APPLICATION OF NSGA- II FOR OPTIMIZATION OF CYLINDRICAL PLUNGE GRINDING PROCESS PARAMETERS

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Abstract

Cylindrical grinding (finishing) operation is widely used for obtaining accurate surface finish on components in automobile sectors. Present industries are facing a challenge of producing high quality components with low power consumption and low manufacturing cost due to increased competition. In this paper, optimum process parameters values are obtained for dressing depth of cut, dressing cross feed rate and grinding feed rate of cylindrical plunge grinding operation. Experiments were performed as per L9 Orthogonal Array with replica on Computer Numerical Control Angular Head grinding machine. Mathematical model has been developed using Response Surface Methodology for determining grinding responses. The results of RSM are further used to obtain pareto front optimal solutions using NSGA II approach. A novel method is developed to obtain grinding ratio. The established results are helpful to decide optimal grinding parameters.

Keywords: cylindrical grinding; grinding ratio; NSGA II; power; surface roughness.

1. Introduction

Grinding process is widely used for finishing the parts in manufacturing industries. It is used for obtaining the close tolerance and generating desired surface quality. The grinding process is classified as surface grinding, cylindrical grinding, and centre less grinding. Cylindrical grinding contributes more in automobile sector and majorly used for machining the shafts. Much research is carried out since last decades in the field of grinding; but still this process is relied on operator's skill, trial and error methods, because it involves number of process parameters which are complex in nature. Various process parameters like, grinding wheel speed, work piece speed, grinding velocity ratio, feed rate of grinding, grinding wheel properties, work piece characteristics, dressing depth of cut, dressing cross feed rate, and types of dresser affect the grinding process. There is a difficulty in transferring laboratory research results to industries (Konrad Wegener et al., 2017; Oliveira et al., 2009).

Further, industries are facing the challenge of producing high quality components with low cost by lowering the power consumption and other resources. This can be made possible through optimizing the process parameters. Therefore it is necessary to select combination of optimum process parameters to produce the components. For optimizing the process parameters like, wheel speed, work piece speed and depth of cut by constraining grinding time, grinding cost and surface roughness NSGAII can give multiple solutions to decision maker (Deb et al., 2002; Gholami & Azizi 2014; Rudrapati et al., 2016). The experiments have been carried out to optimize wheel velocity, work piece velocity, feed and depth of cut for maximum material removal rate on AL/SIC metal matrix composite using Genetic Algorithm (Thiagarajan et.al., 2012).

Further (Oliveira et al., 2009) elaborated the necessity for optimization of process parameters, industrial challenges, research areas, and expectation of automotive sectors in grinding process. Furthermore combination of process parameters, wheel speed, table speed and depth of cut and maximum material removal rate for good quality surface grinding was developed by using Non-Dominated Sorting Genetic Algorithm (NSGA II) is reported in (Janardhan et al., 2011).

A model using Response Surface Method (RSM) for specific energy, material removal rate and surface roughness for composite material is developed and optimized with NSGAII (Pai et al., 2011). Few have experiment L-9 Orthogonal Array for cylindrical grinding operation by selecting work speed, feed and depth of cut and found significant parameters for surface roughness by using ANOVA method (Naresh Kumar et al., 2015). Palmeret al., 2018 found that the feed rate of dressing has the significant effect on wheel topography than a speed ratio. Vitreous grinding wheel, roller dresser and graphite coupons were used to get desired surface roughness. Dressing speed ratio, direction of dresser and grinding wheel has insignificant effect on wheel topography. They realized that power consumption increases with the feed rate and speed ratio and high power produces very coarse wheel; as a result, more rains are pulled out.

