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# Optimization of Dressing Conditions When External Cylindrical Grinding to Minimize Surface Roughness

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## ABSTRACT

This paper studies the influence of the dressing condition on the external cylindrical grinding process to determine the optimal dressing conditions to achieve the minimum surface roughness. Six input parameters in the investigation, including depth of rough dressing, rough dressing time, depth of fine dressing, fine dressing time, non-feeding dressing time, and dressing speed. The study used the response surface method to design the experiment. The experiment results were analyzed by using Minitab R19 software. The regression equation describes the relationship between the input parameters and surface roughness was determined and the optimal dressing condition to achieve the minimum roughness was determined.

***Keywords****—external grinding; dressing condition; surface roughness;*

## I. Introduction

The surface quality of the work piece and the efficiency of the grinding process in general, and the external cylindrical grinding process, in particular, much depends on the dressing condition [1, 2]. However, the introduction of the dressing condition in the practice is also limited in general guidelines [3].

Currently, there are some studies of dressing conditions to improve the efficiency and quality of the grinding process. The research results show a clear influence of the dressing condition on the quality and productivity of the grinding process [4]. The study of Haoyan Cao indicated the grinding conditions should be selected in conjunction with wheel dressing conditions. The constraint of textural gouge shape depends on grinding contact length and dressing conditions [5]. Xun Chen also presents a study about the relation of grinding force and grinding power to the dressing operation by considering the effective density of the cutting edges on the wheel surface [6]. In addition, the relationship between the dressing parameters and the radial wear has been studied by Puerto [7].

The study of Tran Ngoc Giang and Tran Thi Hong study the effect of dressing parameters on surface roughness and Flatness tolerance when surface grinding. In these studies, the six input dressing parameters were investigated and the results have shown the dressing condition hasa great impact on surface roughness and flatness tolerance, the optimization of dressing condition to reached minimum surface roughness or flatness tolerance was also presented [8, 9]. The multi-objective optimization of dressing conditions when surface grinding has been studied [10, 11]. The other study about internal cylindrical grinding has been presented by Le Xuan Hung [12].

In the external cylindrical grinding process, the effect of dressing conditions on the surface roughness, material removal rate, or roughness tolerance has been investigated. These studies applied the Taguchi method to design the experiment and determined the optimum dressing conditions [13-15]. However, the Taguchi method could only determine the optimal dressing condition at the investigated levels. Therefore. In this study, we study the effect of dressing parameters on surface roughness when external cylindrical grinding 90CrSi using the response surface method.

## II. EXPERIMENTAL DESIGN

As literature review above, in this section, an experiment design using response surface Box-Behnken method was applied to investigate the effect of six input parameters including depth of rough dressing, rough dressing time, depth of fine dressing, fine dressing time, non-feeding dressing time, and dressing speed on surface roughness when external grinding 90CrSi. The input parameters and their levels were shown in table 1.

TABLE 1.INPUT PARAMETERS AND INVESTIGATED LEVELS

| No. | Input parameters | Symbol | Unit | Level of investigating | |
|---|---|---|---|---|---|
| | | | | Low | High |
| 1 | Depth of rough dressing | $a_r$ | mm | 0.02 | 0.04 |
| 2 | Rough dressing time | $n_r$ | - | 1 | 5 |
| 3 | Depth of fine dressing | $a_f$ | mm | 0.005 | 0.015 |
| 4 | Fine dressing time | $n_f$ | - | 0 | 4 |
| 5 | Non-feeding dressing time | $n_0$ | - | 0 | 4 |
| 6 | Feed speed | $S_d$ | m/min | 1 | 2 |

The experiments were conducted using the following fixed grinding conditions and equipment: The Cantext Aquatex 3810 with a concentration of 3% and a flow-rate of 10 l/min was used for coolant condition; the grinding condition is: feed rate at 1.8 m/min, depth per cut is 0.005 per single stroke, total depth of cut is 0.05 mm and the speed of grinding wheel is 29.3 m/s; Grinding machine: CONDO-Hi-5 HTS (Japan origin); grinding wheel: Ct80MV1-G 400x40x203 35m/2 (Vietnam origin); dressing tool: 3908-0088C type 2 (Russian origin); surface roughness tester: Mitutoyo 178-923-2A SJ201 (Japan origin). The workpiece properties are described in table 2.

