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Optimization of Cylindrical Grinding Process Parameters for EN353 Steel using Taguchi Technique

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Abstract: Grinding is an abrasive machining process where grinding wheel is used as a cutting tool. In this study cylindrical grinding process parameters are optimized by using Taguchi method. Process parameters considered for the study are grinding wheel speed, depth of cut and table feed rate. EN353 steel is high tensile strength alloy which is mostly used in automobile and aerospace industry where high surface finish and dimensional accuracy is required. An EN353 alloy steel rod of cylindrical shape has been used for grinding operation. Performance of cylindrical grinding operations has been measured by average surface finish. In Taguchi method L9 orthogonal array has been selected. ANOVA has been used to determine effect of each parameter on surface roughness
Keywords: Taguchi method, Grinding, optimization, cutting parameters, surface roughness, EN353

I. INTRODUCTION

Grinding is the most widely used abrasive finishing process among all traditional processes used in production. In grinding operation, the material is removed from the work piece surface by the relative motion of a rotating cylindrical wheel having abrasive particles embedded on its periphery. The abrasive particles are bonded together to form porous body which come into contact with work piece resulting in material removal. The size and distribution of grits along and wheel abrasive structure play an important role in grinding performance. [1] The application of grinding is mainly available for simple geometries like cylindrical or plane surface where size is limited by grinding wheel movement. Grinding is a surface finishing process in which abrasive grains of irregular geometry are randomly spaced along the cutting edge of grinding wheel. The average rake angle of the grains is highly negative, typically 60° or lower, consequently the shear angle is very low. The cutting speed of grinding wheel is very high, typically on the order of 1500 to 2500 RPM. It is the machining processes which improve surface quality and dimensional accuracy of work piece. [2] There are various process parameters of a cylindrical grinding machine that include grinding wheel speed, work speed, table feed, depth of cut, material hardness, grinding wheel abrasive type, grain size, number of passes, coolant type, coolant flow rate. [3] Performance of operation performed are usually measured in surface roughness and material removal rate. Wheel speed and feed rate are very important factors because increasing the both wheel speed and feed rate has negative impact on surface roughness. The material removal rate is affected by the hardness of the work material. The abrasives and grain size to be selected depend upon the work material and the resultant surface finish and material removal desired. This paper investigates the effect input process parameters namely wheel speed, depth of cut and feed rate on surface roughness of the workpiece. [4]

II. EXPERIMENTATION

A. *Methodology of experiment*

There are several optimization techniques to develop product, process or operation. Various techniques can be applied to optimize grinding process. Sometimes different techniques are required integrate to get statistically significant results, which can lead to better conclusions and recommendations. Some extensively used methods in developing a process or a product are Build Test Fix (BTF), Design of Experiment (DOE) and One Variable at a Time (OVAT), BTF is very primitive and unorganized approach. It is iterative method of developing a process focused on improvement from last experiment. DOE is highly efficient method of investigating the effect of parameters as it varies multiple parameter at once. As more parameters are investigated, more number of new combinations are required. DOE cannot control individual parameters and more relies on statistical data. In OVAT approach, variation is done with one variable at a time and other parameters are kept constant until the effect of one parameter is studied.

It is highly precise method to study effect of each parameter at different levels. [5] Depth of cut, feed rate, and wheel speed were identified as most predominant parameters affecting the cylindrical grinding. Based on the observation, Taguchi method has been used to optimize the process parameters. OVAT analysis has been conducted to find out effective range of parameters for optimization study. L9 orthogonal array has been selected from available designs. Standard notation for OA is given below

$OA = Ln(Xm)$

Where n= number of experiments, X= number of levels and m= number of parameters under study. From available designs for 3 levels 3 parameters, OA with least number of experiment required to conducted (L9) has been selected. ANOVA has been conducted to find out contribution of each parameter in the output. Minitab 19 software has been used for analysis.

B. Experimental Machine Selection

Table 1 states the specification of the cylindrical grinding machine used in this study. All the experiments were conducted at Metrology Gauges, Gut No. 248, Plot No.14, MIDC Waluj, Aurangabad, M.S, India.

