Optimize Multiple Responses For Slide Milling Process Using Nanofluid By Taguchi Method Based on GRA Theory

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Abstract: Nanofluids made by mixing the nanoparticles with the cutting fluid can be applied in the machining process to reduce the tool wear and the surface roughness. The Taguchi method based on the grey relational analysis theory was selected to optimize multi-responses for the groove milling process using nanofluids as the tool wear and the surface roughness. The grey relational index (GRI) were determined from the experimental results (the tool wear and the surface roughness) by using the grey relational analysis theory. Then the optimal condition – (the nanoparticle concentration 0.2% and the cutting speed 25mpm) was determined by Taguchi's method through the mean value and ratio (S/N).

Keywords: Nanofluids, Slide milling, GRA, Taguchi

I. INTRODUCTION

The slide milling process is one of the processes to machine the grooves in many parts. In the groove milling process, a slide tool is used to remove material of workpieces with three cutting edges. Thus, the machining processes cause high cutting forces and friction on the cutting tool and high temperature as well [1]. Those factors lead to the reduction of the surface quality, and tool life, so using an appropriate cooling lubricant is very important. In recent years, the nanofluid made by adding the nanoparticles (MoS_2, WS_2, Al2O3, …) into the normal cutting oil has been studied to apply on many machining processes [2]. Many researchers indicated that applying nanofluids on the machining process can reduce the cutting force, temperature, improving surface finish, and decreasing tool wear in the machining process [2]. In recent studies, Ahmed reported that new nanofluids made by mixing SiO_2 the normal oil exhibits the promising were applied on the machining process to reduce the friction and cutting force compared to the normal lubrication [3]. The research of Vasu showed that the Al_2O_3 nanoparticles have many properties consistent with adding to the industrial oils [4]. In 2009, Malkin studied the applying nanofluid (mixing the Al_2O_3 nanoparticles with water) on the grinding process to decrease the cutting forces, the cutting temperature and the surface roughness [5]. Khalil studied the effects of the parameters of cutting fluid added MoS2 nanoparticles on the force, temperature and surface roughness in CNC milling of aluminum alloy [6]. M. Amrita added nano graphite into water SO and studied their effects on cutting forces, temperature, tool wear and roughness of machined surface [7]. Roja Abraham studied the applying Multi-Walled Carbon Nano Tubes suspended in water and sodium dodecyl sulfate surfactant on the turning process to reduce the surface roughness, tool wear and cutting forces [8]. But, the effect of Al2O3 nanoparticle concentration that mixed with cutting fluids in slide milling process has not been published yet.

This research investigates applying the cutting fluids mixed nanoparticle Al2O3 to reduce the tool wear and the surface roughness in the slide milling process. A grey relational index (GRI) was calculated by the grey relational analysis to solve the slide milling operations with multiple performance features. Optimal cutting parameters can then be determined by the Taguchi method using the grey relational index. Tool wear and surface roughness are important characteristics in the groove milling process. Using these characteristics of the cutting conditions, including cutting speed and nanoparticle concentration are optimized in this study.

II. EXPERIMENT SETUP

The machining process uses a slide milling tool with the three cutting edges made by HSS material having hardness 65HRC in the horizontal milling machine, as figure 1. The workpieces were made by C45 steel. The cutting depth and feed rate are selected as the same conditions of the slide milling process used in the machining Company at Viet Nam. And the cutting speed was varied in the range from 25 m/min to 35 m/min.

