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Optimization of cutting parameters using the online method to minimize tool wear

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Abstract
Tool wear is a natural process that develops on the cutting tool during machining operations due to mechanical, chemical and mechanical processes. Tool wear will increase the surface roughness of the material and also increase the vibration of the workbench. This situation will affect the quality of the material as well as the increase of vibration will cause the faults to increase over time. In this study, an effective and efficient methodology is proposed to optimize cutting parameters with online monitoring of tool wear using accelerometer signals. In this strategy, a data acquisition system with tool vibration signals, surface roughness measured from a particular material and then Response Surface Methodology and Genetic Algorithm are integrated to create an automated tool for minimize tool wear. Using this approach, real time acquired 3 axes Vibration (Vx, Vy, Vz) signals data was collected and computer program was written to optimize cutting parameters.

Keywords: Tool wear, genetic algorithm, response surface methodology, DOE.

1. Introduction

Tool wear is a natural process that develops on the cutting tool during machining operations due to mechanical, chemical and mechanical processes. Tool wear will increase the surface roughness of the material and also increase the vibration of the workbench. This situation will affect the quality of the material as well as the increase of vibration will cause the faults to increase over time. Due to the high impact of tool wear on production costs, researchers have developed many mathematical and experimental methods to minimize wear and optimize cutting parameters. In addition, various coating methods have been developed to increase tool life. Many researchers have made studies to investigate the effect of coatings on tool life. To optimize the tool change strategy in the actual chip removal process for optimizing optimum cutting parameters, the tool life distribution model was created and a model was removed [1]. The impact rate of cutting speed and tool tip wear rate were analyzed by ANOVA using tangential cutting force and statistical optimization and dry chip removal using SAE 1050 material and tool wear was observed online [2]. On a machine tool, under the MQL conditions, using the Inconel 617 material, the AlTiN-coated carbide tool insert has examined nAl2O3 gamma concentration and machinability under control factors (cutting speed and feed rate) [3]. Cutting speed and feed rate levels were selected as cutting variables and the effects of cutting parameters on tool life using PVD TiAlN coated tool were modeled using response surface methodology (RSM) [4]. Some researchers have revealed that uncoated cutting tools perform better than coated cutting tools in their studies, and Inconel 718 explained that uncoated cutting tools perform better than coated cutting tools at low cutting speeds in super alloy material processing. [5-6]. Some scholars have studied the effects of tool coating in machining of superalloys with carbide cutting tools. It has been shown that tool coating reduces the friction between the tool and workpiece and consequently results in lower machining temperature [7]. Hanasaki et al. [8] investigated the effect of tool coating on tool wear mode in turning of a high nickel alloy. They concluded that coating of the tools led to reduced flank wear. AlTiN coating is one of the most used coatings for machining hard to cut materials [9,10] and can especially reduce the occurrence of abrasive wear [11]. TiAlN coating was found to be the best-performing coating in that study [12]. Hao et al. studied the wear characteristics of a tool coated with TiAlN, finding that the wear mechanism changed with the cutting speed [13]. When the cutting speed

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was 20 m/min, serious adhesion resulted in cracks between the tool coating and substrate, as well as tool chipping. When the cutting speed was 32 m/min, the newly formed oxide adhered to the wear-tool surface, which reduced friction and prevented tool wear. When the speed was 45 m/min, the oxide film was severely damaged and considerable wear debris was formed.

In this study, an effective and efficient methodology is proposed to optimize cutting parameters with online monitoring of tool wear using accelerometer signals. In this strategy, a data acquisition system with tool vibration signals, surface roughness measured from a particular material and then Response Surface Methodology and Genetic Algorithm are integrated to create an automated tool for minimize tool wear. Using this approach, two different coated cutting tool was selected and real time acquired 3 axes Vibration (Vx, Vy, Vz) signals data was collected and computer program was written to optimize cutting parameters. Details of methodology are given in the following sections.

