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Multi-Objective Optimization of Centerless Grinding Process for 20x- Carbon Infiltration Steel By Genetic And Generalized Reduced Gradient Algorithms

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ABSTRACT: *Two regression equations have used in this paper that present the relationship between roughness* (Ra)*, roundness error* (Δ) *of workpiece surface and some technical parameters of plunge centerless grinding process when grinding 20X-carbon infiltration steel. Those parameters are center height angle of the workpiece* (β)*, longitudinal dressing feed rate* (S_{sd})*; infeed rate* (S_k) *and control wheel velocity* (v_{dd})*. Two algorithms have used in this research are genetic algorithm* (GA) *and generalized reduced gradient algorithm* (GRG) *for optimization* Ra *and* Δ*. Then conducting grinding experiments with each optimum value set of each algorithm. Results as follows: When solving* $f(\Delta, Ra)$ *multi-objective optimization problem,* GRG *and* GA *algorithm have similar results, then two sets of optimum values of these parameters will be found.*

Keywords: *plunge centerless grinding, 20X-carbon infiltration steel, roughness, roundness error, technical parameter, genetic algorithm, generalized reduced gradient algorithm.*

I. INTRODUCTION

In mechanical processing, centerless grinding is a popular method which brings more productivity in comparison with centered grinding since it spends less time for work-holding and dismantle and the stability of the centerless grinder is higher than which of the centered grinder. In cylindrical centerless grinding, the allowance grinding is reduced since the workpiece is fixed by the processing surface itself; the grinding mode (workpiece speed) is enhanced and the possibility to process workpieces with high length to diameter ratio (l/d) is higher than which of the centered grinding method since the workpiece stability is higher when it is fixed on the workrest and the regulating wheel; the feed rate is significantly reduced if the thick wheels are used. For infeed centerless grinding, the workpiece surface can be processed to be benched, tapered or several workpieces can be processed simultaneously. Moreover, this method is used for workpieces with workpieces of certain shapes and sizes difficult to be produced by other processing methods (like lathe or external grinding) such as tappets and piston [1].

Like other machining methods, the quality of the cylindrical finish by grinding is evaluated using many parameters. Of which, the roundness error (Δ) and roughness (Ra) of the workpiece surface are the most important figures which may significantly impact the usefulness of the workpiece [1].

The workpiece surface's Δ and Ra forming mechanism is complex and mostly dependent on other factors (cutting mode, dressing mode, cooling and lubrication) and the machining factors (geometrical parameters, stability and contact behavior) [2].

Today, many manufacturing plants keep choosing the processing parameters (such as machining and dressing parameters) for the centerless grinding based on the mechanics' experiences, trial cutting or model parameters from buit-in lists. The parameter adjustment and selection for workpieces with small value Δ and Ra are usually difficult and time-consuming even for experienced mechanics. The above reasons limit the reducing of workpiece surface's Δ and Ra values and the enhancement of the centerless grinding efficiency.

Researches on the optimization of centerless grinding process were published by some authors: Used GA by Krajnik P et al [3]; Used GA and response surface method by Phan Bui Khoi et al. [4], [5]; Used generalized reduced gradient algorithm by Do Duc Trung et al. [6]; Used grey relational analysis method by Khan A Z et al. [7]; …This research used GA and GRG to solve optimization the multi-objective function $f(\Delta, Ra)$ and then conducting grinding experiments with each optimum value set of each algorithm. Results as follows: GRG and GA have the same results. Then, two sets of optimum values of these parameters will be found.

II. REGRESSION EQUATIONS

Regression equations present the relationship between Ra, Δ of workpiece surface and some technical parameters (include: β, S_{sd}, S_k, v_{dd}) of plunge centerless grinding process when grinding 20X-carbon infiltration steel as follows equations, with levels of input parameters are presented in Table 1 [8].