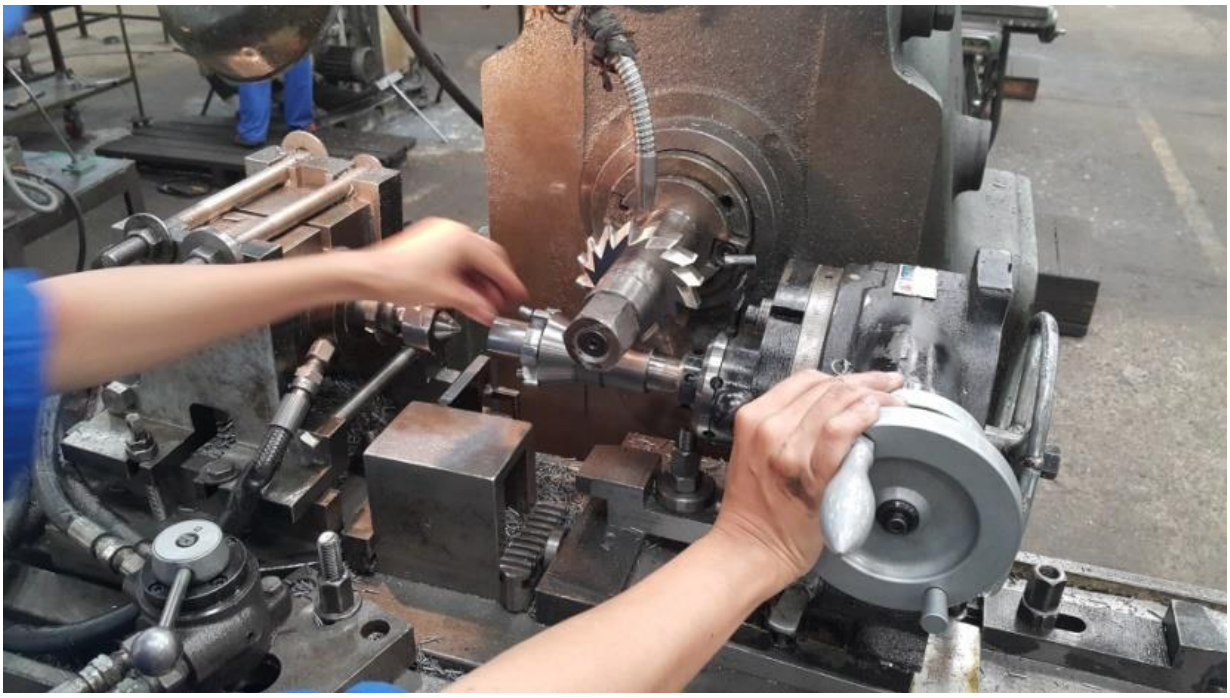

Figure 1. Experiment setup

Depending on the actual machining process, the ISO BW Cool EX-8500V cutting oil was widely used for the slide milling process due to its economical characteristics. In this research, the Al2O3 nanoparticles made by US Research Nanomaterials is added to the normal cutting oil. The Al2O3 nanoparticle with the size of 80nm was selected in order to determine the optimize cutting condition for the slide milling process using the nanofluid. The nanoparticle concentration is 0 %, 0.2% and 0.4%. The surface roughness of the machined surface was measured by the portable surface profilometer Mitutoyo SJ-210. One tool was used to cutting three parts, as figure 2. The flank wear of the slide milling tool is measured after machining 3 products and the results displayed in table 2.

Figure 2 The machined products

III. OPTIMIZATION METHOD

A. Grey relation analysis theory

Grey relation analyses (GRA) is an expérimental analysis method based on the grey system theory developed by China Professor. GRA is widely used in experimental data analysis and multi-objective optimization [9][10][11]. From the experimental data set with different units (tool wear and surface roughness), GRA allows synthesis into a single coefficient.

The first, the tool wear and surface roughness in the slide milling process are standardized in the range from 0 to 1. The formula determining data standardization depends on the characteristics of experimental data sequences. In this research, the smaller - the better quality parameters were chosen to calculate the grey relational grade for tool wear and surface roughness. With the smaller –the better, data standardization can be expressed by:

$$x^{*}_{i(k)} = \frac{\max x_i^0(k) - x_i^0(k)}{\max x_i^0(k) - \min x_i^0(k)} \qquad (1)$$

Where

i=1…m ; k=1….n

m is the number of experimental data

n is the number of parameters;

