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Optimization Of CK35 Steel Centreless Grinding Process By Gradient Descent Algorithm

Nguyen Van Cuong
University of Transport and Communications, Hanoi, Vietnam
E-mail: nguyenvancuong.dhgtvthn@gmail.com AND nguyencuong@utc.edu.vn

***Abstract*—This paper presents a study to determine the optimum value of some parameters when centreless grinding the CK35 steel. The method of centreless grinding used in this study is plunge centreless grinding. Four parameters of the machining process investigated in this study include dressing feed rate, depth of dressing, plunge feed rate and the velocity of regulating wheel. The purpose of the optimization study is to ensure the roughness of workpiece surface with the least value. Testings were conducted with 31 testings in a matrix of central domposite design. A model of surface roughness in quadratic polynomial has been proposed in this study. The gradient descent algorithm has been applied to solve optimization problems. The optimum values of the parameters of dressing feed rate, depth of dressing, plunge feed rate and the velocity of regulating wheel are 76.15 (mm/min), 0.023 (mm), 0.0078 (mm/s) and 34,416 (m/min), respectively. The influence of the above four parameters on surface roughness has also been discussed in this paper.**

***Keywords*—Centreless grinding, surface roughness, optimization, gradient descent algorithm, CK35 steel**

1. Introduction

Centreless grinding is a machining method for high productivity and accuracy. This method is commonly used to process workpiece in the auto industry, aeronautics industry, textile industry, types of dowel pins, and some parts of engines. This method is especially effective when applied in mass production [1]. The method of centerless grinding can be carried out for longitudinal feed, centerless grinding with plunge feed, centreless grinding with using magnetic base, ultrasonic grinding [1-6]. Within the scope of this study, author focus on the method of centreless grinding with plunge feed. Like other finishing methods, the roughness of workpiece surface, when implementing centreless grinding, has a great influence on the workability and longevity of a product. Therefore, the surface roughness is one of the most commonly chosen parameters as an indicator to evaluate the effectiveness of a centreless grinding process. The study to determine the effect of machining process parameters on surface roughness and to build a roughness model of workpiece have been carried out by a number of scientists. Arshad Noor Siddiquee et al. [7], Zahid A. Khan et al. [8] conducted an EN52 steel grinding testing. Phan Bui Khoi et al. [9], Do Duc Trung et al. [10] conducted a 20X steel grinding testing. J. Kopac et al. [11], P. Krajnik et al. [12, 13] conducted a 9SMn28 steel grinding testing. In the studies mentioned above, the optimum values of the parameters were also determined in each study. This study will determine the value of dressing feed rate, depth of dressing, plunge feed rate and the velocity of regulating wheel to ensure that the surface roughness has the smallest value when grinding CK35 steel. The gradient descent algorithm has been applied to solve the optimization problem. After that, the influence of the above four parameters on surface roughness will also be discussed.

2. Plunge centreless grinding experiment

2.1. Components

The component material used in this study is CK35 steel. This type of steel is easy to process, most commonly used to make machine parts in the mechanical industry. The diameters of dimension and length of the component are 20mm and 42mm respectively. The sample is heat-treated to a hardness of 44 HRC.

2.2. Grinding machine and wheels

CNC centreless grinder with symbol STC-2410 was used to perform testing in this study (figure 1).

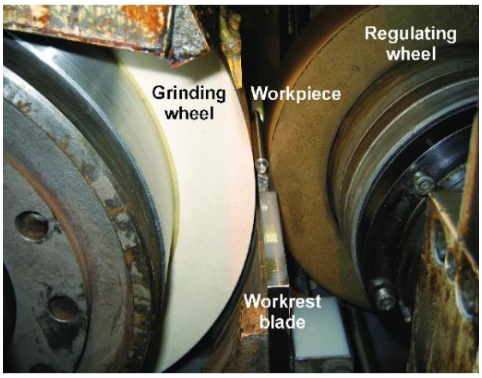

Fig 1. STC-2410 plunge centerless grinding

In this study, grinding wheel with symbol 22A80L8V63L, with dimensions of 500 mm x 80mm x 302 mm are used. The regulating wheel used is a rubber wheel with dimensions of 300 mm x 80mm x 280 mm.

