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MODELING AND OPTIMIZATION OF CYLINDRICAL GRINDING PARAMETERS FOR MRR AND SURFACE ROUGHNESS

Kshitij R Patil[1], Rupesh J Karande[2], Dadaso D. Mohite[3], Vishwas S Jadhav[4]
[1,2]Mechanical Deptment, NBN Sinhgad School of Engineering, Pune (India)
[3]Assistant Professor, Keystone School of Engineering, Pune (India)
[4]Associate Professor, Bharati Vidyapeeth, College of Engineering, Lavale, Pune (India)

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ABSTRACT
Cylindrical grinding is one of the important metal cutting processes used extensively in the finishing operations. The grinding process plays an important role in every manufacturing activity. The surface properties can be altered by changing various grinding parameters in order to achieve best surface finish resulting in low surface roughness value and with possible maximum metal removal rate. Four parameters, namely spindle speed, feed rate, depth of cut and hardness of material were identified and the ranges of the parameters for the investigation were determined from preliminary experiments. Each parameter was investigated at three levels to study the non-linearity effect of the parameters. Taguchi method based L9 orthogonal array was selected and experiments were conducted as per experiment layout plan. Based on Signal to Noise ratio analysis, the optimal settings of the process parameters have been determined. Using these results mathematical model had been formed in order to get right combination of machining parameters. This would reduce time consumption and maintain desired quality with high productivity.

KEYWORDS: Cylindrical Grinding, Optimization, Taguchi Method, Modeling

INTRODUCTION
Grinding plays very important role to acquire great dimensional accuracy with great surface finish. So, finding the role of each parameter with different values could be helpful in predicting the surface properties obtained which can reduce time required for strategic planning and resulting in efficient manufacturing. Cylindrical grinding machine is used for machining of components for smooth surface finishing and to get close tolerances. To improve surface properties and mechanical properties with extended life of object optimal conditions are necessary for manufacturing. Although grinding operation has great importance in total manufacturing process still there optimal parametric values are not accounted by many manufacturers.

EN19 material is applied in various automotive components like valve, machine shaft, machinery components where accurate dimensions are required. The effective use of EN19 can increase life of the components with high quality performance that can increase productivity with more revenue.

The input parameters used for cylindrical grinding machining are depth of cut, spindle speed, feed rate, and hardness of material. The main objective in grinding process is to get better surface finish and high material remove rate (MRR). Efforts were made to find expedient values of parameters on grinding machine and they were measured on the basis of minimum surface roughness (Ra) for EN19 cylindrical bar.

Rajendra B et. al. optimization of the process parameter such as cutting speed, depth of cut and feed rate on surface roughness produced on the machined component. Puneet Kumar et. al. The machining cutting parameters (cutting speed, feed rate and depth of cut) optimized to evaluate high material removal rate and minimum surface roughness. Janardhan et al proposed that in cylindrical grinding metal removal rate and surface finish are the important responses.

A mathematical model is a description of system using mathematical concept and language. The process of developing a mathematical model is termed as mathematical modeling. A model may help to disclose a framework and to concentrate the impacts of various parts, and to make forecasts. Mathematical models can take many forms, including but not limited to frameworks, measurable models, differential conditions, or amusement theoretic models.

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This paper describes an approach to model the structure of grinding response, based on an analysis of grinding parameter. The presented work is a first step to generate a model of complex grinding wheel parameter for MRR and surface roughness.

PROPOSED METHODOLOGY

This present paper, effort is made to optimize the grinding process parameter for minimum surface roughness and maximum MRR and to find mathematical correlation between two or more variables. Experiments were conducted at various level of grinding parameter such as depth of cut, feed rate, spindle speed and hardness of material. The ranges of the parameters for the investigation were determined from preliminary experiments. Each parameter was investigated at three different levels in order to show the efficacy of the parameters at optimum level of the parameters. Taguchi method based L9 orthogonal array was selected and experiments were conducted as per experiment layout plan. In the present work, experimental results were used to find mathematical correlation in the form of non-linear, linear, linear with interaction, linear with square, Quadratic model. These models are developed in response by considering selected grinding parameter. Finally the predicted value are validated and compared with experimental values.