Make and Model	Micromatic GCU/E 350
Max. Grinding Length	500 mm
Grinding wheel	A60 L5 V10, 400 mm external diameter, 50 mm thick and 127 mm internal diameter
Job size (external)	160 mm
Job size (internal)	140 mm

Table 1 Grinding Machine Specification

Figure 2.1 shows setup of cylindrical grinding machine used for grinding operation of the workpiece

Figure.2.1 Setup Cylindrical Grinding Machine

All the test specimens have been inspected for average surface roughness on Mitutoyo Surftest SJ-200 series surface roughness tester

C. Selection of Material

EN353 steel round bars have been used as a workpiece material of diameter 10 mm and length 15 mm. It contains Nickel, Chromium, Molybdenum which increases its tensile strength, ductility and wear resistance capability. It has applications in automobile and aerospace industry. It is also used to produced precision gauges because of its wear resistance property. Literature study indicates that research can be conducted to evaluate effect of process parameters like wheel speed, depth of cut, and feed rate of cylindrical grinding operation on surface roughness. European Standard equivalent of EN353 steel is EN10277. Where ‘1’ denotes steel, the next two number ‘02’ denotes structural steel, next two number ‘77’ denotes sequential number assigned by standard committee. Chemical composition of EN353 Steel is shown in Table 2

C	Mn	Si	Cr	Ni	Mo
0.17	0.6	0.2	0.75	1.25	0.01

Table 2 Chemical Composition of EN353 steel

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Figure 2.2 EN353 Steel and a test specimen

D. OVAT for Wheel Speed

Variation in average surface roughness with change in wheel speed is shown in Figure 2.3.

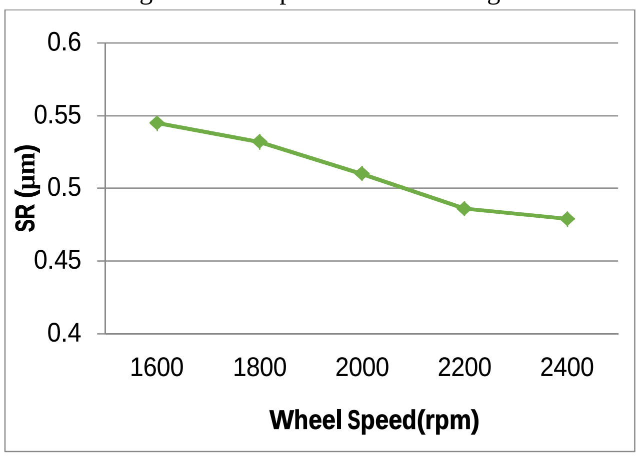

Figure 2.3 OVAT for Wheel Speed Vs SR

Depth of cut and feed rate kept constant and wheel speed varied from 1600 to 2400 rpm. From the fig 2.3, it has been observed that as wheel speed increases from 1600 to 2400 rpm, the surface roughness reduces drastically from 0.545 to 0.439 µm. It also has been observed that, the rate of change of surface roughness is higher in the region of wheel speed of 1800-2200 rpm hence this level of factor has been selected.

E. OVAT for Depth of Cut

Figure 2.4 shows variation in surface roughness with change in depth of cut.

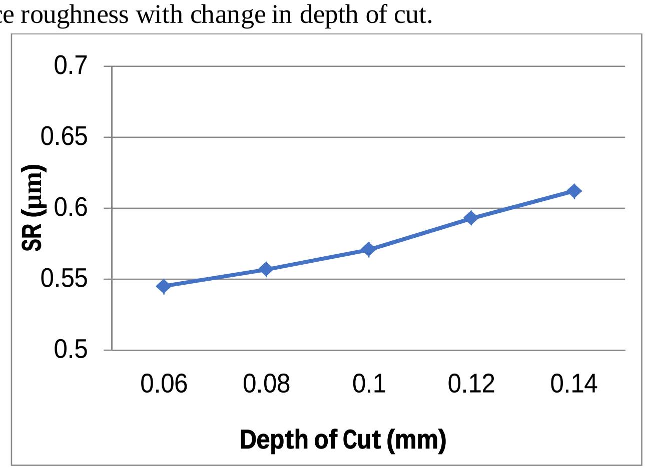

Figure 2.4 OVAT for Depth of Cut

It has been observed that, as depth of cut increases, surface roughness decreases. The rate of change of surface roughness is higher in the region of depth of cut is 0.10 to 0.14 mm hence this level of factor has been selected.

F. OVAT for Feed Rate

Figure 2.5 shows variation in surface roughness with change in feed rate.

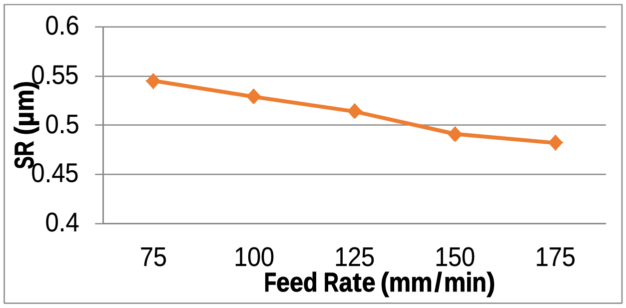

Figure 2.5 OVAT for Feed Rate

It has been observed that, the rate of change of surface roughness is higher in the region of feed rate is 100-150 mm/min hence this level of factor has been selected.

