A REVIEW ON OPTIMIZATION AND ANALYSIS TECHNIQUES IN MACHINING

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ABSTRACT

The various techniques used by the researchers to measure the cutting zone temperature during turning through on-line basis are presented. Also, the various techniques used for monitoring the flank wear of cutting inserts by various researchers and scientists were discussed. The findings of the various researchers in the experimental analyses in turning, using Taguchi's DoE are incorporated in this study. The past researches with empirical modeling in metal cutting for the prediction of flank wear, surface roughness and cutting zone temperature and the findings are discussed. The review of the results obtained in optimization of selected parameters in turning using various non traditional optimization techniques are also presented in this chapter.

Keywords: Empirical Modeling, Optimization, Metal Cuttings, Parameters, Techniques

I. TAGUCHI'S DESIGN OF EXPERIMENTS IN METAL CUTTING

The Taguchi method utilizes the orthogonal arrays from Design of Experiments theory to study a large number of variables with a small number of experiments. The Taguchi method can reduce research and development costs by improving the efficiency of generating information needed to design systems that are insensitive to usage conditions, manufacturing variation, and deterioration of parts. As a result, development time can be shortened significantly; and important design parameters affecting operation, performance, and cost can be identified. Furthermore, the optimum choice of parameters can result in wider tolerances so that low cost components and production processes can be used. Thus, manufacturing and operations costs can also be greatly reduced. Many of the researchers and scientists applied Taguchi's DoE in metal cutting and their research findings. Researchers optimized the turning parameters for surface roughness and tool life based on Taguchi method [1]. The experimental studies were conducted under varying cutting speeds, feed rates, and depths of cut. Commercial Ti-6Al-4V alloy was used as the target material. A CNMG 120408-883 insert which consisted of 94 wt% tungsten carbide with 6 wt% cobalt as the binder was used as the cutting tool material. The surface roughness was measured using a Mitutoyo SJ-201 portable device within the sampling length of 2.5 cm. The cutting tool was studied under Scanning Electron Microscopy. The conclusions revealed that the feed rate and cutting speed were the most influential factors on the surface roughness and tool life, respectively. The surface roughness was chiefly related to the cutting speed, whereas the axial depth of cut had the greatest effect on tool life.

Researchers applied Taguchi parameter design method to optimize the surface finish in turning operation. The control parameters for this operation included: spindle speed, feed rate, depth of cut, and tool nose radius. The work-piece samples were randomly selected, 2.25 inches lengths cut from the aluminium rod [2]. The spindle speed, feed rate, and depth of cut parameters were programmed into the CNC program, which created a straight cut of 0.5 inch in the z axis. The results of this study found that the control factors had varying effects on the response variable, with feed rate and tool nose radius having the highest effects. Also it was concluded that the use of the Taguchi parameter design technique was considered successful as an efficient method to optimize surface roughness in a turning operation. Researchers utilized a Taguchi experimental design to determine the optimal machining parameters for a desired surface roughness for traditional turning [3]. The five factors selected are cutting speed, cutting material, work-piece material, cutting depth, and consecutive cut. In addition to these factors, the seven second-order interactions between these factors were also considered. It was found from the analysis that the most significant influences on surface quality were cutting speed, cutting material, cutting depth, and consecutive cut. It was also noticed that the interactions between cutting speed and cutting depth, cutting speed and consecutive cut, and cutting material and consecutive cut were all significant.

