool. Generally, a large nose radius and a slow feed rate coupled with high

cutting speed gives the best finish.[1][24]

IV. LITERATURE SURVEY

A. Optimization of machining parameter by various methods

Yang W. H. et al. used the Taguchi method for determining optimum cutting parameters. They machined S45C steel work piece with carbide cutting tools. The cutting parameters chosen were cutting speed, feed rate and depth of cut. Taguchi's signal noise ratio and variance analysis were used to determine the effect of the cutting parameters on tool life and surface roughness. They show that tool life and surface roughness can be improved significantly for turning operations. The confirmation experiments were conducted to verify the optimal cutting parameters. The improvement of tool life and surface roughness from the initial cutting parameters to the optimal cutting parameters was about 250%.

Kopac J. et al. conducted experiments to analyse the influence of workpiece material properties, cutting parameters, and TiN (PVD) hard coating on the surface roughness of fine-turned work pieces. A standard Taguchi experimental plan with notation L16 (2^{15}) was chosen for selecting the number of experiments and levels of control factors. The analysis of influence of each control factor on surface roughness has been performed with signal-to-noise response method. They concluded the optimized values of machining parameter from the S/N table to achieve the fine-surface roughness. They confirmed optimal cutting conditions with a verification experiment. In all experiment runs, a better surface roughness in machining with a coated insert was obtained. It was derived that a higher cutting speed results in a smoother surface, which can also be seen from interaction graphs. The feed and the depth of cut also affect the surface roughness of the machined part.

I.Asilturk et al. conducted the experiments for optimization of turning parameters based on the Taguchi method to minimize surface roughness (Ra and Rz). Experiments have been conducted using the L9 orthogonal array in a CNC turning machine. L_9 orthogonal array was selected for three different level of cutting speed in m/min(90,120,150), feed rate in mm/rev(0.18,0.27,0.36)and depth of cut in mm(0.2,0.4,0.6). Dry turning tests were carried out on hardened AISI 4140 (51 HRC) with coated carbide cutting tools. Each experiment is repeated three times and each test uses a new cutting insert to ensure accurate readings of the surface roughness. The statistical methods of signal to noise ratio (SNR) and the analysis of variance (ANOVA) are applied to investigate effects of cutting speed, feed rate and depth of cut on surface roughness. Results of this study indicate that the feed rate has the most significant effect on Ra and Rz. In addition, the effects of two factor interactions of the feed rate-cutting speed and depth of cut-cutting speed appear to be important. The maximum value was found by using the S/N ratio equation of ''the smaller-the better,'' the maximum S/N ratio yielded optimum cutting parameters were 120 m/min for cutting speed, 0.18 mm/rev for the feed rate and 0.4 mm for the depth of cut.

A.Gupta et al Used Taguchi method with logical fuzzy reasoning for multiple output optimization of high speed CNC turning of AISI P-20 tool steel using TiN coated tungsten carbide coatings. The machining parameters such as cutting speed in m/min(120,160,200), feed rate in mm/rev(0.10,0.12,0.14), depth of cut in mm(0.20,0.35,0.50), nose radius in mm(0.40,0.80,1.20) and cutting environment(dry, wet, cryo) are optimized with considerations of the multiple performance measures (surface roughness, tool life, cutting force and power consumption). Taguchi's concepts of orthogonal arrays, signal to noise (S/N) ratio, ANOVA have been fuzzified to optimize the high speed CNC turning process parameters through a single comprehensive output measure (COM) using L_{27} orthogonal array. The result analysis shows that cutting speed of 160 m/min, nose radius of 0.8 mm, feed of 0.1 mm/rev, depth of cut of 0.2 mm and the cryogenic environment are the most favorable cutting parameters for high speed CNC turning of AISI P-20 tool steel.

Kirby E. D. et al. used a fuzzy-nets modeling technique for predict the surface roughness for a turning operation. By use of accelerometer measurements of turning parameters like, feed rate, spindle speed and tangential vibration data during full factorial experimental runs, they developed and trained a fuzzy-nets-based surface roughness prediction system that was predict the surface roughness of a turned workpiece. The fuzzy-nets-based surface roughness prediction system has been developed using a computer numerical control (CNC) slant-bed lathe with a carbide cutting tool. Test data of 72 experiments was used to validate the model with 28 experiments, which yielded an average error rate of 95%. It was observed that the sensor and modeling methods selected had a good potential both for prediction and adaptive control for surface roughness in turning operations.