An experiment was carried out on Titanium alloy for investigating effect of dressing parameters on micro grinding. High dressing overlap ratio was used to get good quality surface and observed that it is better in up dressing than in down dressing (Kadivar et al., 2018). When grinding wheel dressed with multipoint diamond dresser, surface finish of work piece was improved. For experimentation, orthogonal array along with analysis of variance (ANOVA) was used and found that dressing speed has influenced more on surface finish than dressing depth(Holessovsky et al., 2018). Non-dominated Sorting Genetic Algorithm (NSGA II) is a reliable tool for optimization and fulfils the requirements of the combined machining variables for traditional and modern marching processes. NSGA II gives various sets of solutions by combining decision variables (Deb et al., 2002 ; Rudrapati et al., 2016 ; Wang et al., 2016;Yusoff et al., 2011).

The literature review reveals that there is demand for combination of optimum process parameters which can produce quality ground components with optimum use of resource. Chromium bearing steel is wear resistance material and used for making bearings, shafts where surface finish is important. It was also found that many researchers used wheel velocity, work piece velocity, and depth of grinding cut being used as input parameters whereas very few researchers have worked on feed rate of grinding and dressing parameters (Choi et al., 2008).

In this work dressing depth of cut, dressing cross feed rate and grinding feed rate are selected as input parameters for experimentation and NSGA II is used for optimization of parameters. Multiple optimal solutions obtained can be used by end user (manufacture engineer) according to his/her requirements. This paper is organized as follows; Section 2 presents experimental procedure. Section 3 gives detailed information of measurement of surface roughness, grinding power and development of new method of grinding ratio. Mathematical modeling is presented in Section 4; Section 5 elaborates the result and discussion and Section 6 covers conclusions.

2. Experiment procedure

Experiments were conducted on Computer Numerical cylindrical angular grinding machine (AHG 60 X 300) and cylindrical work piece of Chromium bearing steel material is used for grinding. The specimen prepared for performing experiments on CNC cylindrical angular grinding machine is shown in Figure 1

The metallurgical properties of specimen from laboratory analysis report are shown in Table 1.

The grinding wheel having specification 38A60K8VT3 was used for the experimentation. Taguchi method with L-9 Orthogonal Array with two trails was used (Choi et al., 2008; Liu et al., 2018; Unune & Mali 2016).

From the experiments it was observed that, if the feed rate is high, it improves effectiveness of grinding process but greater heat development takes place which increases pressure and ultimately affects on surface finish of work piece. Meanwhile, if it is kept low, then it will not be economical; therefore optimum level of feed rate is required. The values of dressing parameter namely dressing feed rate and dressing depth of cut influences the quality of grinding process (Holesovsky et al., 2018; Lie et al., 2018 ; Patil & Bhalerao 2017). For finding the optimum values of dressing parameters three levels of dressing depth of cut, dressing cross feed rate and feed rate of grinding are selected and shown in Table 2.

The selected output parameters are surface roughness of work piece (Ra), grinding power (Pw) and grinding ratio (Gr) (Yusoff et al., 2011).While conducting the experiment plunge and wet grinding is considered along with the wheel speed – 1250 rpm, wok piece speed – 100 rpm, and depth of grinding – 300 micron. The lubricant soluble oil is used and needle type multipoint diamond dresser used for dressing the grinding wheel. The grinding operation is shown in Figure 2.

3. Measurement of surface roughness, grinding power and grinding ratio

Surface roughness of work piece is measured by using Mitutoyo SJ410 is shown in Figure 3. The Field Instrument System (FIS) unit is power measurement device. The input connections of power transducer are connected to the PLC circuit of the machine. The range of power transducer was 5 to 150 amps. The FIS unit monitor displays the power graph of the grinding cycle, which measures the peak power in various operations such as wheel rotation and coolant on/off operation by the grinding machine. The machine gives the graphical representation of the whole grinding cycle. Figure 4 shows components of FIS