$x_i^0(k)$ is the original sequence,

$x_i^*(k)$ are the sequences after data preprocessing, Min $x_i^0(k)$ and max $x_i^0(k)$ are the smallest and the largest value of $x_i^0(k)$

Next, the grey relational coefficient is determined from the standardized data to indicate the relationship between the desired and actual characteristics such as the tool wear and surface roughness. The grey relational coefficients were calculated by Eq. (2) [12]:

$$\xi_i(k) = \frac{\Delta min + \xi \Delta max}{\Delta_{0,1}(k) + \xi \Delta max} \qquad (2)$$

where,

Δ_{0i} deviation sequences of the reference and comparability sequence

$$\Delta_{0,i} = \|x_0^*(k) - x_i^*(k)\| \qquad (3)$$

$$\Delta_{min} = min_{\forall j \in i} min_{\forall k} \|x_0^*(k) - x_j^*(k)\|$$

$$\Delta_{max} = max_{\forall j \in i} max_{\forall k} \|x_0^*(k) - x_j^*(k)\|$$

$x_0^*(k)$ the reference sequence, and $x_i^*(k)$ is the comparative sequence.

ζ is known as distinguishing coefficient with $\zeta \in [0,1]$, which can be selected to better identify between standardized reference sequences and standardized comparative sequences. In this research, Normal level ζ (0.5) is selected to moderately distinguish the effect. From the calculation, the values of minΔ and maxΔ are respectively 0 and 1. Then The grey relational coefficients were calculated by Eq. (4):

$$\xi_i(k) = \frac{0.5}{\Delta_{0,1}(k) + 0.5} \qquad (4)$$

After the grey relational coefficient is calculated, the grey relational index (GRI) is determined by averaging the value of the grey relational coefficients. The existing GRI between the two series is always distributed between 0 and 1. Grey relational index can be determined using the formula below:

$$\gamma_i = \frac{1}{n} \sum_{k=1}^{n} \xi_i(k) \qquad (5)$$

where γ_i represents GRI; the level of correlation between the reference sequence and the comparability sequence.

B. Taguchi experiment design

Influences of the cutting parameters on the tool wear and surface roughness were analyzed by using the Taguchi experimental design in the slot milling process. The L9 orthogonal array was chosen and shown in table 1. In Taguchi method, the S/N ratio is used to consider the influence of the input factors on the output factor. The greater the value of the S/N ratio, the less the impact of the noise parameters. The S/N ratio as determined as follows:

$$S/N = -10 Log10[MSD] \qquad (6)$$

Where MSD is the mean square error for output factors. The MSD values can be determined by three types of the S/N ratio characteristics: nominal the better, smaller the better, and greater the better. In this paper, the theory of GRA method was used to convert the tool wear and surface roughness of the slide milling process a Grey relational index. The higher – the better quality parameters were chosen to calculate the S/N ratio for the grey relational index of the slide milling process.

The mean-square deviation (M.S.D.) for the-higher-the-better quality characteristic can be expressed as $MSD = \frac{1}{n}\sum_{i=1}^{n} y_i^2$ (7)

Where: yi is the grey relational index.

n is the number of experiments

Table 1 Experimental design based on L9 orthogonal array

Exp. No	Nano. Con. – A (%)	Cutting speed – B (mpm)
1	0.0	25
2	0.0	30
3	0.0	35
4	0.2	25
5	0.2	30
6	0.2	35
7	0.4	25
8	0.4	30
9	0.4	35

IV. RESULT AND DISCUSSION

The normalised input parameters werecalculated for the flank tool wear and surface roughness by formula (3), shown in table 2. The deviation sequences of the absolute value between xo(k) and xi(k), the grey relational coefficient for the tool wear (Hs) and surface roughness (Ra) were determined by equation (2) & (3), shown in table 3. And then, the grey relational grades were calculated by equation (5). Table 4 shows the experimental results for the grey relational grade and order using the experimental layout. The higher value of the grey relational grade means that the corresponding cutting conditions is closer to optimal.