G. Levels of Input Parameters

Three levels for each parameter has been selected for optimization. Selecting more than 3 levels would have needed more experiments to be conducted. Selecting less than 3 levels is not justified for investigation of effect of parameters for 1st time. Table 3 shows three levels of input parameters selected for optimization study.

Sr. No	Level 1	Level 2	Level 3
Speed (rpm)	1800	2000	2200
DOC (mm)	0.10	0.12	0.14
Feed Rate (mm/min)	100	125	150

Table 3 Levels of Input Parameters

III. RESULTS AND DISCUSSION

To get complete understanding of effects of input parameters wheel speed, depth of cut and feed rate on output average surface finish you usually assess signal to noise ratio or main effects plot for means. For this purpose, Minitab 19 statistical software has been used. Modeling of surface roughness has been done. ANOVA has been conducted to find out effect of each parameter on the surface roughness and linear regression model has been established to predict the values of surface roughness.

A. Experimental Results

Table 4 shows the L9 orthogonal array with measurement of surface roughness for runs one to nine. It also shows S/N ratio for all nine experiments.

Ex No	Inputs Factors			Output Responses	
Trial No.	Wheel Speed (rpm)	DOC (mm)	Feed Rate (mm/min)	SR (Ra) (µm)	S/N Ratio
1	1800	0.10	100	0.515	5.76386
2	1800	0.12	125	0.489	6.21382
3	1800	0.14	150	0.467	6.61366
4	2000	0.10	125	0.450	6.93575
5	2000	0.12	150	0.489	6.21382
6	2000	0.14	100	0.486	6.26727
7	2200	0.10	150	0.505	5.93417
8	2200	0.12	100	0.579	5.74643
9	2200	0.14	125	0.503	5.96864

Table 4 L9 orthogonal array with response characteristic

The S/N ratio values are calculated with help of Minitab 19 software. It can be seen that variation in S/N ratio is minimum for all experiment.

B. Main Effects of SR

Figure 3.1 shows the main effects plot from S/N ratios.

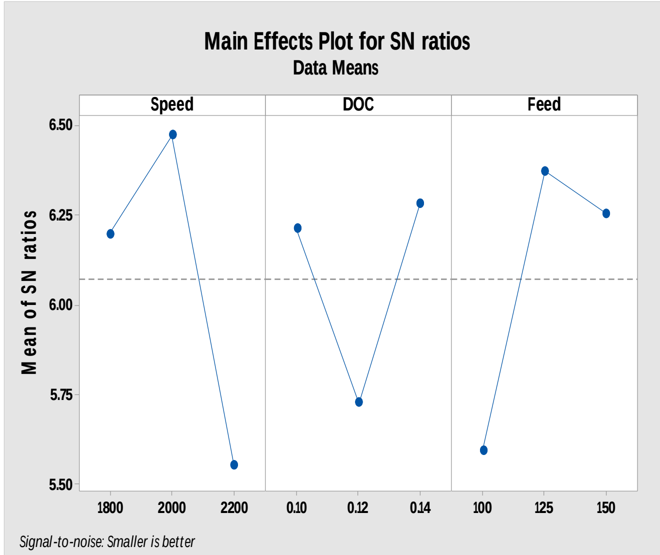

Figure.3.1 Main Effects Plot for S/N Ratio

From main effects plot for S/N ratio, parametric effect on response characteristic i.e. surface roughness can be understood. Wheel speed 2000 rpm at level 3, Feed Rate 125 mm/min at level 2, Depth of Cut 0.14 mm at level 3 gives the highest signal to noise ratio values. The levels at which highest S/N ratio obtained from S/N ratio plot taken as optimum levels setting for machine parameters.