2.Materials and method

The main purpose of the reported research is to determine the appropriate technique to process the wear on the cutting tool that occurs during milling using sensory signals. Multiple vibration signals are obtained in 3 axes, Vx, Vy and Vz components, and the amount of wear occurring in the cutting tool is measured after each process and a design methodology has been developed to minimize tool wear. Therefore, a general full factorial experimental design (DOE) has been applied to meet the shear conditions. At least four independent parameters for milling; cutting speed (Vc), feed per tooth (Sz), Cutting Depth (Dc) and Cutting Width (Wc) must be determined before machining. These parameters were also selected for full factorial experimental design at three levels as given in Table 1.

Table 1. Cutting parameters and ranges for design of 81 experimental runs.

Cutting Speed (Vc) m/min	Feed per Tooth (Sz) mm/rev	Depth of Cut (D_c) mm	Width of Cut (W_c) mm
175	0.08	0.50	2
200	0.10	0.75	3
225	0.12	1	4

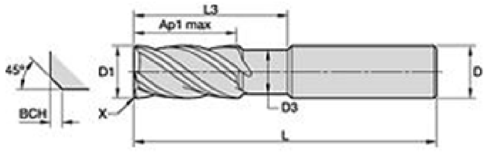
In the Awea BM-1200 vertical machining table, 81 cutting analyzes were performed according to experimental design parameters using EdgeCam software. The vertical machining bench where experimental studies are carried out is shown in Figure 1. During the chip removal process aluminium alloy was used. Chemical analysis of aluminium is shown given in Table 2.

Figure 1. Experimental Setup on Machine Tool

Table 2. Chemical properties of AlMgSiF32

Si %	Fe %	Cu %	Mn %	Mg %	Cr %
0.5	0.32	0.5	0.33	2.76	0.32

In the process of optimizing tool wear, 2 different types of coating with the same geometry were used in our study. In the light of the information we have obtained from the experience, it has been observed that the application of coating on cutting tools increases the tool life by 80-90%. This is very important both in terms of cost and processing quality. Four flutes was used in the experiments for high wear resistance as shown in Figure 2.



ANSI Catalog Number	UADE1200A4BV
Grade	KCPM15
Adapter Style Machine Side	Straight-Cylindrical
[D1]Effective Cutting Dia mm	12
[D]Adapter/Shank/Bore Dia mm	12,0
[D3]Neck Diameter Metric	11,28
[AP1MAX]1st Max Cut Depth mm	26
[L3]Maximum Depth End Mill mm	36
[L] Overall Length Metric	83
[BCH]Corner Chamfer Width mm	0,500
Coating Type	PVD CVD
Coating Layers	Ti Al

Figure 2. Cutting tool properties.

Three axial PCB 356A31 (± 500 g) accelerometers and PCB 480B21 3 input signal conditioners were used to estimate and optimize the amount of wear occurring in the cutting tool from vibration signals. In addition, a Proximity sensor (BDC Electronic, type DCA8/5608KS) placed in the spindle head has been used to detect cutting tool rotation. The signals from the sensors were obtained with the MATLAB software using the NI BNC 2110 connection block and the National Instruments (NI) PCMCI 6036E multi function data acquisition card to convert and record the analog signals obtained during the experiment. The process flow chart is shown in Figure 3.

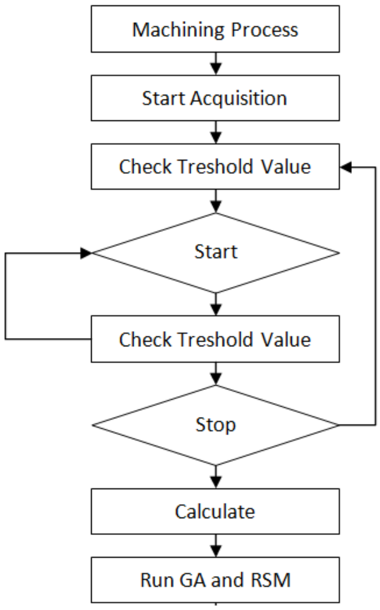


Figure 3. Flow chart in experimental setup.