Bouzid W. Conducted the experiments with four types of inserts in which three chemical vapor depositions coated inserts and one ceramic tool. A method was described for calculating the optimum cutting conditions, in turning for objective criteria such as maximum production rate. The method uses empirical models for tool life, roughness and cutting forces. In this work, the machine power and the maximum spindle speed were considered as the process constraints. The method consists on explaining the feed in relation to the roughness which depends on the cutting speed. Then, the cutting speed which gives the minimum production times was calculated. This value was then compared to the allowed values imposed by the constraints. The obtained results indicate that the described method was capable of selecting the appropriate conditions.

Davim J. P. et al. developed Surface roughness prediction models using artificial neural network (ANN) to investigate the effects of cutting conditions during turning of free machining steel. The machining tests were conducted on a conventional lathe with a 6KW power using cemented carbide inserts as a cutting tool. The ANN model of surface roughness parameters (R_a and R_t) was developed with the cutting conditions such as feed rate in mm/rev(0.10,0.16,0.25), cutting speed in m/min(71,141,283) and depth of cut in mm(0.50,0.75,1.0) as the affecting process parameters. They performed experiments as per L27 orthogonal array with three levels defined for each of the factors in order to develop the knowledge base for ANN training using error back-propagation training algorithm (EBPTA). 3D surface plots were generated using ANN model to study that cutting speed and feed rate have significant effects in reducing the surface roughness, while the depth of cut has the least effect.

A. J. Makadia et al. Used Design of experiments to study the effect of the main turning parameters such as feed rate in mm/rev(0.1,0.15,0.2), tool nose radius in mm(0.4,0.8,1.2), cutting speed in m/min(220,250,280) and depth of cut in mm(0.3,0.6,0.9) on the surface roughness of AISI 410 steel. 81 experiments have been carried out by 3 level full factorial designs. A mathematical prediction model of the surface roughness has been developed in terms of above parameters. The effect of these parameters on the surface roughness has been investigated by using Response Surface Methodology (RSM). Response surface contours were constructed for determining the optimum conditions for a required surface roughness. The developed prediction equation shows that the feed rate is the main factor followed by tool nose radius influences the surface roughness. The surface roughness was found to increase with the increase in the feed and it decreased with increase in the tool nose radius. They concluded that the optimal combination of machining parameters are (255.75m/min,0.1mm/rev,0.3mm,1.2mm) for cutting speed, feed rate, depth of cut and tool nose radius respectively. The verification experiment is carried out to check the validity of the developed model that predicted surface roughness within 6% error.

Raja S. B. et al. Investigated proper selection of machining parameters can obtain better surface finish in minimum possible machining time. In order to help the process planner in judicious selection of machining parameters, empirical data had been used to predict the optimal machining parameters for effective milling. Pilot experiments were conducted on Aluminium material using insert type carbide as tool material. 36 experiments were conducted by using controllable parameters as cutting speed in rev/min(1000,2000,3000,4000), feed in mm/min(100,200,300), and depth of cut in mm(0.2,0.4,0.6). PSO was implemented to obtain global optimum machining parameters to minimize machining time subjected to the desired surface finish. The prediction ability of PSO was verified by conducting confirmation experiments and its relation was presented and discussed. The use of optimization technique greatly replaces the laborious process of machining parameters selection by trial and error method.

B. Optimization of machining parameters and comparison of various methods

Tzeng C. et al. Investigated the optimization of CNC turning operation parameters for SKD11 (JIS) using the Grey relational analysis method. Nine experimental runs based on an orthogonal array of Taguchi method were performed. Carbide coated with titanium was used as cutting tool and four controllable parameters as three different level was used such as cutting speed in m/min(125,155,185), feed rate in mm/rev(0.12,0.16,0.20), depth of cut in mm(0.50,0.65,0.80), and cutting fluid ratio in %(4,8,12). The surface properties of roughness average and roughness maximum as well as the roundness were selected as the quality targets. An optimal parameter combination of the turning operation was obtained via Grey relational analysis. By analyzing the Grey relational grade matrix, the degree of influence for each controllable process factor onto individual quality targets can be found. The depth of cut was identified to be the most influence on the roughness average and the cutting speed was the most influential factor to the roughness maximum and the roundness. Additionally, the analysis of variance (ANOVA) was also applied to identify the most significant factor; the depth of cut was the most significant controlled factors for the turning operations according to the weighted sum grade of the roughness average, roughness maximum and roundness.

