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Application of Generalized Reduced Gradient Method for Optimization of Plunge Centerless Grinding Process

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ABSTRACT

This paper presents the study on optimization of plunge centerless grinding parameters when grinding 20X -carbon infiltration steel (ГОСТ standard - Russia) to achieve minimum of surface roughness value. Using the result of 29 runs in central composite design matrix with input parameters are center height angle of the workpiece (β), longitudinal grinding wheel dressing feed-rate (S_{sd}), plunge feed-rate (S_k) and control wheel velocity (v_{dd}) to given the second order surface roughness model. Using generalized reduced gradient method to get optimization values of input parameters to achieve minimum of surface roughness.

Keywords: Plunge centerless grinding, optimization, generalized reduced gradient, surface roughness, 20X steel

I. INTRODUCTION

Centerless grinding is widely used in industry for precision machining of cylindrical components because of its high production rate, easy automation, and high accuracy. To improve the centerless grinding process, it is necessary to optimize surface roughness, the most critical quality constraints for the selection of grinding factors in process planning.

Researches on the optimization of centerless grinding process were published by some authors: Minimizing the surface roughness and roundness errors of workpiece by selecting the optimization levels of control wheel speed, feed rate and depth of cut [1]. Minimizing the roundness error of workpiece and carrying out the regression analysis to model an equation to average out roundness error [2]. Predicting the set-up conditions to analyze the dynamic and geometrical instabilities, making it possible to study the influence of different machine variables in stability of the process [3]. Minimizing the surface roughness by developing an empirical model for it [4]. Minimizing the lobing effect by developing a stability diagram for workpiece and thereby selecting the grinding parameters and having found out that the characteristic root distribution of the lobing loop is periodic [5]. Investigating the workpiece roundness based on process parameters by both simulation and experimental analysis and finding out that a slower worktable feed rate and a faster workpiece rotational speed result in better roundness error [6]. Minimizing the roundness error of workpiece by selecting the optimization levels of dressing feed, grinding feed, dwell time and cycle time [7].

Minimizing the roundness error of workpiece by selecting the optimization range of the center height angle [8]. Giving a method of how to select the optimal stable geometrical configuration in centerless grinding [9]. Giving an algorithm for providing the optimum set-up condition [10]. Optimization of plunge centerless grinding process to achieve the minimum value of surface roughness and roundness errors by response surface method and genetic algorithm [11, 12].

This paper presents the study on the optimization of plunge centerless grinding process when grinding the 20X-carbon infiltration steel to achieve the minimum value of surface roughness by application of Generalized Reduced Gradient method (GRG). The input parameters include center height angle of the workpiece (β), longitudinal dressing feed-rate (S_{sd}), plunge feed-rate (S_k) and control wheel velocity (v_{dd}).

II. METHODS AND MATERIAL

Experimental System

2.1. Centerless grinding model

Plunge centerless grinding model is illustrated in Figure 1.

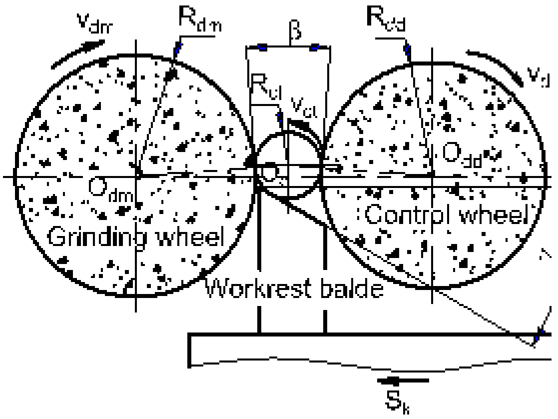

Figure 1. Plunge centerless grinding model

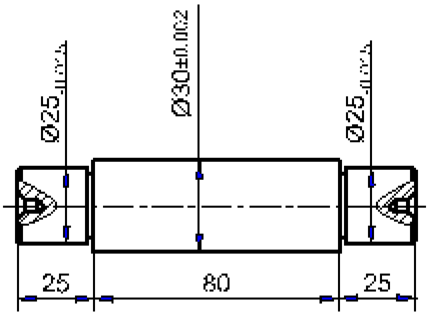

Figure 2. Experimental component

2.2. Components

The component material was the 20 X-carbon infiltration steel, common alloys steel that is usually used in mechanical engineering using centerless grinding process (Fig 2). The chemical composition of experimental component is in Table 1, was supported by specially made workrest blade with a $\gamma = 30^0$.