Signals collected during the experiment, Matlab program has been developed to collect and analyze the proximity signal to mark the 3 axial vibration signals produced by the chip removal process and the shaft revolution in 10 K samples per second. The vibration signals are clipped for each cycle as shown in Figure 4.

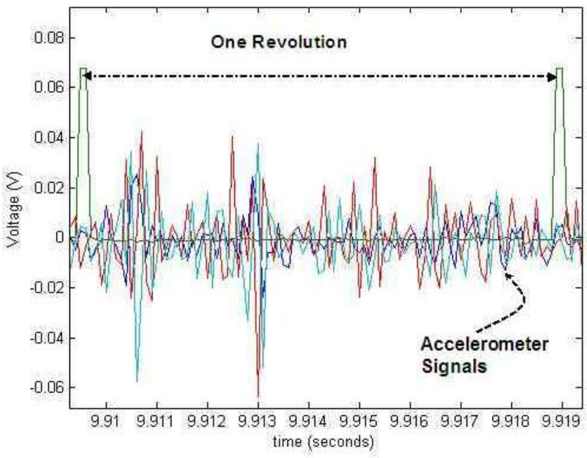


Figure 4. Vibration signals in one revolution of spindle period.

During the experiment, Vc = 225 m/min and Sz=0,12 mm/rev cutting conditions were used. In these cutting conditions, the data given to the machine are recorded with 5970 RPM spindle speed and 2866 mm / min feed speed, 1 mm cutting depth and 4 mm cutting width data. Using equation 1, three average vibration data for each revolution of absolute vibration data (Vx, Vy, Vz) from accelerometer signals were calculated.

$$V_{(x,y,z)} = \frac{1}{n}\sum_{i=1}^{n} |Vibration(i)| \qquad (1)$$

where n represents the total number of data per revolution and vibration (i) vibration data from 1 to n recorded as voltage for a spindle cycle. For comparison and identification, wear quantities in each tool were measured after 81 machined surfaces after treatment. Later, the average of all these absolute values obtained from the vibration data were determined by using optimization techniques and the optimum cutting conditions.

3.Results

In this work, numeric optimization was generated with utilizing experimental data which has less correlated relation between real time acquired 3 axes Vibration (Vx, Vy, Vz) signals data to minimize tool wear. For this reason, 81 experimental run were programmed in developed by applying a three level general full factorial design. In cutting experiments, aluminum alloy material was cut by using 4 cutting conditions (Vc, Sz, D_c W_c). During each machining process of 81 experiments, 3 axes accelerometer vibration signals (Vx, Vy, Vz) and proximity signals were collected synchronize by using a DAQ system at 10 K sampling rate. Average of the 3 axes vibration signals were calculated according to a revolution of spindle for each condition as given in Table 1. To solve the optimization problem effectively, a Genetic Algorithm (GA) program has been developed and coupled with the RSM based analytical models of warpage to find a global optimum. A more effective solution strategy is to replace the objective and constraint functions with corresponding simpler analytical functions using RSM before the solution process. RSM is defined as a model building technique based on statistical design of experiment and least square error fitting [14]. RSM creates a polynomial function, f, for the available data set as following:

$$f = a_0 + \sum_{i=1}^{n} a_i x_i + \sum_{i=1}^{n}\sum_{j=1}^{n} a_{ij} x_i x_j + ... \qquad (2)$$

