Determining the optimum process parameter for grinding operations using robust process

Süleyman Neşeli¹, İlhan Asiltürk²,⁴ and Levent Çelik²

¹ Vocational High School, University of Selçuk, 42075, Konya, Turkey
² Faculty of Technology, University of Selçuk, 42075, Konya Turkey

(Manuscript Received August 11, 2011; Revised May 21, 2012; Accepted May 31, 2012)

Abstract

We applied combined response surface methodology (RSM) and Taguchi methodology (TM) to determine optimum parameters for minimum surface roughness (Ra) and vibration (Vb) in external cylindrical grinding. First, an experiment was conducted in a CNC cylindrical grinding machine. The TM using L27 orthogonal array was applied to the design of the experiment. The three input parameters were workpiece revolution, feed rate and depth of cut; the outputs were vibrations and surface roughness. Second, to minimize wheel vibration and surface roughness, two optimized models were developed using computer-aided single-objective optimization. The experimental and statistical results revealed that the most significant parameter for surface roughness and vibration is workpiece revolution followed by the depth of cut. The predicted values and measured values were fairly close, which indicates (Ra = 94.99 and Vb = 92.73) that the developed models can be effectively used to predict surface roughness and vibration in the grinding. The established model for determination of optimal operating conditions shows that a hybrid approach can lead to success of a robust process.

Keywords: CNC grinding; RSM; Taguchi design; Surface roughness; Vibration monitoring

1. Introduction

In machining operations, the quality of surface finish is an important factor in evaluating the productivity of machined parts. Grinding processes are used to smooth or improve surface finish quality. Cylindrical grinding is a complex, material-removal process with a great number of influencing factors, which are non-linear, interdependent and difficult to quantify. To maximize the surface quality, the selection of grinding parameters is vital; the vibration and surface roughness is chiefly affected by the selection of grinding parameters.

So many factors influence the grinding process that a reproducible workpiece quality is rarely, if ever, achieved. Although many efforts have been made to predict the parameters of the grinding process, many difficulties remain because abrasive processes are dynamic in nature unlike turning and milling processes, as the cutting edges of the grinding wheel are not uniform and act differently on the workpiece at each grinding. To predict the parameters of the grinding process, it is necessary to quantify surface roughness, which is one of the most critical quality constraints for the selection of grinding parameters in process planning. The selection of grinding parameters is traditionally executed by process planners either on the basis of their practical knowledge gained by experience on the shop floor or with the help of data handbooks [1, 2]. This process, however, may be time-consuming and cannot satisfy any economic criteria; also it cannot determine the exact optimum parameters because of restricted experiments [3]. Moreover, these solutions are not reliable or acceptable for selecting the optimum cutting parameters from a productivity point of view. Efficient process set-up should be model based in which the required surface roughness is obtained.

Statistical design of experiments (DOE) refers to the process of planning the experiment so that the appropriate data can be analyzed by statistical methods, resulting in valid and objective conclusions [4-7]. DOE methods such as factorial design, RSM and TM are now widely used for optimize the machining parameters in place of one-factor-at-a-time experimental approach which is time consuming and exorbitant in cost [8]. To this end, much research has been conducted to determine optimal process parameters and to apply various optimization techniques to grinding variables of wheel speed, workpiece speed, depth of dressing, and lead of dressing using a multi-objective function model with a weighted approach [9-13].

Lee et al. [14] proposed to solve the problem of optimiz-
tion for the surface grinding process by using optimizing the grinding variables such as wheel speed, workpiece speed, depth of dressing, and lead of dressing, using a multi-objective function model. This research provided rough-grinding and finish-grinding results that demonstrated the applicability of the proposed Taguchi-sliding-based differential evolution algorithm, and the computational results showed that this proposed Taguchi-sliding-based differential evolution algorithm can obtain better results.

Krishna and Rao [15] proposed a scatter search based optimization approach to optimize the grinding parameters of wheel speed, workpiece speed, and depth of dressing and lead of dressing using a multi-objective function model with a weighted approach for the surface grinding process.