Researchers obtained the optimal setting of turning process parameters (Cutting speed, feed rate and depth of cut) using Taguchi DoE in order to yield optimal tool wear. EN 24 alloy steel rods of 90 mm diameter and 500 mm length were turned on an H-22 centre lathe of HMT using TiC coated carbide inserts [4]. It was found from the experimental result that, speed, feed and depth of cut significantly affect the flank wear. It was noticed that the influence of cutting speed was significantly larger than the influence of feed rate and depth of cut. comparison between ceramics and Cubic Boron Nitride (CBN) cutting tools when machining hardened bearing steels using the Taguchi method. The machine used for turning tests was a Johnford TC35 Industrial type of CNC lathe machine. The material used throughout this work was an AISI 52100 steel. The parameters selected are cutting speed, feed rate and hardness of tool. After each test, the worn cutting tool was measured with the optical tool microscope to determine the degree of flank wear. The improvements of the S/N ratio from the initial testing parameters to the optimal cutting parameters were ranged from 18% to 51% depending on the ANOVA results. Moreover, the ANOVA indicated that the cutting speed was high significant but other parameters were significant effects on the tool life at 90% confidence level. The percentage contributions of cutting speed, hardness of tool, and feed rate were about 41.63, 32.68, and 25.22 on the tool life, respectively. An optimization study by machining a hardened AISI 4140 grade (63 HRc) steel on a lathe by using Al2O3 + TiCN coated ceramic inserts is tudird by many researchers. They determined that Al2O3-base ceramics are required for cutting tools in machining hard steels during wear resistance and high hardness. They ensured optimization in their experimental studies by using the Taguchi method. The experimental parameters chosen were: three different cutting speeds, feed rates and depths of cut. Flank wear and surface roughness were chosen as criteria for performance. The obtained results were analyzed by using Analysis Of Variance (ANOVA). As a result, it was seen that the flank wear value decreased as the cutting speed and the depth of cut increased; however, it first decreased and then increased as the feed rate increased. On the other hand, the surface roughness decreased as the cutting speed increased. In contrast surface roughness increased when the feed rate increased. Zhang and Chen (2009) experimented to optimize the surface quality in a CNC drilling operation using Taguchi design. The control factors in their study were feed rate, spindle speed, peck rate and tool type, while the noise factors simulated were machine shop vibration and the presence or absence of magnetism in the work piece material. Through statistical analysis of response variables and signal-to-noise ratios, the determined significant factors were the spindle speed, tool type and peck rate, and the optimal combination of cutting parameters were selected.

Scientist optimized the controlling parameters in turning operations using DoE and ANOVA. The author presented a study of influence of cutting conditions on the surface finish obtained in turning. The objective was to establish a correlation between cutting speed, feed rate and depth of cut with the roughness evaluating parameters, Ra and Rt, by following the international norms. These correlations were obtained by multiple linear regressions. Finally, confirmation tests were performed to make the comparison between the results predicted from the mentioned correlations and the theoretical results and presented the surface roughness analysis in burnishing operation. The aim of this study was to analyze the evaluation of surface roughness finished by burnishing. Burnishing was done on a surface that was initially turned or turned and then ground. It had been noted that burnishing an AISI 1042 steel offered the best surface quality when using a small feed value [5]. This finishing process improved roughness and introduced compressive residual stresses in the machined surface. Various Researchers conducted the experiment for the analysis of chatter in turning using Taguchi's DoE with L16 orthogonal array. The experiments were conducted by using tungsten carbide tool and the work-pieces used for chatter detection study were cut from rolled steel bars containing about 0.35% carbon. It was found from the experimental result that the cutting speed had a critical value for which the best surface quality can be achieved. Below that critical value, the surface roughness decreased with increased cutting speed and after that value, the surface roughness increased with increased cutting speed. Also it was noticed that the effect of depth of cut on surface roughness was not regular and had a variable character [6]

II. EMPIRICAL MODELING IN METAL CUTTING

Prediction of tool wear is an important study in metal cutting in order to maximize the utilization of the tool and minimize the cost of machining. In order to improve the tool life, the proper setting of machining parameters is crucial before the process takes place. The user of the machine tool must know how to choose cutting parameters in order to minimize tool wear. Many researchers and scientists investigated the general effects of speed of cutting, feed rate and depth of cut on tool wear and surface finish along with the development of empirical models for the objectives and their findings were discussed below. Scientists modeled the temperature distributions in the cutting zone through-the-tool near dry cooling condition. The model described the dual effects of air-oil mixture in near dry machining in reduction of cutting temperature through the cooling effect, as well as the reduction of heat generation through the lubricating effect. In order to pursue model calibration and validation embedded thermocouple temperature measurement in cutting medium carbon steels with uncoated carbide insets were carried out. The validation of cutting temperatures in near dry turning was verified by measuring the temperatures with an embedded thermocouple (Omega K-type) located under the tool insert when cutting AISI 1045 with uncoated carbide tool inserts (Valenite DPMT-2A) on a lathe (CMS GT-27) under various cutting conditions. It was found that the model predictions and experimental measurements showed reasonable agreement [7].