Table 1: Chemical composition of experimental component

C (%)	Si (%)	Mn (%)	P (%)	S (%)	Cr (%)	Ni (%)	Cu (%)
1,02	0,212	0,51	0,018	0,017	0,78	0,017	0,021

2.3. Experimental machine tool

The grinding experiments were conducted on a M1080B centerless grinder in Pho Yen Mechanical Joint Stock Company – Thai Nguyen – Viet Nam (FOMECO), shown in Fig 3.

Grinding wheel: the Al_2O_3 grinding wheel of Hai Duong Grinding Wheels Joint Stock Company, Viet Nam, Cn80.TB$_1$.G.V$_1$.500.150.305x35m/s.

Control wheel: the standard rubber bonded control wheel of 273 mm x 150 mm x 127 mmdimensions was employed.

2.4. Measuring equipment

The surface roughness was measured by a Mitutoyo Surftest SJ-401 (Fig 4) at 0,8 mm cut off value. Each ground component was measured three times. The surface roughness response, summarized in Table 2, is the average reading of three consecutive measurements.

Figure 3.Experimental machine tool

Figure 4. Mitutoyo Surftest SJ-401

3. EXPERIMENT MATRIX

The experiment matrix was conducted under chatter free conditions to keep the grinding wheel speed (34 m/s), the grinding depth (0,05 mm), the depth of dressing (0,01 mm), the spark-out time (1 s) and the coolant flow constant.

In this work, using the Central Composite Design (CCD) with four input parameters (β , S_{sd} , S_k , v_{dd}), their levels are presented in Table 2. This experimental matrix with 29 sets; these sets include 16 single-replicated orthogonal factorial points, 8 axial points located and 5 centre points, shown in Table 3.

Table 2. Input parameters and theirs levels

Input parameters	Symbol	Parameter levels				
		-2	-1	0	1	2
Center height angle (^{0})	β	4,8	6,0	7,2	8,4	9,6
Dressing feed-rate (mm/min)	S_{sd}	100	200	300	400	500
In-feed speed (µm/s)	S_k	2	6	10	14	18
Control wheel velocity (m/min)	v_{dd}	18,9	24,25	29,6	34,95	40,3

The statistical analysis software Minitab 16 was used to determine the regression coefficients. The surface roughness models were developed in the form of non-reduced final equation in terms of coded parameters.

$$\begin{aligned} Ra &= 0{,}4140 - 0{,}065833\beta + 0{,}22750S_{sd} + 0{,}0083333S_k \\ &- 0{,}0575v_{dd} + 0{,}088792\beta^2 + 0{,}113792S_{sd}^2 + 0{,}073792S_k^2 \\ &+ 0{,}026292v_{dd}^2 - 0{,}03875\beta.S_{sd} + 0{,}065\beta.S_k + 0{,}01625\beta.v_{dd} \\ &- 0{,}035S_{sd}.S_k - 0{,}07875S_{sd}.v_{dd} - 0{,}0275S_k.v_{dd} \end{aligned} \quad (1)$$

Table 3. Experimental matrix - CCD

Set	β	S_{sd}	S_k	v_{dd}	$Ra(\mu m)$
1	1	-1	-1	1	0.44
2	0	0	-2	0	0.69
3	-2	0	0	0	0.91
4	-1	1	-1	-1	1.26
5	-1	1	-1	1	1.01
6	0	0	0	0	0.42
7	-1	-1	1	-1	0.52
8	1	-1	1	1	0.58
9	-1	-1	-1	-1	0.51
10	1	1	1	1	0.73
11	0	0	0	-2	0.64
12	-1	-1	1	1	0.48
13	-1	1	1	-1	1.12
14	1	1	1	-1	1.02
15	0	0	0	0	0.40
16	0	0	0	0	0.42
17	0	0	0	0	0.39
18	0	0	0	2	0.40
19	1	-1	-1	-1	0.29
20	1	-1	1	-1	0.57
21	1	1	-1	1	0.70
22	-1	-1	-1	1	0.57
23	-1	1	1	1	0.77
24	2	0	0	0	0.63
25	0	2	0	0	1.35
26	0	-2	0	0	0.39
27	1	1	-1	-1	0.89
28	0	0	2	0	0.73
29	0	0	0	0	0.44