2.3. Measuring equipment

SJ 201 roughness meter was used in this study (figure 2). At each testing, 3 samples were ground, each sample is measured at least three times. The roughness value at each testing is the average value of successive measurements.

2.4. Experimental design

Testing is designed according to the response surface method (RSM) based on the central composite design matrix. Values of input parameters at testing levels are shown in Table 1, the grinding matrix is shown in Table 2.

2.5. Experimental conditions

Testing is carried out with the following conditions:

- Grinding speed: 34 m/s.

- The inclined angle of the regulating wheel centerline compared to the horizontal direction is $1^0 30'$, compared to the vertical direction is $0^0 45'$.

- Use emulsion 12%, flow: 20 liters/minute

- The inclined angle of workrest surface compared to the horizontal plane is 30^0.

Fig 2. SJ-201 surface roughness tester

3. Surface roughness model

Carry out the grinding process in the order shown in Table 2, the roughness value at each testing was also included in this table. Minitab 16 statistical software was used to analyze the testing results, as presented in Table.

From the information in Table 3, the surface roughness model with the input parameters in coded form is presented as follows:

Table 1. Value at levels

Levels	Actual value			
	Dressing feed rate X1 (mm/min)	Dressing depth X2 (mm)	Plunge feed rate X3 (mm/s)	Regulating wheel velocity X4 (m/min)
-2	75	0.005	0.004	22
-1	100	0.01	0.006	28
0	125	0.015	0.008	34
1	150	0.02	0.01	40
2	175	0.025	0.012	46

Table 2. Experimental matrix and result

Test No.	Code value				Actual value				
	X1	X2	X3	X4	X1 (mm/min)	X2 (mm)	X3 (mm/s)	X4 (m/min)	Ra (µm)
1	0	0	0	0	125	0.015	0.008	34	1.02
2	1	-1	-1	1	150	0.01	0.006	40	1.50
3	0	0	0	0	125	0.015	0.008	34	1.02
4	-1	1	1	1	100	0.02	0.01	40	0.47
5	0	0	0	0	125	0.015	0.008	34	1.02
6	1	1	-1	-1	150	0.02	0.006	28	3.01
7	0	0	0	0	125	0.015	0.008	34	1.02
8	0	0	0	2	125	0.015	0.008	46	0.95
9	-1	1	-1	1	100	0.02	0.006	40	0.25
10	0	0	0	0	125	0.015	0.008	34	1.02
11	1	1	1	-1	150	0.02	0.01	28	3.23

12	1	-1	-1	-1	150	0.01	0.006	28	1.57
13	1	1	1	1	150	0.02	0.01	40	3.16
14	0	0	2	0	125	0.015	0.012	34	1.24
15	-1	-1	1	-1	100	0.01	0.01	28	1.04
16	1	1	-1	1	150	0.02	0.006	40	2.94
17	-2	0	0	0	75	0.015	0.008	34	1.18
18	0	0	0	0	125	0.015	0.008	34	1.02
19	0	0	0	-2	125	0.015	0.008	22	1.10
20	0	0	0	0	125	0.015	0.008	34	1.02
21	-1	-1	-1	1	100	0.01	0.006	40	1.10
22	-1	-1	1	1	100	0.01	0.01	40	1.37
23	0	2	0	0	125	0.025	0.008	34	2.46
24	1	-1	1	1	150	0.01	0.01	40	1.72
25	0	0	-2	0	125	0.015	0.004	34	0.80
26	-1	1	1	-1	100	0.02	0.01	28	0.55
27	-1	-1	-1	-1	100	0.01	0.006	28	1.37
28	2	0	0	0	175	0.015	0.008	34	3.71
29	1	-1	1	-1	150	0.01	0.01	28	1.79
30	0	-2	0	0	125	0.005	0.008	34	0.78
31	-1	1	-1	-1	100	0.02	0.006	28	0.33

Table 3. Regression information

Response Surface Regression: Ra versus X1, X2, X3, X4

The analysis was done using coded units.

