Chapter 6
Selection of Multi-point Diamond Dresser for Grinding Process Using Grey Relation Analysis

V. V. Pansare, V. S. Gadakh, and S. S. Patil

Introduction

Grinding is one of the oldest manufacturing processes and has been used since the Stone Age to accomplish such tasks as creating hunting tools. Because of the growing demand for higher productivity at reduced cost, manufacturing industries require that the grinding process should run more effectively with reduced lead time to achieve an acceptable level for grinding conditions. The goal of the grinding process is to produce parts with maximum surface finish and accuracy on hard components.

Dressing is an operation performed on the grinding wheel surface in order to reform the wheel, which occurs after losing its original shape through wear. The purpose of dressing is to remove the glazed and loaded surface from the grinding wheel, for improving the cutting ability of the grinding wheel during the process. Generally dressing has crucial effect on wheel performance with respect to the surface finish and grinding ratio in subsequent grinding process produced on the workpiece. There are mainly two categories of multi-point diamond dressers: (1) natural (ND) and (2) synthetic dresser. Natural diamond dresser is again classified into grit and

V. V. Pansare (✉)
Department of Mechanical Engineering, Amrutvahini College of Engineering, SPPU, Pune, Maharashtra 422608, India
e-mail: pansareviraj3@gmail.com

V. S. Gadakh
Department of Production Engineering, Amrutvahini College of Engineering, SPPU, Pune, Maharashtra 422608, India
e-mail: vijay.gadakh@avcoe.org

S. S. Patil
Department of Production Engineering, Sinhgad College of Engineering, Vadgaon Bk., SPPU, Pune, Maharashtra 411041, India
e-mail: sanjayspatil70@gmail.com

S. Kumar and K. P. Rajurkar (eds.), *Advances in Manufacturing Systems*,
Lecture Notes in Mechanical Engineering,
https://doi.org/10.1007/978-981-33-4466-2_6

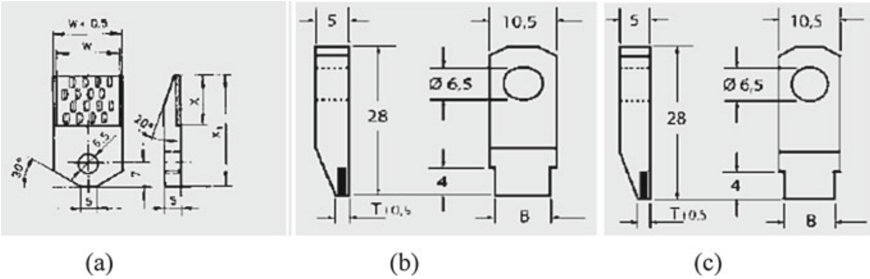

Fig. 6.1 Types of multi-point dressers. **a** Needle blade with natural diamond dresser, **b** MCD needle blade dresser, **c** CVD needle blade dresser [1]

needle types, whereas synthetic dressers are classified into chemical vapor deposition (CVD) type multi-point diamond dresser and monocrystalline diamond (MCD) type dressers. The detail of each dresser type is shown in Fig. 6.1.

Needle blade with natural diamond dressers are useful for angular plunge/straight and profile dressing of specially fused Al_2O_3, all Al_2O_3 and sintered Al_2O_3 grinding wheels with 46–80 grit size. MCD needle blade dressers are preferably used for profiling, sintered Al_2O_3, SiC and straight dressing of hard grinding wheels. Similarly, CVD needle blade dressers are mostly preferred for special fused Al_2O_3 and sintered Al_2O_3 grinding wheels and high-precision straight dressing of Al_2O_3 [1].

Fritsche and Bleicher [2] have produced active grain stack model which provides information of grinding wheel structure and interaction of different layers with each other. Patil and Bhalerao [3] reported that for getting good surface finish dressing parameters play an important role in CNC cylindrical angular grinding machine. Choi et al. [4] developed generalized process models for cylindrical plunge grinding process. It is reported that their models can predict performances at different conditions of grinding process. Jiang et al. [5] produced a mathematical model to predict the ground surface roughness and topography by considering grinding, wear and dressing variables. Sinha et al. [6] selected optimal dressing parameters depending on grit size of wheel. It is reported that optimum range of dressing depth and dressing lead for a specific grit size grinding wheel significantly influences the ground product quality as well as the prime grinding attributes like grinding forces. Hecker and Liang [7] developed a mathematical model to predict surface roughness of ground parts. Liu et al. [8] presented a kinematic simulation study using single-point diamond dresser to predict the surface roughness in grinding process with the help of different abrasive grain shapes.