Third output parameter, grinding ratio (Gr) is a ratio of volume of work piece removal and volume of wheel wear. It is better to keep high grinding ratio. There is no standard method observed in practice to find the grinding ratio. In one method, weight of grinding wheel and work piece are taken before and after grinding operation, but there are some issues like wheel mounting, setting and balancing of wheel which affects the quality of grinding. Moreover it takes long time and more than one operator for loading the wheel, if it is heavy machine. Here, a new innovative method which measures the grinding ratio is developed. Here, a new innovative method for measuring the grinding ratio is developed which takes less time and does not hamper the quality. Process flow diagram for measuring the grinding ratio is shown in Figure 5. Graphite sheets (70 X 35 X 3) mm are fixed on dressing holder for impressions of wheel before grinding operation. Grinding operation is carried out on the specimen and then impression of wheel is taken on the same graphite. Difference in impressions is viewed under microscope (Patil and Bhalerao, 2018).

A formula is used for finding grinding ratio as follows.

$$Grindingratio = MR/WR \qquad (1)$$

Where, $Materialremoval = \frac{\pi}{4} X \Delta Dm^2 XL \qquad (2)$

$$Wheelremoval = \frac{\pi}{4} X \Delta dw^2 XL \qquad (3)$$

Where, L is the working length of specimen equal to 35.5 mm, ΔD is the difference between initial and final diameter of the work piece and Δd is the difference between initial and final diameter of the wheel.

4. Mathematical Modeling

The mathematical model has been developed using Response Surface Methodology which represents the relation between various responses (surface roughness (Ra), grinding power (Pw), and grinding ratio (Gr) and coded grinding variables [dressing depth of cut, (D) dressing cross feed rate (C) and grinding feed rate (Fr)] are developed.

$$Ra(z1) =$$

$$0.1843 + 0.0037(x1) + 0.089(x2) + 0.0221(x3) - 0.0113(x1)(x2) + 0.0044(x1)(x3) + 0.0064(x2)(x3) \quad (4)$$

$$Pw(z2) =$$

$$2.5368 + 0.3109(x1) + 0.02074(x2) + 1.0704(x3) - 0.1674(x1)(x2) + 0.4349(x1)(x3) + 0.3849(x2)(x3) \quad (5)$$

$$Gr(z3) =$$

$$9.6738 - 0.0423(x1) - 0.8873(x2) - 0.0452(x3) - 0.136(x1)(x2) + 0.0285(x1)(x3) + 0.1314(x2)(x3) \quad (6)$$

Above equations are used as objective function, which are further optimized using non-dominated sorting genetic algorithm (NSGA II). Multi objective optimization process is used for minimizing or maximizing above functions. In present case, surface roughness (Ra) and grinding power (Pw) functions are minimized while the grinding ratio (Gr) function is maximized. The feasible limit of control variables for roughness, power and grinding ratio for optimization are given in equation (4), (5) and (6) respectively. The equations z1 and z2 are used for Minimization, whereas Z3 is used for maximization and are subjected to $-1 \leq x(i) \leq 1, where\ i = 1,2,3$;.

5. Results and Discussions

NSGA II is used for multiple objective optimizations. Aim of the optimization is to minimize surface roughness, power, and maximize the grinding ratio. NSGA II gives the user a set of solutions that can be used according to requirement. Pareto front for surface roughness of work piece, (Ra) Grinding power,(Pw) and Grinding ratio(Gr) are presented graphically in three dimensions on graph (As shown in Figure 6). There are trade off combinations of optimum input processes parameters in coded form.

A population size is 50, cross over probability is 0.8, mutation probability is 0.01. Numbers of points on Pareto- front are 16 and number of generation 147. Table 4 shows optimum values of design variables of cylindrical grinding operation. Table 5 shows results of objective functions namely surface roughness (Ra) value, grinding power (Pw) and grinding ratio (Gr).