C. ANOVA Result

In ANOVA, the ratio between the variance of the cutting parameter and the error variance is called Fisher's ratio (F). It is used to determine whether the parameter has a significant effect on the quality characteristic by comparing the F test value of the parameter with the standard F table value at the P significance level. [3] If the F test value is greater than P test the cutting parameter is considered significant. Relevance of the models is tested by analysis of variance (ANOVA). It is a statistical tool for testing the null hypothesis for planned experiments, in which several different variables are studied simultaneously. [4] ANOVA is used to quickly analyze the variances in the experiment using the Fisher test (F test). ANOVA table shown the result of the ANOVA analysis. ANOVA analysis makes it possible to observe that the value of P is less than 0.05 in the three parametric sources. It is therefore clear that wheel speed, feed rate, depth of cut of the material have an influence on the EN 353 Steel. The last column of cumulative ANOVA shown the percentage of each factor in the total variance that indicates the degree of impact on the outcome. Table 6 shows results obtained from analysis of variance.

Source	DOF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
Speed	2	0 .004646	0.002323	37.81	0.026	44.26
DOC	2	0.001996	0.000998	16.24	0.058	19.01
Feed	2	0.003730	0.001865	30.35	0.032	35.54
Error	2	0.000123	0.000061			
Total	8	0.010495				

Table 6 ANOVA Result

It shows that the wheel speed (44.26%), the feed rate (35.54%) and the depth of cut (19.01%) have major influence on the surface roughness. Contribution of speed (44.26%) is highest among all three parameters hence it is most dominating parameter while depth of cut is least affecting parameter.

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D. Development of Regression Model for Surface Roughness

Regression model has been developed using Minitab software. Substituting the experimental values of the parameters in regression equation, values for surface roughness have been predicted for all levels of study parameters. Graphical representation also shows that predicted and experimental values of surface roughness correlates with each other.

Regression Equation –

Surface roughness = 0.408 + 0.000097 [Wheel Speed] – 0.117 [DOC] – 0.000793 [Feed].

Table number 7 gives comparison between experimentally measured and predicted surface roughness by developed mathematical equation.

Sr. No.	Experimental value	Predicted value	Error %
1	0.515	0.491	4.88
2	0.489	0.469	4.26
3	0.467	0.456	2.41
4	0.450	0.490	4.61
5	0.489	0.468	4.48
6	0.486	0.506	4.11
7	0.505	0.490	3.06
8	0.579	0.527	4.82
9	0.503	0.505	3.90

Table 7 Experimental and Predicted Values of SR

Difference between surface roughness values calculated using regression equation and experimental values for each experience found less than 10%. Hence, we can say that the regression equation developed is valid. Figure 3.2 shows the graphical representation of experimental and values calculated using regression equation.

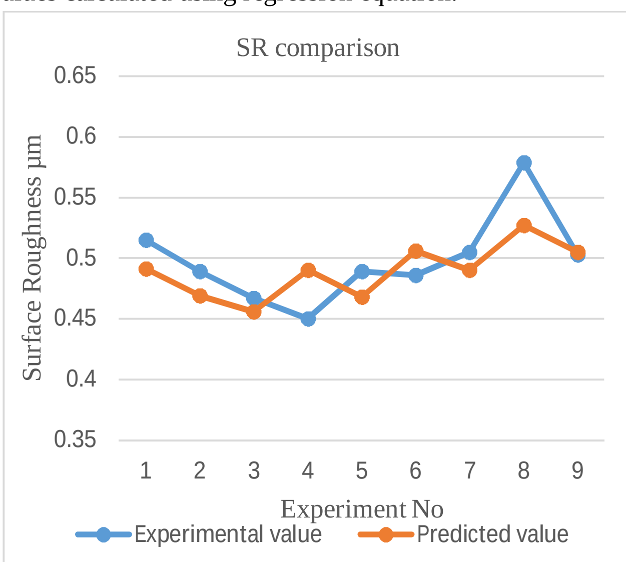

Figure 3.2 Comparison between Experimental and Predicted value of surface roughness.

E. Confirmation Experiment Result

Table 8 shows the difference between value of surface roughness of confirmation experiment and value predicted from regression model developed

Parameter	Model value	Experimental value	Error %
SR	0.487	0.447	4.80

Table 8 Confirmation Experiment Result

Confirmation experiment is conducted by keeping parameters at optimum levels suggested by Taguchi method and the surface value obtained has been compared with value predicted by the regression model keeping the parameters at same levels. It can be seen that the difference between experimental result and the predicted result is 4.8%. This indicates that the experimental value corelates to the estimated value.

F. Conclusions

In this study the influence of process parameters such as wheel speed, feed rate, depth of cut and their optimization for grinding of EN353 Steel has been studied by using Taguchi Method. Following conclusions are drawn.