Where a_0, a_i and a_{ij} are tuning coefficients and n is the number of parameters (i.e. process parameters). The polynomial models generated by RSM are often referred to as Response Surface (RS) models in the literature. To cerate RS models, a computer program has been written in this study. The program has the capability of creating RS polynomials up to 10^{th} order if sufficient data exist. All cross terms in the models can be taken into account. RS models can also be generated in terms of inverse of parameters. That is, x_i can be replaced as $\frac{1}{x_i}$ (i.e. inversely) in RS model if desired. In creating the RS models, FEA results based on D-optimal experimental design method is utilized. Statistical three-level full factorial experimental design is employed as the basis for Doptimality [14]. To create a quadratic response surface model (n+1)/(n+2)/2 number of analysis results are required where n is the the number of design parameters. In the literature 50% more points than required are recommended for the improvement of the prediction accuracy of the model [14]. Multi-objective optimization is applied to minimize tool wear value. Optimum cutting parameter values found to achieve this purpose are shown in Table 3. After each cutting conditions, the wear values of both coated cutting tools were measured and recorded and the values were transferred to the optimization program written. Measurement values were calculated by measuring the pixel pitches of the image images taken under a microscope in a computer environment. The values obtained after each experiment are shown in Figure 5.

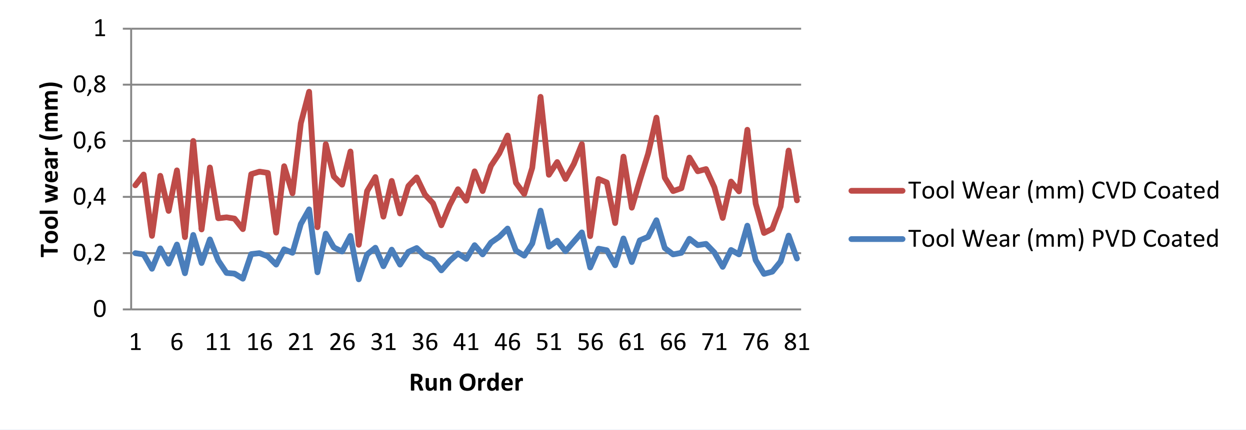


Figure 5. Cutting conditions and response data for experimental runs.

Table 3. Cutting parameters when tool wear is minimized at the same time.

	Tool Wear PVD Coated (mm)	**Tool Wear CVD Coated (mm)**	**Optimum Cutting Parameter Values**			
			Cutting Speed (Vc) m/min	Feed per Tooth (Sz) mm/rev	Depth of Cut (D_c) mm	Width of Cut (W_c) mm
GA	0.102	0.123	225	0.1	1	3

4.Results

In this study, the design methodology of the most appropriate cutting parameters, for AlMgSiF32 material with 2 different coated cutting tool. In this proposed methodology, the use of optimization method has been investigated to minimize tool wear. The best cutting parameters were examined with the optimization method. Response surface methodology, and the power of the genetic algorithm were used to integrate optimum values. Experimental analysis data were performed for the combination of process parameters designed using the D-optimal experimental design method. The models of the tool wear result are created by using the surface response methodology that takes advantage of the experimental setup. The response surface models are then integrated with an effective genetic algorithm to find optimum process parameter values. Genetic optimization has significantly reduced tool wear values. From optimization results, it was seen cutting parameters of all of them change more effective when optimization criteria is changed. PVD coated cutting tool performance was observed to give better results than CVD coated cutting tool performance. These values can be a basis for those working in the machining industry. As a result, the optimization methodology proposed in this study can be successfully used to improve and determine the best production conditions in cutting operations.

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