I. Asilturk et al. Determined multi-objective optimal cutting conditions and mathematic models for surface roughness (Ra and Rz) on a CNC turning. Firstly, cutting parameters namely, cutting speed in m/min(50,100,150), depth of cut in mm(1,1.5,2), and feed rate in mm/rev(0.15,0.2,0.25) are designed using the Taguchi method. They conducted 27 experiments by using L_{27} orthogonal array. The AISI 304 austenitic stainless workpiece is machined by a coated carbide insert under dry conditions. The influence of cutting speed, feed rate and depth of cut on the surface roughness is examined. Secondly, the model for the surface roughness, as a function of cutting parameters, was obtained using the response surface methodology (RSM). Finally, the adequacy of the developed mathematical model was proved by ANOVA. They concluded that, Both Taguchi and response surface statistical analyses indicated that the main effect of the feed rate is the most significant factor on the workpiece surface roughness (Ra and Rz) with the percent contribution of 85.5% in bringing down the average roughness values and, the RSM was found to be effective for the identification and development of significant relationships between cutting parameters. The percentages of error all fall within 1%, between the predicted values and the experimental values.

A. Aggarwal et al. finds an experimental investigation into the effects of cutting speed in m/min(120,160,200), feed rate in mm/rev(0.10,0.12,0.14), depth of cut in mm(0.20,0.35,0.50), nose radius in mm(0.40,0.80,1.20) and cutting environment(dry, wet, cryo) in CNC turning of AISI P-20 tool steel. Tin coated tungsten carbide inserts was used as cutting tool and three levels are used for experiment. Design of experiment techniques, i.e. response surface methodology (RSM) and Taguchi's technique; have been used in their experimental study. L27 orthogonal array and face centered central composite design have been used for conducting the experiments. Taguchi's technique as well as 3D surface plots of RSM revealed that cryogenic environment is 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. Though both the techniques predicted near similar results, RSM technique seems to have an edge over the Taguchi's technique.

Ahilan C. et al. Proposed the development of neural network models for prediction of machining parameters in CNC turning process. Experiments were designed based on Taguchi's Design of Experiments (DoE) and conducted with cutting speed, feed rate, depth of cut and nose radius as the process parameters and surface roughness and power consumption as objectives. Results from experiments were used to train the developed neuro based hybrid models. Among the developed models, performance of neural network model trained with particle swarm optimization model was superior in terms of computational speed and accuracy. Developed models were validated and reported. Signal-to-noise (S/N) ratios of responses were calculated to identify the influences of process parameters using analysis of variance (ANOVA) analysis.

I.Asiltrurk et al. use the artificial neural network and multiple regression method for modeling and prediction of surface roughness in turning operations of AISI 1040 steel. The surface roughness is measured during turning at different cutting parameters such as cutting speed in m/min(150,219,320), feed rate in mm/rev(0.12,0.2,0.35), and depth of cut in mm(1,2,4). They take 27 experiments on AISI 1040, 35 HRC steel by carbide inserts cutting tool. Full factorial experimental design is implemented to increase the confidence limit and reliability of the experimental data. The back-propagation training algorithms, the scaled conjugate gradient (SCG) and levenberg-Marquardt(LM) were used for ANNs training. The best result having the minimum error was obtained by SCG algorithm with five neurons. Multiple regression and neural network-based models are compared using statistical methods. They conclude that, the ANN model estimates the surface roughness with high accuracy compared to the multiple regression model. The feed rate is the dominant factor affecting the surface roughness, followed by cutting of depth and cutting speed. The determination coefficient (R^2) is 99.8% for training data and 99.4% for the testing data in neural network model, while it is achieved as 98.9% for multiple regression models.

T.Ozel et al Utilized neural network modeling to predict surface roughness and tool flank wear over the machining time for variety of cutting conditions in finish hard turning. Regression models are also developed in order to capture process specific parameters. The experimental data obtained from performed experiments in finish turning of hardened AISI H-13 steel with Cubic boron Nitride (CBN) tool. The data sets from measured surface roughness and tool flank wear were employed to train the neural network models. Trained neural network models were used in predicting surface roughness and tool flank wear for other cutting conditions. A comparison of neural network models with regression models is also carried out. Predictive neural network models are found to be capable of better predictions for surface roughness and tool flank wear within the range that they had been trained. Predictive neural network modeling is also extended to predict tool wear and surface roughness patterns seen in finish hard turning processes. Decrease in the feed rate resulted in better surface roughness but slightly faster tool wear development, and increasing cutting speed resulted in significant increase in tool wear development but resulted in better surface roughness. Increase in the workpiece hardness resulted in better surface roughness but higher tool wear. Overall, CBN inserts with honed edge geometry performed better both in terms of surface roughness and tool wear development.