Table 2. Data normalization of each performance characteristics

TT	A (%)	B (m/min)	Hs (µm)	Ra (µm)	Normalization of Hs	Normalization of Ra
1	0.0	25	90	2.020	0.369565	0.414696
2	0.0	30	95	2.507	0.304348	0.169602
3	0.0	35	118.3	2.844	0	0
4	0.2	25	41. 67	0.857	1	1
5	0.2	30	45	0.971	0.956522	0.942627
6	0.2	35	46.67	1.100	0.934783	0.877705
7	0.4	25	51.67	1.604	0.869565	0.624056
8	0.4	30	61. 67	1.693	0.73913	0.579265
9	0.4	35	63.33	1.968	0.717391	0.440866

Table 3 Grey relational coefficient

No.	**A (%)**	**B (m/min)**	**Deviation sequences of Hs**	**Deviation sequences of Ra**	**Grey Coe. of Hs**	**Grey Coe. of Ra**
1	0.0	25	0.630435	0.585304	0.442308	0.4607
2	0.0	30	0.695652	0.830398	0.418182	0.375828
3	0.0	35	1	1	0.333333	0.333333
4	0.2	25	0	0	1	1
5	0.2	30	0.043478	0.057373	0.92	0.897065
6	0.2	35	0.065217	0.122295	0.884615	0.803478
7	0.4	25	0.130435	0.375944	0.793103	0.570813
8	0.4	30	0.26087	0.420735	0.657143	0.543045
9	0.4	35	0.282609	0.559134	0.638889	0.472084

Further, optimization of the multiple responses for the slide milling process can be converted into the optimization of a single grey relational index. The grey relational indexes were analyzed by the software Minitab 16. The ANOVA analysis was used to reveal the effect of output parameters to the grey relational indexes in the slide milling process with 96.2 % confidence intervals as shown in Table 5.

Table 4. Grey relational index and its order

No.	**A (%)**	**B (m/min)**	**GRI**	**S/N of GRI**	**Order**
1	0.0	25	0.451504	-6.90677	7
2	0.0	30	0.397005	-8.02409	8
3	0.0	35	0.333333	-9.54243	9
4	0.2	25	1	0.00000	1
5	0.2	30	0.908533	-0.83319	2
6	0.2	35	0.844046	-1.47267	3
7	0.4	25	0.681958	-3.32484	4
8	0.4	30	0.600094	-4.43562	5
9	0.4	35	0.555486	-5.10653	6

Table 5 Analysis of variance for the grey relational index

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**
Nanoparticle concentration (A)	2	0.414939	0.414939	0.207470	1400.62
Cutting speed (B)	2	0.026915	0.026915	0.013457	90.85
Residual Error	4	0.000593	0.000593	0.000148	-
Total	8	0.442446	-	-	-

The ANOVA results indicate that the nanoparticle concentration (F= 1400.62) greatly effect to the GRI values and the cutting speed (F=90.80) weakly effect to the GRI values. Figures 3 show the influence of the nanoparticle concentrations and cutting speed on the GRI values in the slide milling process using the cutting fluid added Al2O3 nanoparticles. The GRI value increases while the nanoparticle concentration increases from 0% to 0.2%. The nanoparticle concentration (0.2%) has the greatest GRI value. The GRI value decreases while the cutting speed increases from 25m/min to 35m/min.