TABLE 2.90CrSi STEEL PROPERTIES

| Steel grade: 90CrSi | | | | | | |
|---|---|---|---|---|---|---|
| C | Si | Mn | Cr | P | S | Co |
| 0.85-0.95 | 12-1.6 | 0.3-0.6 | 0.95-1.25 | ≤0.03 | ≤0.03 | ≤1 |

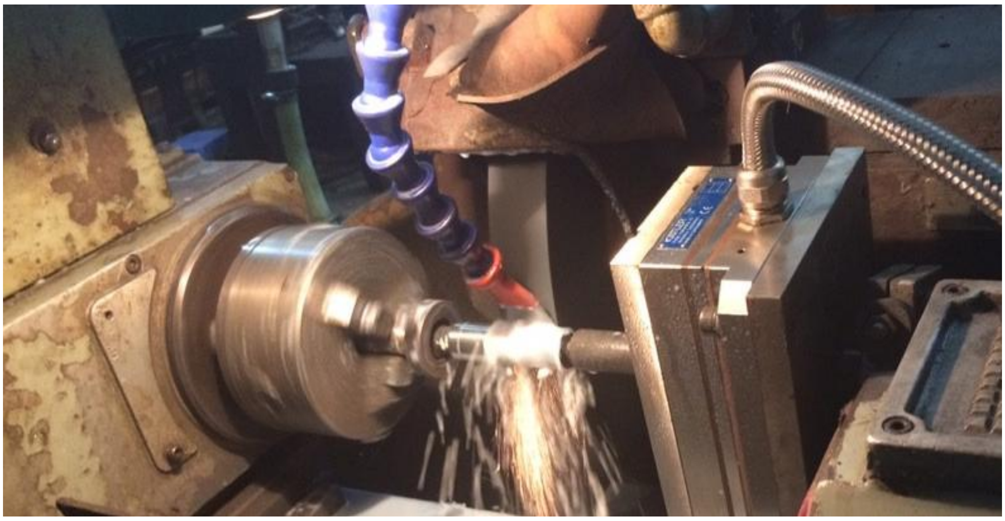

Fig 1. Experiment setup

According to the response surface method, the experiment design is calculated based on the input data in table 1. By using Minitab R19, the experiment design table with 54 experiments is listed in table 3. The surface roughness of each run is described in table3 either.

TABLE 3.EXPERIMENT DESIGN AND MEASUREMENT RESULTS

| Std Order | Run Order | Pt Type | Blocks | $a_r$ | $n_r$ | $a_f$ | $n_f$ | $n_0$ | $S_d$ | Mean of Ra(μm) |
|---|---|---|---|---|---|---|---|---|---|---|
| 30 | 1 | 2 | 1 | 0.04 | 3 | 0.01 | 0 | 4 | 1.5 | 0.233 |
| 46 | 2 | 2 | 1 | 0.04 | 3 | 0.005 | 2 | 2 | 2 | 0.331 |
| 37 | 3 | 2 | 1 | 0.03 | 1 | 0.01 | 2 | 0 | 2 | 0.252 |
| 16 | 4 | 2 | 1 | 0.03 | 5 | 0.015 | 2 | 4 | 1.5 | 0.264 |
| … | …. | … | … | … | … | … | … | … | … | … |
| 20 | 51 | 2 | 1 | 0.03 | 3 | 0.015 | 4 | 2 | 1 | 0.359 |
| 17 | 52 | 2 | 1 | 0.03 | 3 | 0.005 | 0 | 2 | 1 | 0.411 |
| 48 | 53 | 2 | 1 | 0.04 | 3 | 0.015 | 2 | 2 | 2 | 0.379 |
| 15 | 54 | 2 | 1 | 0.03 | 1 | 0.015 | 2 | 4 | 1.5 | 0.355 |

## III. RESULT AND DISCUSSIONS

In order to find the optimum set of dressing parameters, the ANOVA method is conducted by using Minitab R19 to determine the influence of input parameters on the surface roughness.