- From results one can select any optimum combination based on priority. For producing good quality surface on the work piece with less power consumption, serial number 11 from Table 5 can be selected.
- It can produce better surface finish (0.1537 micron) on the work piece at minimum power consumption (0.87KW) and minimum grinding ratio (8.51). Coded values for dressing depth of cut, dressing cross feed rate, and grinding feed rate, from Table 4 are 0.9994,0.9863 and (-0.9726) respectively.
- In case of giving the priority to wheel life, one can select serial number 2 of Table 5,surface roughness 0.1694 µm, grinding power consumption 1.8752 kW and grinding ratio 10.7872 and its corresponding value given in Table 4 (0.9057, -0.9926, -0.9915) dressing depth of cut, dressing cross feed rate and grinding feed rate respectively

6. Conclusion

- Experiments have been performed on CNC angular grinding machine as per L9 orthogonal array using input process parameters such as dressing depth of cut, dressing feed rate and grinding feed rate in order to analyse surface roughness, grinding power and grinding ratio.
- The mathematical models have been formulated using Response Surface Methodology (RSM) for determining grinding responses.
- The results of RSM are further used to obtain pareto front optimal solutions using NSGA II approach.
- A new method has been proposed for estimating grinding wheel wear and grinding ratio for cylindrical plunge grinding operation.
- The better surface finish of 0.1537 µm is obtained at 0.87 kW of power consumption. The higher grinding ratio of 10.7872 is obtained corresponding to input process parameters of 40 µm dressing depth of cut, 60 mm/min dressing cross feed rate, and 0.6 mm/min grinding feed.
- The demonstrated results are helpful to decide optimal grinding parameters.

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Figure 1 Specimens prepared for experiments.