Habib [16] developed a comprehensive mathematical model for correlating the interactive and higher order influences of various Electrical discharge machining (EDM) parameters through RSM, utilizing relevant experimental data as obtained through experimentation.

Another important work was presented by Agarval and Rao [17] about grinding parameter optimization. As a result of their study, a new analytical surface roughness model was developed on the basis of the stochastic nature of the grinding process, governed mainly by the random geometry and the random distribution of cutting edges on the wheel surface having random grain protrusion heights.

Malkin [18] investigated the process monitoring and studied various grinding aspects such as cutting mechanisms, the specific energy and the interrelationship of the parameters. His research showed that the grinding process had very complex cutting mechanisms and that replicability of results was difficult to obtain under the same grinding conditions.

Shaji [19] reported a study on the Taguchi method for evaluating process parameters in surface grinding with graphite as a lubricant. They analyzed the effect of the grinding parameters (wheel speed, table speed, depth of cut and the dressing mode) on the surface finish and the grinding force.

Kwak [3] showed that the various grinding parameters caused a geometric error generated during the surface grinding, using the Taguchi method, and that the geometric error could be predicted by means of the response surface method. Usually, the equation for predicting cutting time is unknown during the early stages of cutting operations.

Jeang [20] studied to determine the optimal cutting parameters required to minimize the cutting time while maintaining an acceptable quality level. He formulated an objective function using CATIA software, with assistance from the statistical method and response surface methodology (RSM). Results showed the statistical method in cooperation with the optimal solutions found from mathematical programming can also be used as references for the possibility of robust design improvements.

This paper illustrates how response surface designs and orthogonal array fractions can be used in a series of grinding experiments to formulate a high performance robust product.

Taking this research a step further, the Taguchi and response surface methodology are used to predict the wheel vibration and the surface roughness in the external cylindrical grinding of the hardened AISI 8620 steel and also to select the optimum grinding conditions. Also, this research would benefit from future applications, especially as introduced in a real-world application, such as a manufacturing plant. It is also advantageous to perform studies similar to this in academia as class learning exercises.

2. Profile parameters of surface roughness

Surface roughness plays an important role in determining how a real object will interact with its environment. A good-quality workpiece surface can improve fatigue strength, corrosion resistance, and thermal resistance. In addition, the final surface roughness also affects several functional attributes of parts like friction, wearing, light reflection, heat transmission, coating and ability of distributing, and holding a lubricant [20-23].

The surface roughness universally recognized standard is ISO 4287:1997. Actually, there are various simple surface roughness amplitude parameters used in industry, such as roughness average ($Ra$), root-mean-square ($rms$) roughness ($Rq$), and maximum peak-to-valley roughness ($Ry$ or $Rmax$) [24, 25]. In quantifying surface roughness the unit $\mu m$ is used worldwide. Therefore, the parameter $Ra$ is used for surface roughness in this study. $Ra$ is specified by Eq. (1).

$$Ra = \frac{1}{L} \int_{0}^{L} |f(x)| dx$$

where $Ra$ is the arithmetic average deviation from the mean line, $L$ is the cut-off length, $f$ the ordinate of the profile curve. In this study, the average surface roughness ($Ra$) is measured within the selected cut-off value of 0.8-2.5 mm, depending on the magnitude of the roughness.

3. Monitoring of vibration signals

Two important roles of the monitoring system are to provide information to optimize the process and to contribute to establishing the database, which is necessary to determine the setup parameters. The major problems in the grinding processes are chatter vibration and surface roughness deterioration [26]. The process is highly complex and it is affected by dynamic stability of the workpiece. Vibration is a direct cause of poor workpiece quality. Hence, the quality of the parts, namely surface finish, depends largely on the stability of the process. Here, we are going to test the ability of the vibration signal to follow the changes of workpiece surface roughness to achieve high quality.