Researcher predicted the tool and chip temperature in continuous and interrupted machining. The temperature distribution was solved using the finite difference method. The temperature field in each differential element was modeled as a first-order dynamic system, whose time constant was identified based on the thermal properties of the tool and work material, and the initial temperature at the previous chip segment. The transient temperature variation was evaluated by recursively solving the first order heat transfer problem at successive chip elements. Simulations were performed for different materials under various cutting conditions. The results both for continuous and interrupted machining processes agreed well with experimentally measured temperatures [8].

Scientists developed the mathematical model to predict the surface roughness using Response Surface Methodology (RSM). An experimental investigation was conducted to determine the effects of cutting conditions and tool geometry on the surface roughness in the finish hard turning of the bearing steel (AISI 52100). Mixed ceramic inserts made up of aluminium oxide and titanium carbonitride SNGA, having different nose radius and different effective rake angles, were used as the cutting tools. It was found that the multiple regression coefficient of the first order model was found to be 0.9233. This showed that the first order can explain the variation to the extent of 92.33%. Also it was estimated that the multiple regression coefficient of the second order was found to be 0.9608. This means that the second order can explain the variation to the extent of 96.08% [9]. Researchers obtained the empirical equation by multiple linear regression to investigate the effect of surface roughness factors in the machining of 2024Al/Al2O3 particle composites. A plan of experiments, based on Taguchi method, was performed machining with different cutting speeds using coated carbide tools K10 and TP30. Machining tests were carried out without coolant and at a constant depth of cut equal to 2 mm and feed rate of 0.1 mm/rev. The surface roughness models obtained by the multiple linear regression (correlation coefficient of 0.98 and 0.95, and the mean absolute error of 4.66% and 4.77% for K10 and TP30 tools) showed that the satisfactory correlation was established. Also, it was observed that there was a good agreement between the predicted and experimental data.

Scientist employed numerical model to predict the surface integrity in finish turning of 15-5PH stainless steel. A metallurgical model had been calibrated for 15-5PH steel using experimental dilatometry results. The metallurgical model had been implemented in a numerical model for the prediction of surface integrity after turning. It was found from the analysis and comparison that there was a good adequacy between calculated and measured residual stress profiles [10].

III. FINITE ELEMENT ANALYSIS IN METAL CUTTING

The use of Finite Element codes has been proved to be an effective technique for analyzing the flow of material in general and the cutting process in particular. The Finite Element methods are suited for analyzing large elastic-plastic deformation problems including temperature dependent material properties and high strain rates. Attempts to apply Finite Element techniques to machining to predict the cutting zone temperature have been made by many researchers. Reports have been filed with respect to finite element study of tool temperatures in cutting that accounts for tool nose radius and included angle effects. The steady state temperature response is calculated using NASTRAN solver. Experimental measurements of the average rake face temperature using tool-work thermocouple technique are performed. The thermocouple results were compared with the predicted values of temperature and found there is a good agreement between experimentally measured and predicted values of cutting zone temperature.

A few Researcher used AISI H-13 work-piece material and CBN tool material and the modeling of tool-chip interface friction is based on Coulomb's friction law with friction coefficient set constant value of 0.5. A cutting tool, with -5o rake angle, 5o clearance angle and 0.02 mm cutting edge radius was used for the analysis. The feed is equal to 0.05 mm/rev, while three different cutting speeds namely, 200, 250 and 300 m/min are considered. Finally it is concluded that the proposed models are practical, since only a minimum amount of experimental work is needed, and produce reliable results, allowing for industrial use in pursue of optimal production. While a few applied the Finite Element code DEFORM-2D to simulate the plane strain cutting process. The existing version of the code was modified to study the continuous and segmented chip formation and performed the simulation with reasonable accuracy. The influence of various parameters such as cutting speed, rake angle and depth of cut on the tool-chip interface temperature has been studied. The results of extensive Finite Element Method simulations and comparison with the experimental data are reported. From the literature review, it is known that the simulation type is incremental with the step increment to cut 1 mm of 100 steps. There was a considerable accuracy in predicting the results. In order to increase the accuracy of the predicted result, the step increment is defined to cut 10 mm with 1000 steps and the predicted value of tool-chip interface temperature is compared with experimentally observed cutting zone temperature for various test conditions.