Table 1. Values of the input parameters at experimental levels

Input parameters	Symbol	Values at experimental levels				
		-2	-1	0	1	2
Center height angle of the workpiece	$\beta\,(^0)$	4,8	6,0	7,2	8,4	9,6
Longitudinal dressing feed rate	$S_{sd}\,(mm/\min)$	100	200	300	400	500
Infeed rate	$S_k\,(\mu m/s)$	2	6	10	14	18
Control wheel velocity	$v_{dd}\,(m/\min)$	18,90	24,25	29,60	34,95	40,30

$$\begin{aligned} Ra = {} & 0,4140 - 0,065833\beta + 0,22750S_{sd} + 0,008333S_k - 0,0575v_{dd} \\ & +0,088792\beta^2 + 0,113792S_{sd}^2 + 0,073792S_k^2 + 0,026292v_{dd}^2 \\ & -0,03875\beta.S_{sd} + 0,065\beta.S_k + 0,01625\beta.v_{dd} - 0,035S_{sd}.S_k \\ & -0,07875S_{sd}.v_{dd} - 0,0275S_k.v_{dd} \end{aligned} \tag{1}$$

$$\begin{aligned} \Delta = {} & 1,232 - 0,25\beta - 0,18083S_{sd} - 0,125S_k - 0,01417v_{dd} \\ & +0,13658\beta^2 + 0,22033S_{sd}^2 + 0,15658S_k^2 + 0,46908v_{dd}^2 \\ & -0,33375\beta.S_{sd} + 0,14625\beta.S_k + 0,2925\beta.v_{dd} - 0,24875S_{sd}S_k \\ & -0,1875S_{sd}v_{dd} - 0,1675S_kv_{dd} \end{aligned} \tag{2}$$

Optimization

To solve the multi-objective function $f(\Delta, Ra)$, this problem can write as follows equation:

$$\begin{cases} Ra = f(\beta, S_{sd}, S_k, v_{dd}) \to \min \\ \Delta = f(\beta, S_{sd}, S_k, v_{dd}) \to \min \\ 0 \le Ra \le 0,63 \\ 0 \le \Delta \le 3 \\ -2 \le \beta, S_{sd}, S_k, v_{dd} \le 2 \end{cases} \tag{3}$$

In generalized case, with multi-objective function: equation (3) is similar follows equation (4) [9]:

$$\begin{cases} f(x) = \left(\dfrac{1}{Ra} + \dfrac{1}{\Delta}\right)^{-1} = \dfrac{Ra.\Delta}{Ra + \Delta} \to \min \\ 0 \le \Delta \le 3 \\ 0 \le Ra \le 0.63 \\ -2 \le \beta, S_{sd}, S_k, v_{dd} \le 2 \end{cases} \quad (4)$$

Using GRG by Solve/ Excel tool to solve equation (4), the result shows in table 2.

Table 2. Optimal value of parameters for $f(x)$ by GRG

Parameter	β	S_{sd}	S_k	v_{dd}	$Ra\ (\mu m)$	$\Delta\ (\mu m)$	$f(x)$
Code value	0,6129	-1,6179	-1,1891	-2,0000	0,2229	2,6562	0,2056

This is performed with an adopted optimization program, developed in Excel [10]; population of appointed size is randomly chosen between the lower and upper values and undergoes a process of evolution in a simulated competitive environment. The latter mechanism consists of tournament selection, linear crossover and nonuniform mutation. Both bit-exchange crossover and bit-flip mutation occur at every cycle, according to assigned probabilities. Optimization has been achieved by determination of three control parameters of the genetic algorithm; the size of the population and the probability values for crossover and mutation [4], [11], quoted in Table 3. The considered factor ranges relate to the region of interest. The fitness of each individual is evaluated (Figure 1).