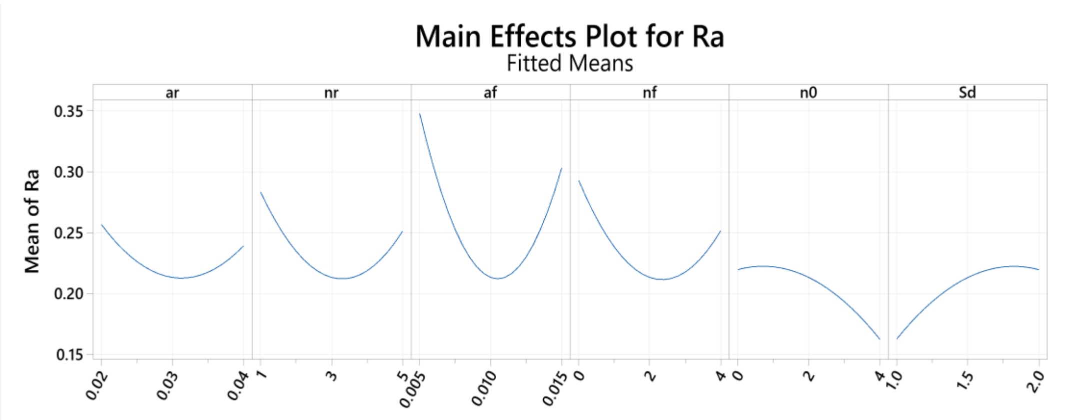


Fig2.Effect of input factors on surface roughness

Observing the analysis result in figure 2 shows all of the input parameters affect the response in the quadratic form. This result indicated that investigated area has extreme value and the optimal value of the input parameter can be determined.

The influence degree of input factors is described in the Pareto chart in figure 3.

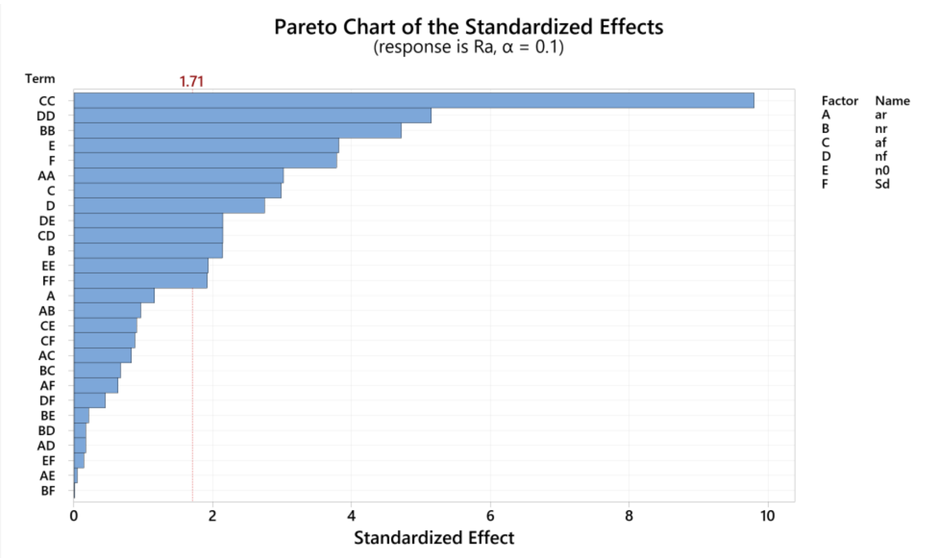


Fig 3. The influence degree of input factor on surface roughness

The figure shows clearly that the quadratic effect of CC ($a_f$*$a_f$) is largest, then followed by the effect of DD ($n_f$*$n_f$), BB ($n_r$*$n_r$), E ($n_0$), F ($S_d$), AA ($a_r$*$a_r$), C ($a_f$), D ($n_f$), DE ($n_f$*$n_0$), CD ($a_f$*$n_f$), B ($n_r$), EE ($n_0$*$n_0$) and FF ($S_d$*$S_d$).

After determining the influence of the input factor on surface roughness and then remove the negligible influence factors. The regression equation coefficients are determined by using Minitab R19 software. The calculated results are shown in Table4.