Estimated Regression Coefficients for Ra

Term	Coef	SE Coef	T	P
Constant	1.02360	0.07312	13.999	0.000
X1	0.73040	0.03949	18.497	0.000
X2	0.24340	0.03949	6.164	0.000
X3	0.08950	0.03949	2.267	0.038
X4	-0.02750	0.03949	-0.696	0.496
X1*X1	0.36518	0.03618	10.094	0.000
X2*X2	0.15968	0.03618	4.414	0.000
X3*X3	0.01012	0.03618	0.280	0.783
X4*X4	0.01012	0.03618	0.280	0.783
X1*X2	0.56535	0.04836	11.690	0.000
X1*X3	0.03135	0.04836	0.648	0.526
X1*X4	-0.01275	0.04836	-0.264	0.795
X2*X3	0.03135	0.04836	0.648	0.526
X2*X4	-0.01275	0.04836	-0.264	0.795
X3*X4	0.03675	0.04836	0.760	0.458

S = 0.193450 PRESS = 3.44890

R-Sq = 97.56% R-Sq(pred) = 85.94% R-Sq(adj) = 95.42%

$$Y = Ra = 1.0236 + 0.7304 * X1 + 0.2434 * X2 + 0.0895 * X3 – 0.0275 * X4 + 0.36518 * X1 * X1 + 0.15968 * X2 * X2 + 0.01012 * X3 * x3 + 0.01012 * X4 * X4 + 0.56535 * X1 * X2 + 0.03135 * X1 * X3 – 0.01275 * X1 * X4 + 0.03135 * X2 * X3 – 0.01275 * X2 * X4 + 0.03675 * X3 * X4 \quad (1)$$

4. Optimization of grinding process by gradient descent algorithm

Gradient descent is a first-order iterative optimization algorithm for finding a local minimum of a differentiable function. To find a local minimum of a function using gradient descent, we take steps proportional to the negative of the gradient (or approximate gradient) of the function at the current point. But if we instead take steps proportional to the positive of the gradient, we approach a local maximum of that function; the procedure is then known as gradient ascent. Gradient descent was originally proposed by Cauchy in 1847 [14].

This section will determine the values for the parameters of dressing feed rate, depth of dressing, plunge feed rate and the velocity regulating wheel for minimum surface roughness value. Substantially, this job is to find the value of Xi (with i = 1 ÷ 4) in equation (1) for minimum Y. With the value of the Xi parameters in coded form, the optimization problem is written as follows:

$$\begin{cases} Y = Ra = f\,(Xi) \rightarrow min \\ Y > 0 \\ -1 \leq Xi \leq 2 \end{cases} \quad (2)$$

The gradient descent algorithm has been integrated into Excel's Solver tool. Use this function to solve the problem (2), the result is shown in Figure 3.

Table 4. Optimization value of parameters

Parameters	Code value	Actual value
Dressing feed rate	-1.954	76.15 (mm/min)
Dressing depth	1.597	0.023 (mm)
Plunge feed rate	-0.105	0.0078 (mm/s)
Regulating wheel velocity	0.736	34.416 (m/min)

From the results presented in Figure 3, the optimal values of dressing feed rate, depth of dressing, plunge feed rate and the velocity of regulating wheel are determined in both coding and real numbers as shown in Table 4. When machining with this optimal value set, the surface roughness has a minimum value of 0.224 µm.