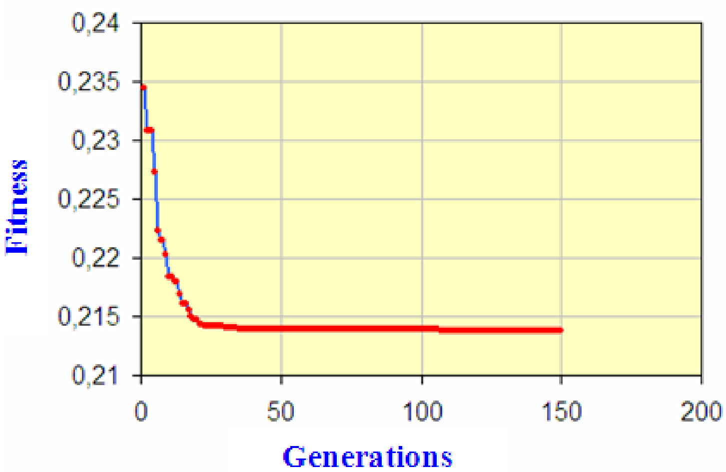

Figure 1. Genetic algorithm graph of $f(x)$

Table 3. Optimal value of parameters for $f(x)$ by GA

Population	150
Crossover probability	0,25
Mutation probability	0,05
β	0,5938
S_{sd}	-1,7478
S_k	-1,1235
v_{dd}	-2,0000
$Ra\ (\mu m)$	0,2319
$\Delta\ (\mu m)$	2,7447
$f(x) = \dfrac{Ra.\Delta}{Ra + \Delta}$	0,2138

Optimal value of β, S_{sd}, S_k, v_{dd} and value of multi-objective function $f(x)$ when solving by GRG and GA that show in table 4.

Table4. Optimal value of β, S_{sd}, S_k, v_{dd} and value of $f(x)$ by GRG and GA

Algorithm	$\beta(^0)$	$S_{sd}(mm/\min)$	$S_k(\mu m/s)$	$v_{dd}(m/\min)$	$f(x)$
GRG	7,9355	138,2100	5,2436	18,9000	0,2056
GA	7,9126	125,2200	5,5060	18,9000	0,2138

To compare for optimal results of GRG and GA, it is necessary to grind at least 22 parts for each optimal value sets. The value of some main technical parameters of cutting condition that had used to conducting (1) and (2) equations [8], as bellow:

- Grinding wheel: $Cn80.TB_1.G.V_1.500.150.305x35m/s$.
- Control wheel: $R273x150x203$.
- Experimental machine: M1080B
- Workpiece: 20X-carbon infiltration steel, diameter Ø30, length 130, with heat treatment of 60÷62HRC (figure 2).
- Grinding wheel dressing condition:

+ Grinding wheel velocity: $v_{dm} = 34(m/s)$.

+ Depth of dressing: $t_{sd} = 0,01(mm)$.

- Control wheel dressing condition:

+ Control wheel velocity: $v_{dd} = 257(m/\min)$.

+ Depth of dressing: $t^*_{sd} = 0,01(mm)$.

+ longitudinal dressing feed rate: $S^*_{sd} = 30(mm/\min)$.

- Grinding wheel velocity: $v_{dm} = 34(m/s)$.

Results of experiment for each optimal value of parameters sets are shown in table 5.

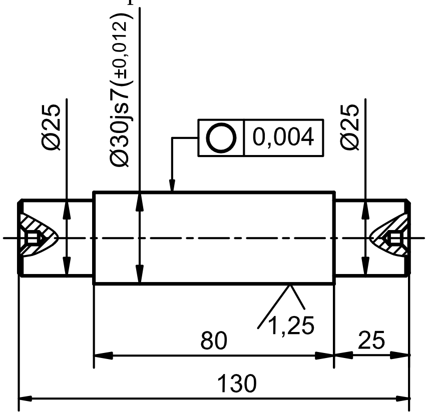

Figure 2. Workpiece

Table 5. *Value of multi – objective function $f(x)$ with value of β, S_{sd}, S_k, v_{dd} of GRG and GA*

Runs	Multi – objective function $f(x)$	
	GRG algorithm	GA algorithm
1	0,28	0,24
2	0,24	0,28
3	0,26	0,24
4	0,24	0,24
5	0,27	0,24
6	0,24	0,25
7	0,25	0,22
8	0,26	0,26
9	0,22	0,27
10	0,23	0,24
11	0,27	0,23

12	0,22	0,28
13	0,24	0,24
14	0,24	0,24
15	0,25	0,24
16	0,24	0,24
17	0,25	0,25
18	0,25	0,22
19	0,22	0,26
20	0,24	0,27
21	0,28	0,24
22	0,22	0,23

The statistical analysis software Minitab 16 was used to compare results of GRG and GA, the results are shown in table 6 and figure 3.