From the reported literature and industrial survey, it is observed that majority of the papers dealt with process parameter optimization using different well-established algorithms, either for grinding process-related parameters or developed some models to predict the performances. Very few literatures discussed about single-point diamond dresser in grinding process; however, literature lacks in terms of multi-point diamond dresser for grinding process. Hence, the purpose of present work is to select best multi-point diamond dresser in cylindrical plunge grinding process for getting better surface finish.

Experimental Procedure

The present work illustrates the selection of best multi-point diamond dresser in cylindrical plunge grinding process. The effect of grinding process parameters such as grinding feed rate, dressing cross feed rate and dressing depth of cut on surface finish (SR), maximum grinding ratio (GR) and optimum power (P) were considered using the Taguchi method. In Taguchi method, it is required to consider all design aspects which affect the variation of functional characteristics of the product from target values. The Taguchi method is a popular optimization method as it reduces the number of experiments [9].

Experiments were performed on CNC angular head grinding machine (Model: AHG 60X300) with EN31 cylindrical workpiece material and grinding wheel (Specification: 38A60K8VT3) was employed. A L_9 orthogonal array was used as per Taguchi design with three trials [9]. A large number of trials were performed to find out the working range of grinding parameters using Taguchi's single parameter approach. The working range of the grinding parameters chosen is shown in Table 6.1.

During experimentation plunge and wet grinding were considered along with the depth of grinding 300 μm, and the wheel speed and workpiece speed of 1250 rpm and 100 rpm, respectively. Soluble oil was used as lubricant while different types of multi-point diamond dressers, namely natural (Order # 69014185757), MCD (Order # 66260392047) dresser and CVD (Order # 66260336093) dresser were used.

The workpiece surface roughness was measured using Mitutoyo SJ-410. For grinding power measurement, field instrument system (FIS) unit was used, as shown in Fig. 6.2. For grinding ratio measurement, the material removal volume and wheel wear volume were found out. But it is a complex task to measure the material removal volume. For that specially made graphite sheets were taken for the impressions of the grinding wheel after the grinding operation. The graphite sheets were mounted using the bolts on the dresser fixture. The dimension of graphite sheet is 70 × 35 × 3 mm. The graphite sheets were observed under the microscope (Make: Metatech, Model: MVH-1) for finding the change of initial diameter and final diameter. The

Table 6.1 Grinding factors working range with their levels

S. No.	Factors	Symbol	1	2	3
1	Dressing depth of cut	*D* (μm)	10	20	40
2	Dressing cross feed rate	*C* (mm/min)	60	80	120
3	Grinding feed rate	FR (mm/min)	0.6	1.2	2.4
4	Dresser	*d*	ND	MCD	CVD

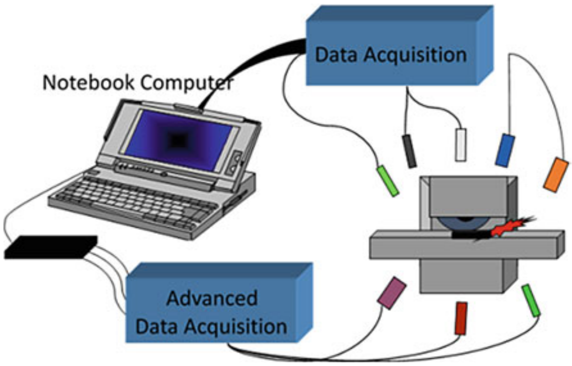

Fig. 6.2 Process of power measurement with field instrument system

grinding ratio can be calculated as:

$$\text{Grinding ratio} = \frac{MR}{WR} = \frac{\frac{\pi}{4} \times \Delta D_m^2 \times L}{\frac{\pi}{4} \times \Delta d_w^2 \times L} = \frac{\Delta D_m^2}{\Delta d_w^2}$$

where L is the specimen length as 40 mm, ΔD_m and Δd_w are the difference between initial and final diameter of the work material; and initial and final diameter of the grinding wheel, respectively.