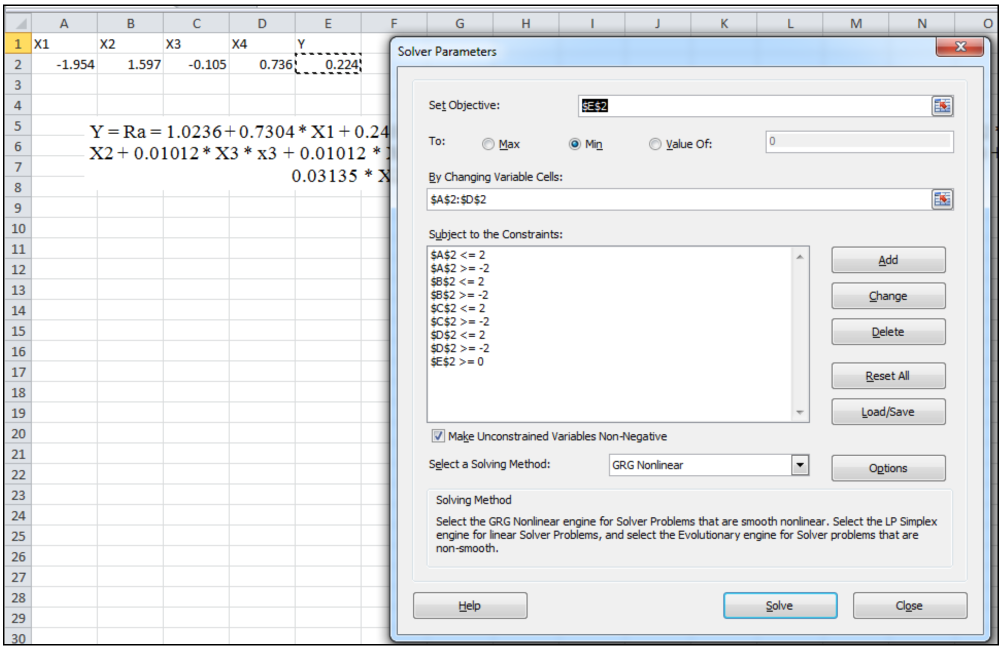

Fig 3. Using descent gradient algorithm in excel

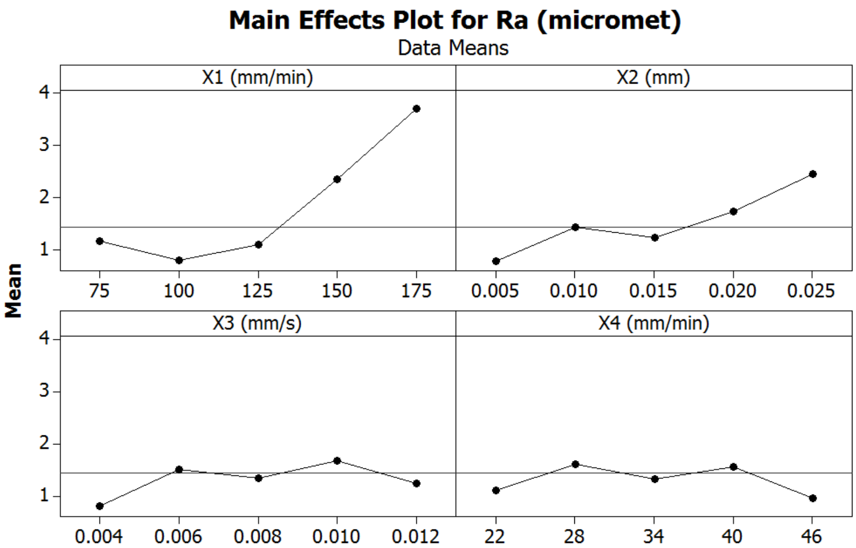

Fig 4. Main effects plot for surface roughness

5. Influence of parameters on surface roughness

Use Minitab 16 statistical software to analyze the data in Table 2, the results are as shown in Figure 4.

This figure shows that: The dressing feed rate is the parameter that has the greatest influence on the surface roughness, followed by the extent of the influence of depth of dressing, plunge feed rate. The velocity of regulating wheel has a negligible influence on the surface roughness. Increasing the dressing feed rate and the depth of dressing will increase the roughness of the surface rapidly. When increasing the value of plungel feed rate, the surface roughness increases and decrease, from time to time.