Table 6. Comparison information for Mean, StDev and SE Mean of $f(x)$ between GRG and GA

Two-Sample T-Test and CI: GRG, GA

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Two-sample T for GRG vs GA

      N    Mean   StDev  SE Mean
GRG  22  0.2482  0.0156   0.0033
GA   22  0.2491  0.0154   0.0033


Difference = mu (GRG) - mu (GA)
Estimate for difference:  -0.00091
95% CI for difference:  (-0.01036, 0.00854)
T-Test of difference = 0 (vs not =): T-Value = -0.19  P-Value = 0.847  DF = 41
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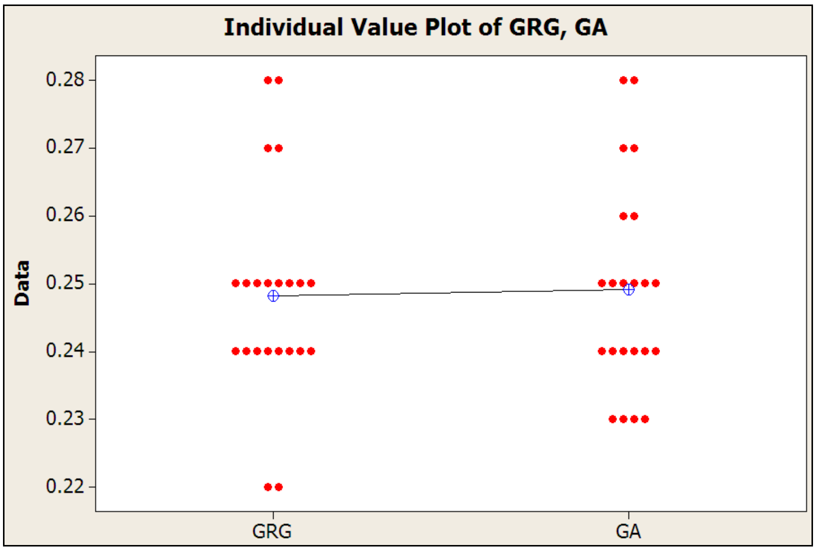

Figure 3. Comparison graph for **Mean** of $f(x)$ between GRG and GA

See table 6 and figure 3, we known:

- Value of **Mean, StDev, SE-Mean** of multi – objective function $f(x)$ of GRG very near its of GA. Beside, $P - value = 0,847$ is bigger more than signify level (commonly, signify level is 0,05).

  95% parts using technical parameters of GA: $0,219 \le f(x) \le 0,279$; Similary, 95% parts using technical parameters of GRG: $0,218 \le f(x) \le 0,279$ [12].
- Then, we have an important comment: optimal result of GRG is same its of GA. Optimal value of technical parameters are $\beta = 7,9^0$; $S_{sd} = 138,2(mm/\mathrm{min})$; $S_k = 5,2(\mu m/s)$; $\mathrm{v}_{dd} = 18,9(\mathrm{m/min})$ or $\beta = 7,9^0$; $S_{sd} = 125,2(mm/\mathrm{min})$; $S_k = 5,5(\mu m/s)$; $\mathrm{v}_{dd} = 18,9(\mathrm{m/min})$.

III. CONCLUSION

- Multi objective functions $f(\Delta, Ra)$ was solved by two optimization algorithms namely GRG and GA which are used by many scientists in order to find a optimum value of the parameters β, S_{sd}, S_k, v_{dd} for each algorithm; verified through experiments showed that in this case, GRG and GA have the same results.
- Two sets of optimum values of technical parameters are: $\beta = 7,9^0$; $S_{sd} = 138,2(mm/\min)$; $S_k = 5,2(\mu m/s)$; $v_{dd} = 18,9(m/\min)$ or $\beta = 7,9^0$; $S_{sd} = 125,2(mm/\min)$; $S_k = 5,5(\mu m/s)$; $v_{dd} = 18,9(m/\min)$.

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