1) The optimal solution obtained for surface roughness based on the combination of cylindrical grinding machine parameters and their levels is (i.e. wheel speed is 2000 rpm at level 2, feed rate is 125 mm/min at level 2 and depth of cut is 0.14mm at level 3).
2) ANOVA results indicate that contribution of wheel speed on surface roughness is highest followed by feed and depth of cut. Wheel speed is most dominant factor. This may be due to fact that build up edges formation decreases and cutting speed increases. Depth of cut is least dominant
3) Values of surface roughness obtained in confirmation experiment is least in all experiment conducted. Hence, good surface finish can be achieved using suggested level of parameters by Taguchi method.
4) Values of surface roughness calculated using regression model correlates with experimental values with error less than 10%. Hence the model developed is valid and experimental results of surface roughness with any combination of grinding parameters can be estimated within selected levels using the model.

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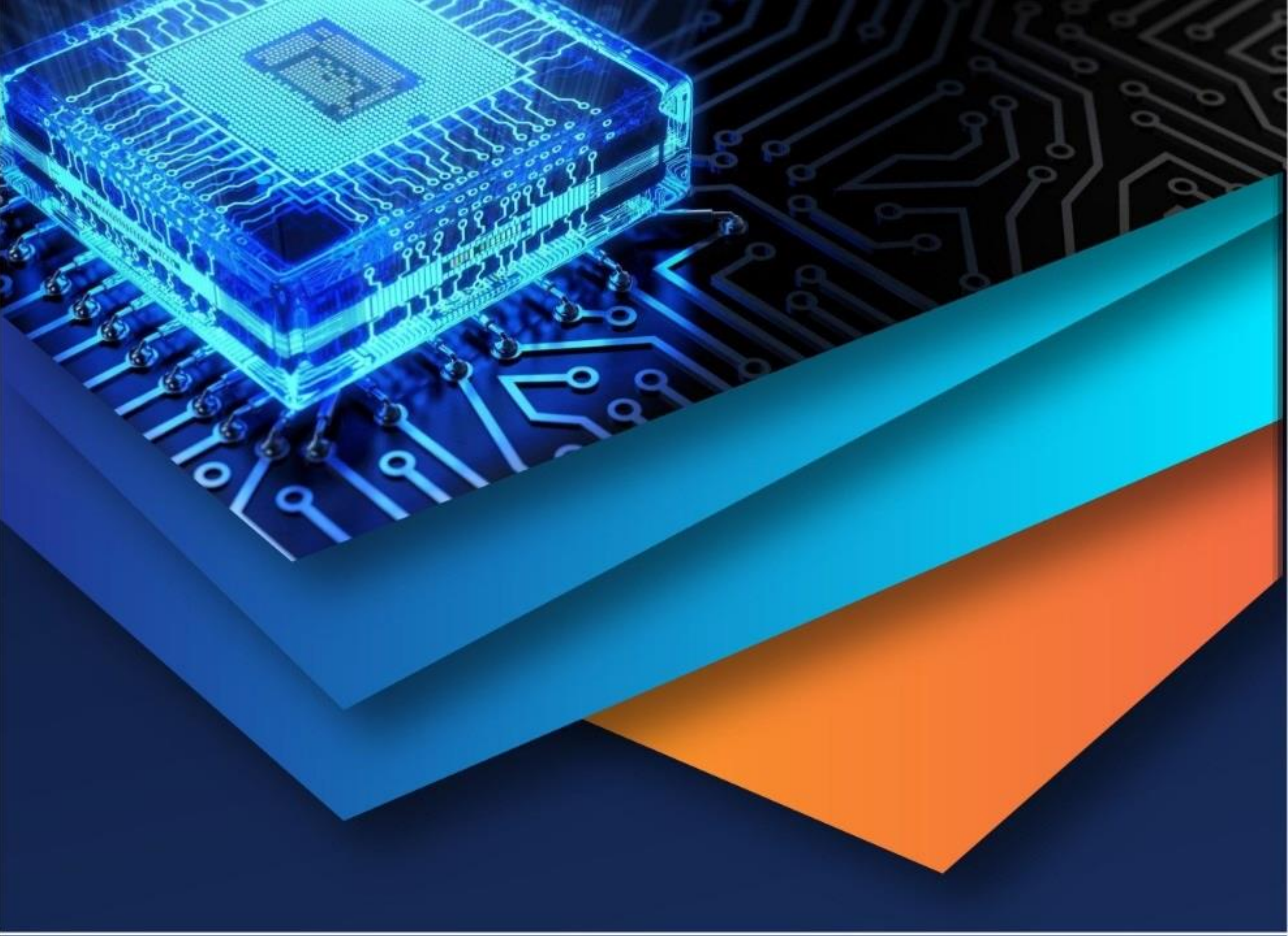

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