B.C.Routara et al. conducted the experiment for optimization of cutting condition in CNC turning for minimum surface roughness. They used the response surface methodology technique to optimize the parameters for EN-8 steel. The second order mathematical model in terms of machining parameters were developed for surface roughness prediction using response surface methodology on the basis of experimental results. The experimentation was carried out with coated carbide tool for machining or EN-8 steel considering 20 experiments. The model selected for optimization has been validated with F-test. They use five levels for three variable parameters as depth of cut in mm(0.032,0.15,0.25,0.35,0.368), feed in mm/rev(0.0222,0.08,0.16,0.24,0.2876) and spindle speed in rpm(528,800,1200,1600,1872) for experiment. They also attempt to optimize the surface roughness prediction model using Genetic Algorithm to find optimum cutting parameters. The surface roughness parameters R_a, R_q, R_{sm}, are decreases with increase in depth of cut and spindle speed but increases with increases in feed. They also concluded that, the optimization of these models using genetic algorithm has resulted in a fairly useful method of obtaining machining parameters in order to obtain the best possible surface quality.

Ganeshan H. et al. determined the optimal machining parameters for continuous profile machining with a set of practical constraints, cutting force, power and dimensional accuracy and surface finish. A continuous finished profile had many types of operations such as facing, taper turning and circular turning. To model the machining process, several important operational constraints had been considered. These constraints were taken to account in order to make the model more realistic. A model of the process had been formulated with non-traditional algorithms; a genetic algorithm (GA) and Particle Swarm Optimization (PSO) were applied to resolve the problem and the results obtained from GA and PSO are compared. The result showed PSO produces better results and by using this technique machining time can be further minimized.

Raja S. et al. used non-traditional optimization techniques like, Simulated annealing, genetic algorithm, and particle swarm optimization for exploring optimal machining parameters for single pass turning operation, multi-pass turning operation, and surface grinding operation to studied the behaviour of optimization techniques based on various mathematical models. The most affecting machining parameters were considered as cutting speed, feed, and depth of cut. Physical constraints were speed, feed, and depth of cut, power limitation, surface roughness, temperature, and cutting force.

V. CONCLUSION

The following points were observed as a sort of conclusion of their work:

1) Particle swarm optimization has proved to be the best among the other non- traditional optimization techniques simulated annealing and genetic algorithm.
2) Particle swarm optimization technique tends to converge to the global optimal solution at a faster rate.

3) All the computational time is less than half minute and hence computational cost is not going to be an affecting parameter in obtaining the required objective function.
4) Since all the proposed techniques can obtain a global optimum solution within a reasonable execution time on a personal computer.
5) All the non-traditional techniques can be easily used to implement for other engineering applications.

The current work presented a review of the different approaches that are used for predicting the surface roughness. All the methodologies that are presented here can exhibit advantages and disadvantages when compared to one another, but given this trend the most promising seem to be the theoretical and the AI approaches. A comparison of these two approaches reveals that AI models take into consideration the particularities of the equipment used and the real machining phenomena, information that is stored in the experimental data used to develop the models. On the other hand, the theoretical approach is based on conventions and idealizations, which are responsible for errors and limitations. Surprisingly enough, a combined effort that would involve both AI and analytical modelling so as to validate, refine or correct the theoretical models was not found in the literature. Finally, the set of parameters that are thought to influence surface roughness and thus have been investigated by the researchers is diagrammatically displayed in Figure 1.

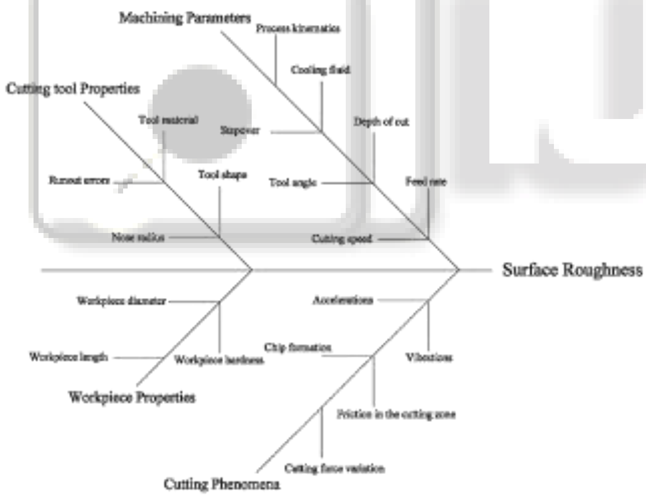

Fig. 1: Fishbone diagram with the parameters that affect surface roughness.

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