TABLE 4.THE ESTIMATED COEFFICIENTS OF INPUT PARAMETERS AND THEIR INTERACTION

**Coded Coefficients**

| Term | Coef | SE Coef | T-Value | P-Value | VIF |
|---|---|---|---|---|---|
| Constant | 0.2135 | 0.0132 | 16.14 | 0.000 | |
| $a_r$ | -0.00871 | 0.00661 | -1.32 | 0.196 | 1.00 |
| $n_r$ | -0.01604 | 0.00661 | -2.43 | 0.020 | 1.00 |
| $a_f$ | -0.02238 | 0.00661 | -3.38 | 0.002 | 1.00 |
| $n_f$ | -0.02058 | 0.00661 | -3.11 | 0.003 | 1.00 |
| $n_0$ | -0.02858 | 0.00661 | -4.32 | 0.000 | 1.00 |
| $S_d$ | 0.02833 | 0.00661 | 4.28 | 0.000 | 1.00 |
| $a_r$*$a_r$ | 0.0346 | 0.0101 | 3.42 | 0.001 | 1.30 |
| $n_r$*$n_r$ | 0.0540 | 0.0101 | 5.34 | 0.000 | 1.30 |
| $a_f$*$a_f$ | 0.1122 | 0.0101 | 11.10 | 0.000 | 1.30 |
| $n_f$*$n_f$ | 0.0589 | 0.0101 | 5.83 | 0.000 | 1.30 |
| $n_0$*$n_0$ | -0.0221 | 0.0101 | -2.19 | 0.034 | 1.30 |
| $S_d$*$S_d$ | -0.0220 | 0.0101 | -2.17 | 0.036 | 1.30 |
| $a_f$*$n_f$ | 0.0279 | 0.0115 | 2.43 | 0.020 | 1.00 |
| $n_f$*$n_0$ | 0.0279 | 0.0115 | 2.43 | 0.020 | 1.00 |

**Model Summary**

| S | R-sq | R-sq(adj) | R-sq(pred) |
|---|---|---|---|
| 0.0324025 | 86.82% | 82.09% | 74.33% |

The regression equation of surface roughness is described by the following model:

**Regression Equation in Uncoded Units**

$$Ra = 1.076 - 21.61a_r - 0.0890n_r - 99.77a_f - 0.1110n_f - 0.0061n_0 + 0.320S_d + 346a_r*a_r + 0.01350n_r*n_r + 4486a_f*a_f + 0.01474n_f*n_f - 0.00553n_0*n_0 - 0.0879S_d*S_d + 2.79a_f*n_f + 0.00697n_f*n_0$$

Based on the determined regression equation, the calculate the optimal value of the input parameters to achieve the minimum surface roughness is determined by Minitab R19 software.

TABLE 5.THE CALCULATED OF THE OPTIMAL VALUE OF THE INPUT PARAMETERS

**Solution**

| Solution | $a_r$ | $n_r$ | $a_f$ | $n_f$ | $n_0$ | $S_d$ | Ra Fit | Composite Desirability |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.03131 | 3.3030 | 0.01056 | 1.8182 | 4 | 1 | 0.1092 | 1 |

From the optimal calculation results in table 5, an optimal set of dressing condition parameters can be obtained to achieve the smallest surface roughness based on the adjustment range of the machine are $a_r$ = 0.03 mm, $n_r$ = 3 times, $a_f$ = 0.01 mm, $n_f$ = 2 times, $n_0$ = 4 times and $S_d$ = 1 m/min. The predicted value of Ra corresponding to optimum dressing condition is 0.1123 µm.

## IV. CONCLUSION

The current study presents the optimization to achieve the minimum surface roughness with the optimum dressing condition when external cylindrical grinding. The response surface method and ANOVA are applied to find the orthogonal array for the experimental plan. The following conclusions can be made:

- All of the dressing parameters investigated affect surface roughness. Among them, the quadratic effect of CC ($a_f*a_f$) is largest, and then followed by the effect of DD ($n_f*n_f$), BB ($n_r*n_r$), E ($n_0$), F ($S_d$), AA ($a_r*a_r$), C ($a_f$), D ($n_f$), DE ($n_f*n_0$), CD ($a_f*n_f$), B ($n_r$), EE ($n_0*n_0$) and FF ($S_d*S_d$).

- The regression equation for the relationship between dressing parameters and surface roughness is determined as follows:

$$Ra = 1.076 - 21.61a_r - 0.0890n_r - 99.77a_f - 0.1110n_f - 0.0061n_0 + 0.320S_d + 346a_r*a_r + 0.01350n_r*n_r + 4486a_f*a_f + 0.01474n_f*n_f - 0.00553n_0*n_0 - 0.0879S_d*S_d + 2.79a_f*n_f + 0.00697n_f*n_0$$

- The optimum dressing condition is determined to be $a_r$ = 0.03 mm, $n_r$ = 3 times, $a_f$ = 0.01 mm, $n_f$ = 2 times, $n_0$ = 4 times and $S_d$ = 1 m/min. And the optimum value of surface roughness is 0.1123 µm.

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