Conclusion

Some conclusions from this study when centreless grinding CK35 steel as follows:

- The optimum values of dressing feed rate, depth of dressing, plunge feed rate and the velocity of regulating wheel are 76.15 (mm/min), 0.023 (mm), 0.0078 (mm/s) and 34,416 (m/min), respectively. When processing with these optimum values of the parameters, the surface roughness reaches the smallest value equal to 0.224 µm.

- The dressing feed rate is the parameter that has the greatest influence on the surface roughness, followed by the extent of the influence of depth of dressing, plunge feed rate. The velocity of regulating wheel has a negligible influence on the surface roughness. Increasing the dressing feed rate and the depth of dressing will increase the roughness of the surface rapidly. When increasing the value of plunge feed rate, the surface roughness increases and decreases, from time to time.

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References

1. Marinescu Loan D., Eckart Uhlmann and Brian Rowe W. (2006), *Handbook of machining with grinding wheels*, CRC Press Taylor & Francis Group.
2. Yongbo Wu, Yufeng Fan, Masana Kato (2006), *A feasibility study of microscale fabrication by ultrasonic-shoe centerless grinding*, Precision Engineering 30, 201–210.
3. Yongbo Wu, Yufeng Fan, Masana Kato, Jun Wang Katsuo Syoji and Tsunemoto Kuriyagawa (2003), *A New Centerless Grinding Technique without Employing Regulating Wheel,* Key Engineering Materials. Vol. 238-239, 355-360.
4. W. Xua, Y. Wu (2011), *A new in-feed centerless grinding technique using a surface grinder*, Journal of Materials Processing Technology 211, 141–149.
5. W. Xu, Y. Wu, T. Sato, W. Lin (2010), *Effects of process parameters on workpiece roundness in tangential-feed centerless grinding using a surface grinder*, Journal of Materials Processing Technology 210, 759–766.
6. Weixing Xu, Yongbo Wu (2012), *Simulation investigation of through-feed centerless grinding process performed on a surface grinder*, Journal of Materials Processing Technology 212, 927–935.
7. Arshad Noor Siddiquee, Zahid A. Khan, Zulquernain Mallick (2010), Grey relational analysis coupled with principal component analysis for optimisation design of the process parameters in in-feed centreless cylindrical grinding, Int J Adv Manuf Technol 46:983–992.
8. Zahid A. Khan, Arshad Noor Siddiquee, Manzoor Hussain Sheikh (2012), *Selection of optimal condition for finishing of centreless-cylindrical ground parts using grey relational and principal component analyses*, International Journal of Materials and Product Technology, Vol.43 No.1/2/3/4, 2 – 21.
9. Phan Bui Khoi, Do Duc Trung, Ngo Cuong (2014), *A study on multi - objective optimization of plunge centerless grinding process*, International Journal of Mechanical Engineering & Technology, Vol. 5, No. 11, 140-152
10. Do Duc Trung, Ngo Cuong, Phan Bui Khoi, Tran Quoc Hung (2015), *Application of Generalized Reduced Gradient Method for Optimization of Plunge Centerless Grinding Process*, International Journal of Scientific Research in Science, Engineering and Technology, volume 1, issue 2, 368-372.
11. J. Kopac, P. Krajnik and J.M. d'Aniceto (2005), *Grinding analysis based on the matrix experiment*, 13th International scicentific conference on achivements in mechanical and materials engineering, 332-334.
12. P. Krajnik, J. Kopac, A. Sluga (2005), *Design of grinding factors based on response surface methodology*, Journal of Materials Processing Technology 162–163, 629–636.
13. P. Krajnik, A. Sluga, J. Kopac (2006), *Radial basis function simulation and metamodelling of surface roughness in centreless grinding*, Journal of Achievements in Materials and Manufacturing Engineering. Vol 14, No. 12, 104-110.
14. Lemaréchal, C. *(2012), Cauchy and the Gradient Method*, Doc Math Extra, *251–254.*