III. RESULTS AND DISCUSSION

4. Generalized Reduced Gradient (GRG)

4.1. Basic ideas of GRG

The nonlinear program to be solved is assumed to have the form

$$\text{minimize } f(X) \quad (2)$$

$$\text{subject to } g_i(X) = 0, \text{i}=1,\ldots,\text{m} \quad (3)$$

$$l_i \leq X_i \leq u_i, \text{i}=1,\ldots,\text{n} \quad (4)$$

Where X is n-vector and u_i, l_i are given lower and upper bounds $u_i > l_i$. We assume $m < n$ since, in most cases, $m \geq n$ implies and infeasible problem or one with a unique solution. The form $(2)-(4)$ is completely general, since inequality constraints may always be transformed to equalities, as in (3), by the addition of slack variables. The vector X contains as components both the <natural> variables of the problem and these slacks.

The fundamental idea of GRG is to use the equalities (3) to express m of the variables, called basic variables, in terms of the remaining $n-m$ nonbasic variables. This is also the way the Simplex Method of linear programming operates. Let $\overline{X}$ be a feasible point and let y be the vector of basic variables and x the nonbasicat $\overline{X}$, so that X is partitioned as

$$X = (y, x), \overline{X} = (\overline{y}, \overline{x}) \quad (5)$$

And the equalities (3) can be written

$$g(y, x) = 0 \quad (6)$$

Where

$$g = (g_1, \ldots, g_m) \quad (7)$$

Assume that the objective f and constraint functions g_i are differentiable. Then, by the implicit function theorem, in order that the equations (6) have a solution $y(x)$ for all x in some neighborhood of $\overline{x}$, it is sufficient that the mxn basic matrix $\partial g / \partial y$, evaluated at $\overline{X}$, be nonsingular.

Assume that it is. Then the objective may be expressed as a function of x only:

$$F(x) = f(y(x), x) \quad (8)$$

And the nonlinear program is transformed, at least for x close to $\overline{x}$, to a reduced problem with only upper and lower bounds:

$$\text{minimize } F(x) \quad (9)$$

Subject to

$$l_{NB} \le x \le u_{NB} \quad (10)$$

Where l_{NB} and u_{NB} are the vectors of bounds for x. GRG solves the original problem $(2)-(4)$ by solving a sequence of problems of the form $(9)-(10)$. Such problems may be solved by simple modifications of unconstrained minimization algorithms.

4.3. Application of GRG

To get the optimization of β, S_{sd}, S_k, v_{dd} value for minimum the value of surface roughness (Ra), objective function Ra can be written:

$$\begin{cases} Ra = f(\beta, S_{sd}, S_k, v_{dd}) \to \min \\ 0 \le Ra \le 0{,}63 \\ -2 \le \beta, S_{sd}, S_k, v_{dd} \le 2 \end{cases} \quad (11)$$

Application of GRG, using Solver Excel Program, result shows in Table 4 and Figure 5.

Table 4. GRG optimization (coded units)

β	0,5895
S_{sd}	-1,6334
S_k	-1,1631
v_{dd}	-2,0000
Ra	0,2228

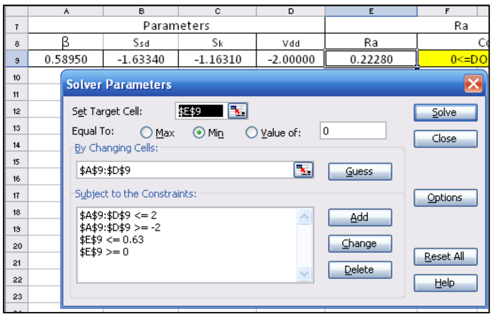

Figure 5. Screen of GRG in Solve Excel Program

IV. CONCLUSION

Success in application of GRG method for optimization of plunge centerless grinding. Thus, for 20X – carbon infiltration steel, to achieve the minimum value of surface roughness, the optimal value of parameters is given.

V. ACKNOWLEDGEMENTS

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