IV. NON TRADITIONAL OPTIMIZATION TECHNIQUES IN METAL CUTTING

Conventional optimization techniques like Full factorial method, Taguchi's DoE, etc., are useful only for specific optimization problems which need only the best levels of parameters for the calculation of local optimal solution. Consequently, non-traditional optimization techniques such as AGA, SAA, PSO technique etc., are used to obtain the global solution. Many researchers applied these nontraditional optimization techniques in their experimental results to obtain the global solution and their outcomes are presented below and optimized the turning parameters for surface profile generated during in CNC turning of AISI 1040 steel using GA. The second order mathematical models in terms of machining parameters were developed based on experimental results. The three different surface parameters such as average surface roughness, root mean square surface roughness and mean line peak spacing for the surface texture were measured. Finally the nontraditional technique, Genetic Algorithm was applied to obtain machining condition. The confirmatory tests conducted with optimum parameter combinations showed good agreement with the predictions. Researchers optimized cutting parameters of composite materials using GA and studied the effects of cutting parameters on material removal rate, specific energy, volume fraction, surface roughness and flank wear. The work material used was 2124 Aluminium alloy reinforced with green bonded silicon carbide particles of size 25 m with different volume fractions manufactured through stir casting route. Multiple regression models were used to represent the relationship between input and output variables and GA was used to optimize the process. It was found from the experimental result that the proposed Genetic Algorithm was found to yield to much better quality solutions.

Notable Scientist presented a Real Coded Genetic Algorithm (RCGA), to find the optimal combination of machining conditions. The issues related to RCGA such as solution representation, crossover operators, and repair algorithms in detail were presented. The RCGA used the following parameters: crossover probability of 0.25, mutation probability of 0.1, roulette wheel selection, the maximum number of generation was 1000, and the population size is 50. The results show that RCGA was reliable and accurate for solving the machining condition optimization models [11]. While various scientists developed the genetic algorithm based optimization program for the identification of material mechanical behavior during machining process. A MATLAB code was developed to deal with nonlinear multivariable optimization problems using genetic algorithm. The combination of elitism and roulette wheel strategy was utilized as selection scheme. The integrated single-point and multipoint-crossover operator was proposed to diversify the binary strings. Three identification tests based on different searching scheme were carried out. The obtained Johnson–Cook parameters, along with the parameters obtained by other researchers, were used in the forward analytical machining simulation to examine their effectiveness. All machining force predictions based on the proposed non equidistance PSZ analysis showed improved results. An Indian scientist used two recent algorithms for evolutionary optimization – known as PSO and DE. Several schemes for controlling the convergence behaviors of PSO and DE by a judicious selection of their parameters were explained. Simulations were carried out to obtain a comparative performance analysis of the new method with respect to past research results with application of nontraditional optimization techniques which revealed that a significant progress had been made in the field of swarm intelligence and evolutionary computing [12].

V. CONCLUSION

The effects of various alternative methods of cooling of cutting insert, effects of machining parameters such as cutting speed, feed rate, and depth of cut, effects of various MQL parameters, effects of cutting tool geometry and effects of material hardness on machining characteristics such as flank wear, surface roughness, cutting zone temperature studied by various researchers were reviewed. The collection of all the experimental results obtained by various researchers and scientists formed base for this research work.The various methods used by the previous researchers to measure the cutting zone temperature formed the basis for the use of embedded K-type thermocouple in the rake surface of cutting insert. Also the tool wear monitoring techniques used by various researchers lead to identify the defects in monitoring the tool wear and to incorporate a technique to measure the audible acoustic emission signal. From the literature survey, it is clear that there are so many traditional and non traditional optimization techniques applied for the minimization of flank wear and surface roughness. Few authors experimentally measured the cutting zone temperature which has the direct impact on flank wear and surface roughness, but the results of Taguchi's DoE, Regression model, AGA, SAA, PSO and DE had not been compared and correlated. Hence, in this research, the effects of cutting zone temperature on flank wear values have been analyzed and the results of the objectives obtained by the above techniques are compared with the experimental values.

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