Figure 2 Grinding operation

Figure 3 Surface Roughness Tester

Figure 4 Components of FIS System

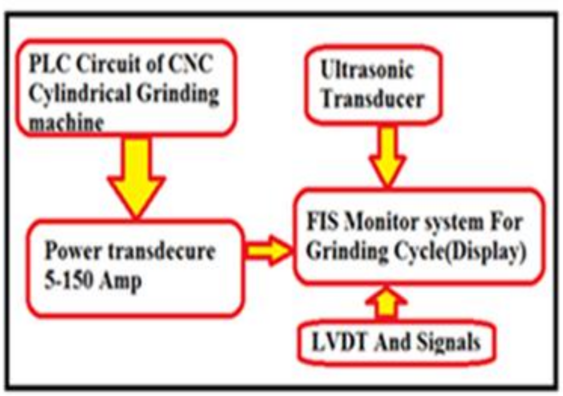

Figure 5 Flow process diagram of measuring grinding ratio

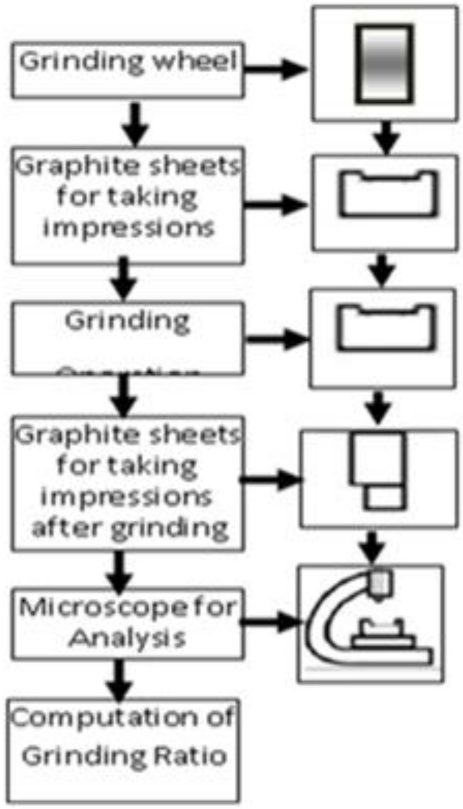

Figure 6 Optimal front in three dimensions

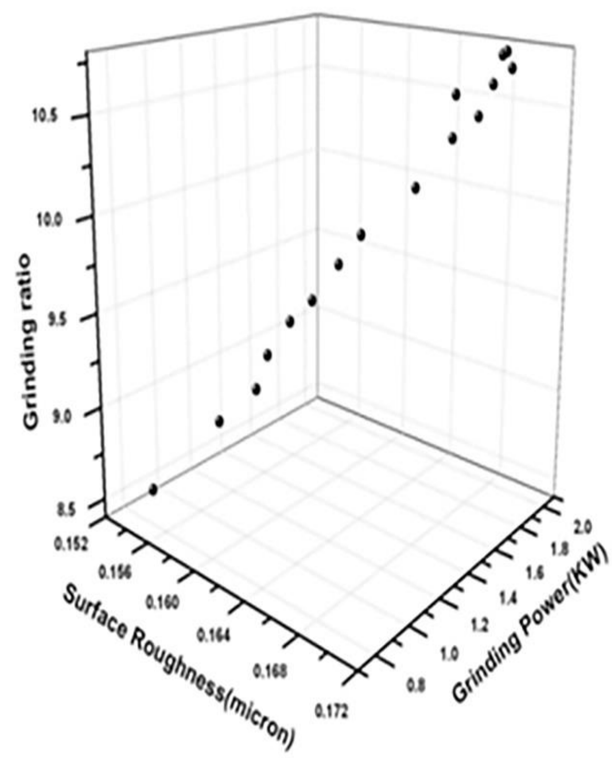

Table 1 Specimen metallurgical analysis

Element	C	Mn	Si	S	P	Cr
Lab analysis value (%)	0.97	0.36	0.22	0.012	0.012	1.49

Table 2 Input parameters, their levels and coded values

Parameters	Dressing depth of cut	Dressing cross feed rate	Grinding feed rate
Symbol	D	C	Fr
Units	micros	mm/min	mm/min
Level I	10	60	0.6
Level II	20	80	1.2
Level III	40	120	2.4
Coded value for level I	-1	-1	-1
Coded value for level II	-0.33	-0.33	-0.33
Coded value for level III	1	1	1

Table 3 shows L-9 Orthogonal array with average result

Run	Ra(μm)	Pw(kW)	Gr
1	0.146	1.48	11.13
2	0.165	1.86	9.89
3	0.226	3.66	9.44
4	0.176	2.34	11.04
5	0.194	3.01	10.08
6	0.17	1.41	9.06
7	0.21	3.92	10.07
8	0.161	1.34	9.54
9	0.176	2.31	8.16

Table 4 Optimum input process parameters in coded form

Serial number	D	C	Fr
1	0.8566	-0.0588	-0.9892
2	0.9057	-0.9926	-0.9915
3	0.5314	-0.9926	-0.8441
4	0.9456	-0.6271	-0.9710
5	0.7189	-0.8029	-0.9753
6	0.9299	0.0969	-0.9855
7	0.9299	-0.7237	-0.9632
8	0.6431	-0.8582	-0.8794
9	0.9776	-0.4131	-0.9699
10	0.8734	0.5092	-0.9676
11	0.9992	0.9863	-0.9726
12	0.9085	-0.1947	-0.9906
13	0.9914	0.6555	-0.9632
14	0.9689	-0.9279	-0.9753
15	0.9299	0.3469	-0.9855
16	0.9816	0.1912	-0.9892

Table 5 Surface roughness, power and grinding ratio.

Serial number	Ra (μm)	Pw (kW)	GR
1	0.1623	1.4054	9.7248
2	0.1694	1.8752	10.7872
3	0.1681	1.9936	10.7394
4	0.1673	1.7128	10.3688
5	0.1667	1.7928	10.5614
6	0.1612	1.3227	9.5421
7	0.1685	1.7719	10.4790
8	0.1682	1.9146	10.6061
9	0.1658	1.6035	10.1234
10	0.1588	1.1516	9.0794
11	0.1537	0.8700	8.5124
12	0.1633	1.4673	9.8767
13	0.1569	1.0605	8.8951
14	0.1699	1.8626	10.7146
15	0.1592	1.1941	9.2563
16	0.1602	1.2606	9.4292