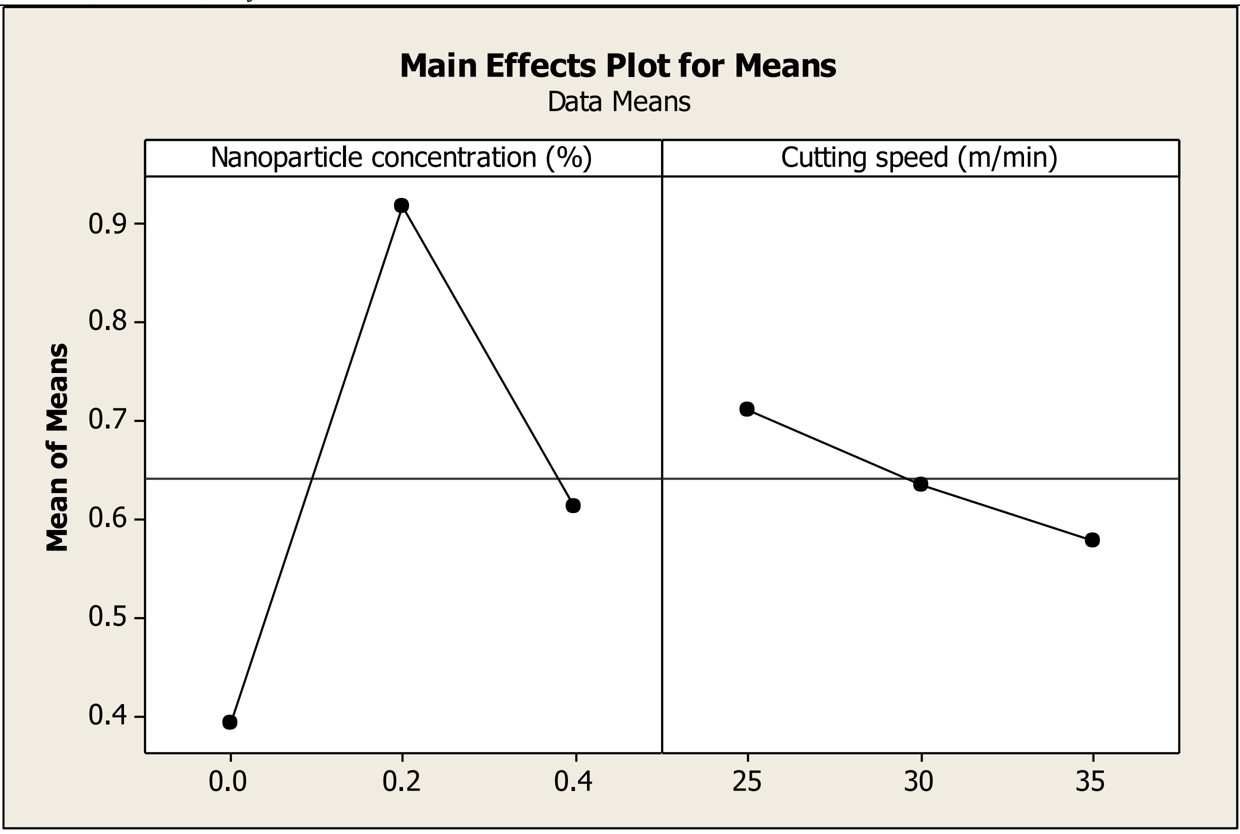

Figure 3. Main effects plot for the GRI value

In Taguchi method, the S/N ratio is used to determine the optimal parameter settings. The signal to noise ratio (S/N) for GRI was determined and shown in table 4. Table 6 shows the results of ANOVA S/N ratio of GRI with 96.4 % confidence intervals. Thisresults indicated that the nanoparticle concentration (F= 385.53) are parameters that influence the S/N ratio of the GRI value is the greatest. Figure 4 shows the effect of the factor on the S/N ratio for the GRI. These evinced that the lower cutting speed (25 mpm, B1) and the nanoparticle concentration of 0.2% (A2) contributed to the largest S/N ratio.