Fig 1:-Grinding Machine Used for experiment

EXPERIMENTAL WORK

The experiments where conducted on the cylindrical grinding machine. The control factors are depth of cut, feed rate, spindle speed and hardness where based on preliminary investigations of experiments. The method is popularly known as the factorial design of experiments.A full factorial design will identify all possible combinations for a given set of factors. Since most industrial experiments usually involve a significant number of factors, a full factorial design results in a large number of experiments. To reduce the number of experiments to a practical level, L9 Orthogonal array of Taguchi optimization method is used as a small set from all the possibilities is selected. The method of selecting a limited number of experiments which produces the most information is known as a L9 Orthogonal array of Taguchi optimization method . The different control factors of experiments are shown in table 1

Table 1:-Controlled Factors

Sr no	Factors	Symbols	Level		
			I	II	III
1	Depth of cut (μm)	d	20	30	40
2	Feed rate (mm/rev)	*f*	0.06	0.12	0.18
3	Spindle Speed (rpm)	n	145	247	415
4	Hardness (HRC)	h	30	40	50

Fig 2:- Grinding operation on work piece

Workpiece Preparation

EN 19 steel rod having Rockwell hardness as 25 HRC and length of 120 mm & diameter 35 mm was taken. Specimen piece was then mounted on the center lathe machine for further machining. , the specimen was allowed for heat treatment process to increase its hardness. Hardening is a metal working process used to increase the hardness. The metal hardness is directly proportional to the uniaxial yield stress at the location of the strain imposed . A harder metal has a higher resistance to plastic deformation than a less harder metal. Servoquench oils are generally used for all quenching operations as it uesful on a wide variety of steel to impart the desired and required hardness to components without distortion. The Servo quench oil is Servo quench H11oil is used.

Experimental Conditions

Table 2:- Specification of Machine

Grinding Machine	JONES – SHIPMAN(1310) Cylindrical Grinding Machine
Workpiece	EN19 Steel bar
Grinding Wheel	Sillicon Carbide
Coolant	Soluble oil and Continous ON
Wheel Speed	3600 rpm

Experimental result

Table 3:- Experimental Results for MRR and Surface Roughness

Expt. No.	**d (µm)**	**f (mm/rev)**	**n (rpm)**	**h (HRC)**	**Material Removal Rate (MRR) (g/sec)**		**Surface Roughness (Ra-value) (µm)**	
					Mean	**S/N ratio**	**Mean**	**S/N ratio**
1	20	0.06	145	30	0.07692	-22.2789	0.6490	3.75511
2	20	0.12	247	40	0.11160	-19.0467	0.9420	0.51898
3	20	0.18	415	50	0.07744	-22.2207	0.6534	3.69642
4	30	0.06	247	50	0.17260	-15.2592	0.6164	4.20275
5	30	0.12	415	30	0.25840	-11.7541	0.9228	0.69785
6	30	0.18	145	40	0.2363	-12.5307	0.8436	1.47727
7	40	0.06	415	40	1.444	3.19134	0.7498	2.50109
8	40	0.12	145	50	1.2288	1.78962	0.6380	3.90359
9	40	0.18	247	30	2.0177	6.09713	1.0476	-0.4039

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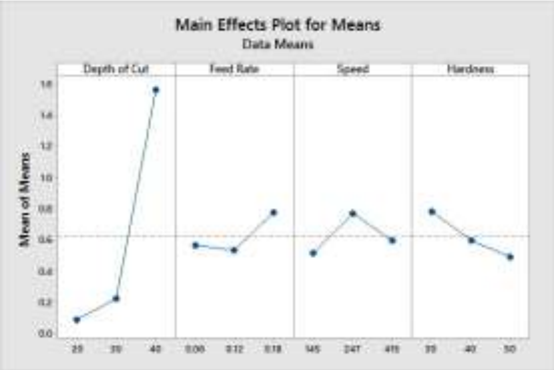

Fig 3:- Main Effect plot For Mean for MRR

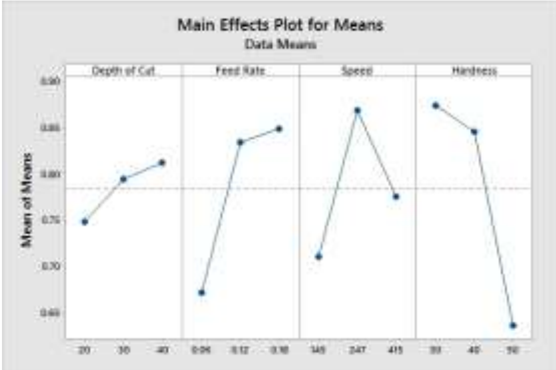

Fig 4:- Main Effect plot For Mean for Ra

MRR increases with increase in the grinding depth of cut and grinding cross feed rate. Also, MRR decreases with increase hardness of material . d3 is 40µm, f3 is 0.18mm/rev, n2is 247rpm, h1is 30HRC.
Surface roughness increases with increase in the grinding depth of cut and grinding feed rate. Also, Surface roughness decreases with increase in speed to some extent and then it increases with further increase in speed. d1 is 20µm, f1is 0.06mm/rev, n1 is 145rpm, h3is 50HRC.