GR, SR and P were evaluated for all the different types of dressers and are presented in Table 6.2. In this work, SR and P are non-beneficial attributes, where smaller values are desirable, whereas GR is beneficial attribute, where maximum values are preferable. The values of SR and P are normalized as per the following Eq. (6.1).

$$x_i^*(k) = \frac{\max x_i^0(k) - x_i^0(k)}{\max x_i^0(k) - \min x_i^0(k)} \tag{6.1}$$

Table 6.2 Surface roughness, power and grinding ratio

Run	D	C	FR	d	GR	Avg. SR	Power (kW)
1	1	1	1	1	10.02	0.146	1.48
2	1	2	2	2	6.66	0.294	2.42
3	1	3	3	3	9.60	0.548	5.06
4	2	1	2	3	9.59	0.354	3.99
5	2	2	3	1	7.70	0.194	3.01
6	2	3	1	2	9.16	0.271	1.16
7	3	1	3	2	9.99	0.388	4.34
8	3	2	1	3	7.85	0.252	1.46
9	3	3	2	1	7.36	0.176	2.31

Table 6.3 Normalized values of the responses

GR	SR	P
1.0000	1.0000	0.9179
0.0000	0.6318	0.6769
0.8750	0.0000	0.0000
0.8720	0.4826	0.2744
0.3095	0.8806	0.5256
0.7440	0.6891	1.0000
0.9911	0.3980	0.1846
0.3542	0.7363	0.9231
0.2083	0.9254	0.7051

Similarly, the value of GR is normalized as per the following Eq. (6.2).

$$x_i^*(k) = \frac{x_i^0(k) - \min x_i^0(k)}{\max x_i^0(k) - \min x_i^0(k)} \tag{6.2}$$

where $i = 1$ to 9, $k = 1$ to n; n is the performance measure, and i is the trial number. Table 6.3 shows the normalized values. The grey relational coefficient (GRC) [$\xi_i(k)$] is determined as follows:

$$\xi_i(k) = \frac{\Delta_{\min} + \zeta\,\Delta_{\max}}{\Delta_{0i}(k) + \zeta\,\Delta_{\max}} \tag{6.3}$$

Note that larger-the-better is achieved when $x_i(k) = x_0(k)$, that is, when $x =$ reference.

Here, $x_0^*(k)$ denotes the reference sequence; $x_j^*(k)$ indicates the comparability sequence; $\zeta \in [0 - 1]$ is the distinguishing coefficient; 0.5 is widely accepted; $\Delta_{0i} = \left\| x_0^*(k) - x_i^*(k) \right\|$ is the difference in absolute value between $x_0^*(k)$ and $x_j^*(k)$; $\Delta_{\min} = \min_{\nabla j \in i} \min_{\nabla j \in k} \left\| x_0^*(k) - x_i^*(k) \right\|$ is the smallest value of Δ_{0i}; $\Delta_{\max} = \max_{\nabla j \in i} \max_{\nabla j \in k} \left\| x_0^*(k) - x_i^*(k) \right\|$ is the largest value of Δ_{0i}. After calculating GRCs, the grey relational grade (GRG) is obtained as:

$$\gamma_i = \frac{1}{n} \sum_{k=1}^{n} \xi_i(k) \tag{6.4}$$

where γ_i is the GRG and 'n' is the number of output characteristics. The GRC and the related GRG for every experimental run are determined and shown in Table 6.4. The maximum value of GRG shows optimal grinding parameters.

Table 6.4 Grey relational coefficient, grade and rank

GR	SR	P	GRG	Ranking
1.0000	1.0000	0.8590	0.9530	1
0.3333	0.5759	0.6075	0.5056	8
0.8000	0.3333	0.3333	0.4889	9
0.7962	0.4914	0.4079	0.5652	7
0.4200	0.8072	0.5132	0.5801	6
0.6614	0.6166	1.0000	0.7593	2
0.9825	0.4537	0.3801	0.6054	5
0.4364	0.6547	0.8667	0.6526	3
0.3871	0.8701	0.6290	0.6288	4

Table 6.5 Mean GRG at each level

Factors	Mean GRG			Difference
	1	2	3	
D	0.5090	0.6969*	0.4608	0.2361
C	0.5915*	0.5748	0.5003	0.0913
FR	0.6887*	0.5165	0.4615	0.2271
d	0.6001*	0.5079	0.5587	0.0922

*Indicates the optimal setting

Optimal Setting of Grinding Parameters

At each level the mean value of GRG is determined. The maximum value GRG shows the better output characteristics. The mean GRG and the optimal level of the grinding parameter are shown in Table 6.5. Further a graph is plotted (Fig. 6.3), as per the highest GRG value for each parameter in Table 6.5, and the optimal level of the grinding factors is $D_2C_1FR_1d_1$.