Table 5 Analysis of variance for the S/N ratios of GRI

Source	DF	Seq SS	Adj SS	Adj MS	F
Nanoparticle concentration (A)	2	81.9598	81.9598	40.9799	385.53
Cutting speed (B)	2	5.7851	5.7851	2.8925	27.21
Residual Error	4	0.4252	0.4252	0.1063	-
Total	8	88.1700	-	-	-

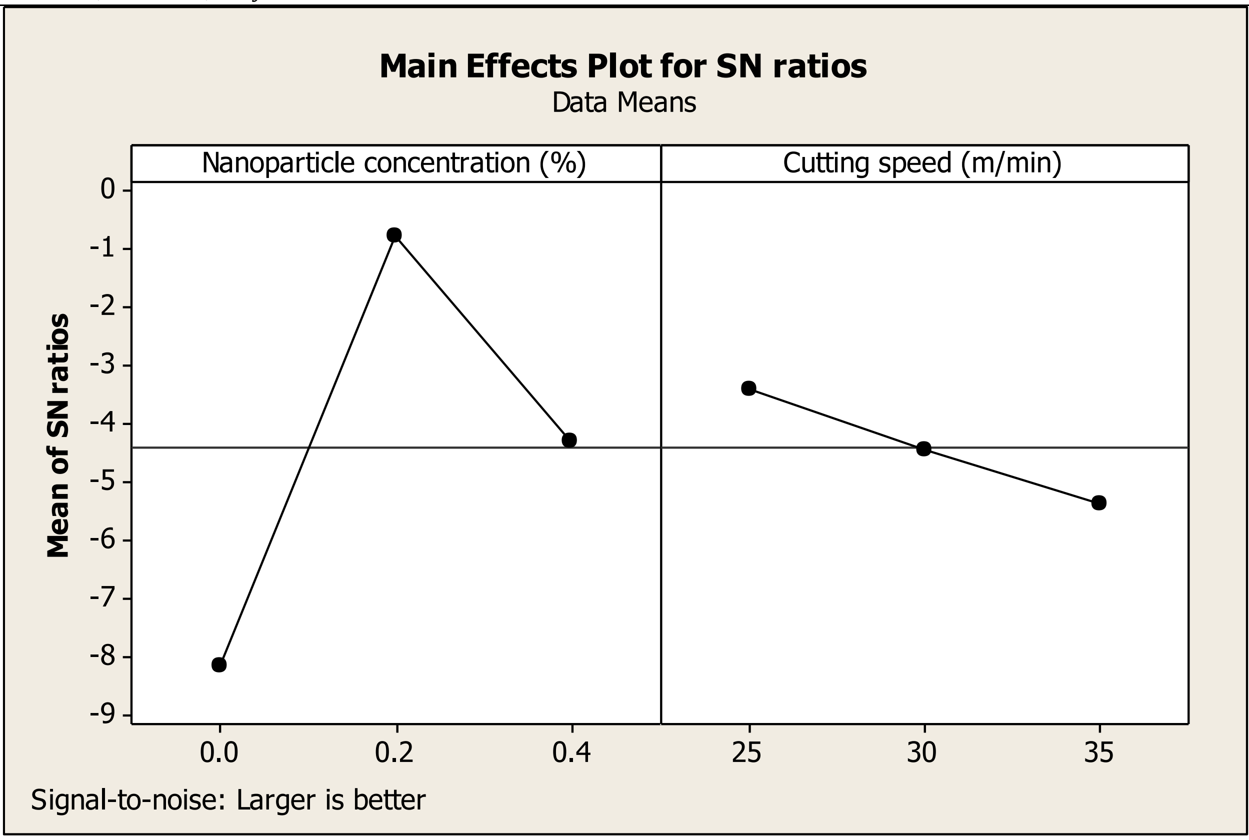

Figure 4. Main effects plot for the S/N ratio of GRI value

V. CONCLUSION

Grey relational analysis is an effective and efficient method for optimizing multi-response process parameters. The cutting parameters for slide milling process using nanofluids are optimized with L9 array designed by Taguchi method and Grey relational analysis. A single GRI value was determined by using a GRA theory and Taguchi method to optimize multiple responses in the slide milling process using nanofluids. The research results show that the nanoparticles concentrations are the great effect factor to the GRI index by using Taguchi method based on GRA theory within the slide milling process using nanofluids. The optimum parameter values for different control parameters have been suggested as nanoparticles concentration 0.2% and cutting speed 25 mpm.

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