MATHEMATICAL MODELING

Mathematical Modeling is utilized for solving the problems in which output parameters are related by several input parameters and the goal is to optimize the response. In this work, linear, non-linear, linear with interaction, linear with square and quadratic mathematical model was developed using multiple regression analysis in order to find correlations between Grinding parameters like as depth of cut ,feed rate ,spindle speed,hardness are selected. The response is MRR and surface roughness. The predicted surface roughness and MRR of grinding process can be expressed in terms of the investigation independent variable.

The mathematical models commonly used for the cylindrical grinding with the variables under consideration are represented by:
$y = \phi (d, f, n, h)$
where y is the grinding response, ϕ is the response function and d, f, n and h are grinding variables.
$MRR=\varphi(d,f,n,h)$ (1)
Where MRR= Material removal rate(g/sec),φ is the response function and d,f,n,h is the grinding parameter and for surface roughness
$Ra=\varphi(d,f,n,h)$ (2)
Where Ra= surface roughness (µm), φ is the response function and d,f,n,h is the grinding parameter

A. Non-linear Model

$$y = c_1 \times d^{a1} \times f^{a2} \times n^{a3} \times h^{a4} \quad (3)$$

In above equation $c_1$is constant and exponent $a_1, a_2,\ a_3, a_4$ are mathematical model constant

$$MRR = 3.26288 \times 10^{-6} \times (d)^{4.0022} \times (f)^{0.2102} \times (n)^{0.0874} \times (h)^{-0.5489} \quad (4)$$

$$Ra = 4.069 \times (d)^{0.1042} \times (f)^{0.2183} \times (n)^{0.0877} \times (h)^{-0.5485}$$
(5)

B. Linear form Model

$$y = a_0 + a_1 \times d + a_2 \times f + a_3 \times n + a_4 \times h \quad (6)$$

In above equation $a_0\ a_1, a_2,\ a_3, a_4$ are mathematical model constant

$$MRR = -1.2586 + 0.0733 \times (d) + 1.709 \times (f) + 0.0002 \times (n) - 0.0142 \times (h) \quad (7)$$

$$Ra = 0.9234 + 0.0029 \times (d) + 1.574 \times (f) + 0.0002 \times (n) - 0.0115 \times (h) \quad (8)$$

C. Linear with interaction Model

$$y = a_0 + (a_1 \times d) + (a_2 \times f) + (a_3 \times n) + (a_4 \times h) + (a_5 \times d \times f) + (a_6 \times d \times n) + (a_7 \times d \times h) + (a_8 \times f \times n) + (a_9 \times f \times h) + (a_{10} \times n \times h) \quad (9)$$

In above equation a_0 $a_1, a_2, a_3, a_4, a_5, a_6, a_7, a_8, a_9$ are mathematical model constant.

$$MRR = 0.1821 \times (d) - 0.0052 \times (n) - 0.102 \times (h) - 0.0003 \times (d \times n) - 0.0005 \times (d \times h) - 0.0054 \times (f \times n) - 0.0239(f \times h) + 0.0003 \times (n \times h) \quad (10)$$

$$Ra = -0.0482 \times (d) - 0.0061 \times (n) - 0.0936 \times (h) - 0.0003 \times (d \times n) - 0.0001 \times (d \times h) - 0.0271 \times (f \times n) - 0.0557(f \times h) + 0.0002 \times (n \times h) \quad (11)$$

D. Linear with square Model

$$y = a_0 + (a_1 \times d) + (a_2 \times f) + (a_3 \times n)(a_5 \times d^2) + (a_6 \times f^2) + (a_7 \times n^2) + (a_8 \times h^2) \quad (12)$$

In above equation a_0 $a_1, a_2, a_3, a_4, a_5, a_6, a_7, a_8,$ are mathematical model constant.