Analysis of Variance

ANOVA is used to study the factors that significantly influence the quality measures. ANOVA (Table 6.6) results show that the dressing depth of cut and grinding feed rate are the significant grinding parameters that affect the multiple performance measures. Moreover, dressing cross feed rate and type of diamond dresser are less significant grinding process factors due to minimum values of percentage contribution. From the experiments, the optimal level parameter is $D_2C_1FR_1d_1$. The mean value of GRG

Fig. 6.3 Main effect of grey relational grade (GRG)

Table 6.6 ANOVA for the means

Factors	DoF	Adj SS	Adj MS	Contribution (%)
D	2	0.0933	0.0466	45.63
C	2	0.0141	0.0070	6.92
FR	2	0.0842	0.0421	41.18
d	2	0.0127	0.0063	6.25
Total	8	0.2045		100

DoF degrees of freedom; *Adj SS* adjusted sum of square; *Adj MS* adjusted mean square

of the grinding parameter at respective level is taken from Table 6.4 and the predicted value of GRG is calculated as 0.953.

Confirmation Tests

The experimental validation at optimal setting of grinding parameters was done. The natural type dresser, dressing cross feed rate 60 mm/min, dressing depth of cut 20 µm and grinding feed rate 0.6 mm/min were fixed; the achieved mean surface finish, power and grinding ratio are 0.153 µm, 1.49 kW and 9.96, respectively. The validated experimental results with value of GRG are given in Table 6.7.

Table 6.7 Grey relation grade values

Level setting	Optimum grinding parameter	
	Predicted	Experimental
GR		9.98
SR		0.153
P		1.49
Grey relational grade	0.9387	0.9431

Conclusion

The Taguchi-based grey relational analysis is applied to find out the cylindrical grinding process parameters. Multiple performance measures are reported in this paper and the following conclusions are drawn:

- The optimal level of the dressing depth of cut is 20 μm, dressing cross feed rate 60 mm/min, and grinding feed rate 0.6 mm/min when natural type dresser is used.
- In this investigation the dressing depth of cut is an important factor that contributes ~46% to the overall contribution.
- Dressing depth of cut and grinding feed rate are the significant grinding factors that affect the multiple performance measures.
- Dressing cross feed rate and type of diamond dresser are less significant grinding factors due to least percentage contribution.

Acknowledgements This research work was supported by Saint-Gobain. The authors are thankful to Mr. Anurag Doshi, Saint-Gobain who gives us insight and expertise that greatly helped the research.

References

1. Tools D, Wheels W (2010) diamond tools for dressing grinding. Dressing tools
2. Fritsche A, Bleicher F (2015) Evaluating and influencing dressing results by changing the grain size distribution based on statistical and experimental investigations. In: Seliger G, Yusof NM (eds) Procedia CIRP, 12th global conference on sustainable manufacturing—emerging potentials. Elsevier B.V., pp 718–723
3. Patil SS, Bhalerao YJ (2017) Ranking of vitrified grinding wheel parameters by using analytical hierarchical process (AHP) for surface roughness of work piece in grinding operation. In: International conference on advances in mechanical, industrial, automation and management systems (AMIAMS). IEEE, pp 185–188
4. Choi TJ, Subrahmanya N, Li H, Shin YC (2008) Generalized practical models of cylindrical plunge grinding processes. Int J Mach Tools Manuf 48:61–72. https://doi.org/10.1016/j.ijmachtools.2007.07.010
5. Jiang JL, Ge PQ, Bi WB et al (2013) 2D / 3D ground surface topography modeling considering dressing and wear effects in grinding process. Int J Mach Tools Manuf 74:29–40. https://doi.org/10.1016/j.ijmachtools.2013.07.002

6. Sinha MK, Setti D, Ghosh S, Rao PV (2014) An investigation into selection of optimum dressing parameters based on grinding wheel grit size. In: Dixit US, Narayanan RG, Sankar MR (eds) 5th international & 26th all India manufacturing technology, design and research conference (AIMTDR 2014), 12–14 Dec 2014, IIT Guwahati, Assam, India, pp 1–6
7. Hecker RL, Liang SY (2003) Predictive modeling of surface roughness in grinding. Int J Mach Tools Manuf 43(43):755–761. https://doi.org/10.1016/S0890-6955(03)00055-5
8. Liu Y, Warkentin A, Bauer R, Gong Y (2013) Investigation of different grain shapes and dressing to predict surface roughness in grinding using kinematic simulations. Precis Eng 37:758–764. https://doi.org/10.1016/j.precisioneng.2013.02.009
9. Nikalje AM, Kumar A, Srinadh KVS (2013) Influence of parameters and optimization of EDM performance measures on MDN 300 steel using Taguchi method. Int J Adv Manuf Technol 69:41–49. https://doi.org/10.1007/s00170-013-5008-8