$$MRR = 3.969 - 0.2884 \times (d) - 7.4209 \times (f) + 0.0076 \times (n) - 0.0476 \times (h) + 0.006 \times (d^2) + 38.3038 \times (f^2) + 0.0004 \times (h^2 \quad (13)$$

$$Ra = -1.3484 + 0.0118 \times (d) + 6.4239 \times (f) + 0.0046 \times (n) - 0.0606 \times (h) + 0.0001 \times (d^2) + 20.6389 \times (f^2) - 0.0009 \times (h^2) \quad (14)$$

E. Quadratic Model

$$y = a_0 + (a_1 \times d) + (a_2 \times f) + (a_3 \times n) + (a_4 \times h) + (a_5 \times d^2) + (a_6 \times f^2) + (a_7 \times n^2) + (a_8 \times h^2) + (a_9 \times d \times f) + (a_{10} \times d \times n) + (a_{11} \times d \times h) + (a_{12} \times f \times n) + (a_{13} \times f \times h) + (a_{14} \times n \times h) \quad (15)$$

In above equation a_0 $a_1, a_2, a_3, a_4, a_5, a_6, a_7, a_8, a_9, a_{10}, a_{11}, a_{12}, a_{13}, a_{14}$ are mathematical model constant.

$$MRR = -0.0979 \times (d) + 0.0117 \times (n) + 0.0036 \times (d^2) - 0.0222 \times (h^2) - 0.0004 \times (d \times n) + 0.0018 \times (d \times h) - 0.0071 \times (f \times n) + 0.0003 \times (n \times h) \quad (16)$$

$$Ra = -0.0484 \times (d) + 0.0115 \times (n) + 0.0024 \times (d^2) - 0.0032 \times (h^2) - 0.0001 \times (d \times n) + 0.006 \times (d \times h) - 0.01871 \times (f \times n) + 0.0002 \times (n \times h) \quad (17)$$

The error between experimental values and predicted values of the mathematical model can be calculated by the method of least squares

$$E_{\text{least square}} = (y_{10}-y_{c1})^2 + (y_{20}-y_{c2})^2 + (y_{30}-y_{c3})^2 \quad (18)$$

Equation (18) gives the least square error between observed values and computed values by model.

RESULT

The mathematical models i.e. linear, non-linear , linear with interaction, linear with square and quadratic developed for the response MRR and surface roughness is valid only for the experimental and grinding conditions used in this work.

The experiment for optimum combination of d3f3n2h1 produced Maximum MRR of 2.01780 g/sec. The result obtained by confirmation experiment is close agreement with the results obtained by predicted Taguchi analysis. The variation in the result is 0.049%.

The experiment for optimum combination of d1f1n1h3 produced Minimum surface roughness 0.4229 μm. The result obtained by confirmation experiment is close agreement with the results obtained by predicted Taguchi analysis. The variation in the result is2.62%

Table 4:- Comparison between experimental and predicted results

	Material Removal Rate			Surface Roughness		
Expt	Experimental Result MRR(g/sec) **d3f3n2h1**	Optimal Result (g/sec) **d3f3n2h1**	Least square result	Experimental Result Ra (μm) **d1f1n1h3**	Predicted Result (μm) **d1f1n1h3**	Least square result
Linear Model	2.0177	1.60442	0.0086883	0.5504	0.529852	0.00064
Non linear Model	2.0177	1.46944	0.0059592	0.5504	0.544495	0.00058
Linear with interaction Model	2.0177	1.23545	0.060058	0.5504	1.32017	0.02227
Linear with square Model	2.0177	2.74748	0.162365	0.5504	0.605734	0.067695

Quadratic Model	2.0177	2.86923	0.275107	0.5504	0.93781	0.80967

CONCLUSION

This paper present that it has use mathematical model and optimization to decide the optimal process parameter. The output parameter is surface roughness and MRR.

1. The optimum valve for surface roughness is 20mm depth of cut , 0.06mm/rev is the feed rate, 145rpm is the spindle speed , hardness is 50 HRC.
2. The optimum valve for MRR is 40mm depth of cut , 0.18mm/rev is the feed rate, 247 rpm is the spindle speed , hardness is 30 HRC.
3. Mathematical models, the linear and non linear models were found to be better in terms of the predictive performance.
4. The most effective model is Non-linear model in mathematical modeling in case of experiment.
5. The most Dominating Factor for MRR is Depth of Cut and for Surface Roughness is Hardness of Material.

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