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Analysis and Optimization of Speed, Feed and Number of Teeth of Circular Saw for a Special Purpose Sawing Machine

A. H. Rasal¹, Prof. (Dr.) V. R. Naik², R. A. Mane³

M.E. P.D.D. Student, Department of Mechanical, Textile and Engg. Institute, Ichalkaranji, Kolhapur,
Maharashtra, India.¹

Head of Mechanical Department, Textile and Engg. Institute, Ichalkaranji, Kolhapur, Maharashtra, India.²

Asst. manager, Paranjape Autocast Pvt, Ltd., Satara, Maharashtra, India.³

ABSTRACT: This paper deals with the increasing of productivity by selecting suitable machining parameters i.e. speed, feed and number of teeth, of a special purpose machine designed and developed for sawing process. The component is a cylinder head made of aluminium alloy (IS designation 4223). This machine uses a carbide tipped circular saw. The feeding of job against the circular saw is done hydraulically. The tests are conducted and reading are tabulated using MINITAB software. Response Surface Methodology technique is used for analysis and optimization of the mentioned parameters.

KEYWORDS: Response Surface Methodology, speed, feed, number of teeth Surface roughness, Production rate.

1. INTRODUCTION

In industry, designed experiments can be used to systematically investigate the process or product variables that influence product quality. After identifying the process conditions and product components that influence product quality, direct the improvement efforts to enhance a product's manufacturability, reliability, quality, and field performance.

Because resources are limited, it is very important to get the most information from each experiment to be performed. Well-designed experiments can produce significantly more information and often require fewer runs than haphazard or unplanned experiments. In addition, a well-designed experiment will ensure evaluation of the effects identified as important. For example, if there is an interaction between two input variables, be sure to include both variables in the design rather than doing a "one factor at a time" experiment. An interaction occurs when the effect of one input variable is influenced by the level of another input variable. Designed experiments are often carried out in four phases: planning, screening (also called process characterization), optimization, and verification [1].

II. RELATED WORK

Response surface methodology (RSM) uses various statistical, graphical, and mathematical techniques to develop, improve or optimize a process. Response surface methods are used to examine the relationship between one or more response variables and a set of quantitative experimental variables or factors. These methods are often employed after identifying the controllable factors and find the factor settings that optimize the response. Designs of this type are usually chosen when there is a curvature in the response surface.

- i. Find factor settings (operating conditions) that produce the "best" response
- ii. Find factor settings that satisfy operating or process specifications

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- iii. Identify new operating conditions that produce demonstrated improvement in product quality over the quality achieved by current conditions
- iv. Model a relationship between the quantitative factors and the response

Process parameters

Cutting speed (rev / min): It is a travel of a point on the cutting edge relative to the surface of cut in unit time in the process accomplishing the primary cutting motion. It is expressed in rev/min [2,3].

Cutting feed (mm / sec): The work table on which the component is mounted advances towards the circular saw with the specified feed. It is expressed in mm/sec.

Number of teeth: Circular saws have specified number of teeth. These are available according to the company manufacturing catalogue [4].

Response parameters

Surface roughness (μ): It is component of surface texture. It is qualified by vertical deviations of real surface from its ideal form. Unit is micrometer.

Production rate: The total number of components machined in a specified time limit. It can be specified as jobs / hour or jobs / shift or jobs / day.

III. DESIGN OF EXPERIMENT

The design of experiment (D.O.E.) chosen for the special purpose machine is a Response surface methodology, by carrying out a total number of 15 experiments [5]. According to the manufacturing catalogues, range of process parameters is selected as mentioned in following table. The number of teeth for circular saw is selected as per standard.

Sr. no.	Factors	Levels	
		Low level	High level
1	Speed (rev/min)	1120	1200
2	Feed (mm/sec)	2	4
3	Teeth	90	150

Table 1: Level values of input factors

Box-Behnken Design

Factors : 3 Replicates : 1
Base runs : 15 Total runs : 15
Base blocks : 1 Total blocks : 1

Run	Speed (rev/min)	Feed (mm/sec)	Teeth
1	1120	2	120
2	1200	2	120
3	1120	4	120
4	1200	4	120
5	1120	3	90
6	1200	3	90
7	1120	3	150
8	1200	3	150
9	1160	2	90
10	1160	4	90
11	1160	2	150
12	1160	4	150
13	1160	3	120
14	1160	3	120
15	1160	3	120

Table 2: Total runs to be performed on the special purpose machine

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The above table shows the combination set generated for each single run [6-8]. These combinations are set accordingly and tests are conducted. The worker used is same individual during the total testing procedure.

IV. EXPERIMENTAL INVESTIGATION

The following image shows the designed and developed special purpose machine. Fig 1(a) shows the set up of cutting mechanism that mainly includes carbide tipped circular saw, a fixture using hydraulic clamp system for holding the job. Fig 1(b) shows the control panel used for adjusting the process parameters such as cutting speed & cutting feed. Its values are seen on the display monitor.



1(a)



1(b)

Fig 1: (a) Image of the special purpose machine (b) Image of the control panel.

V. EXPERIMENTAL RESULT

After completion of experimentation, surface roughness and production rate of 15 specimens are measured. The production rate is calculated on the basis of machining time required for a single job. Thus production rate per shift is calculated. A high precision, high accuracy surface roughness tester is used for conducting the roughness test of the components. Their results are given in the following table 3.

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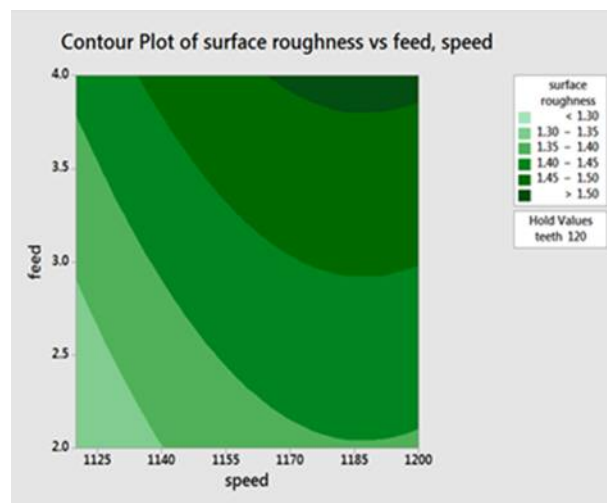
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Run	Speed (rev/min)	Feed (mm/sec)	Teeth	Surface roughness (μ)	Production rate
1	1120	2	120	1.312	855
2	1200	2	120	1.415	872
3	1120	4	120	1.391	868
4	1200	4	120	1.495	898
5	1120	3	90	1.437	868
6	1200	3	90	1.561	882
7	1120	3	150	1.269	872
8	1200	3	150	1.321	885
9	1160	2	90	1.392	868
10	1160	4	90	1.597	884
11	1160	2	150	1.325	875
12	1160	4	150	1.415	893
13	1160	3	120	1.495	888
14	1160	3	120	1.395	872
15	1160	3	120	1.425	878

Table 3: Runwise values of surface roughness and production rate

VI. ANALYSIS USING RSM

Analysis of response surface roughness: The following Fig 2(a) shows the contour plots generated for surface roughness versus speed, feed . This helps to verify the value of surface roughness obtained for corresponding values of speed & feed. Fig. 2(b) shows a graphical representation of obtained surface roughness values for a specified set of speed, feed, & number of teeth.

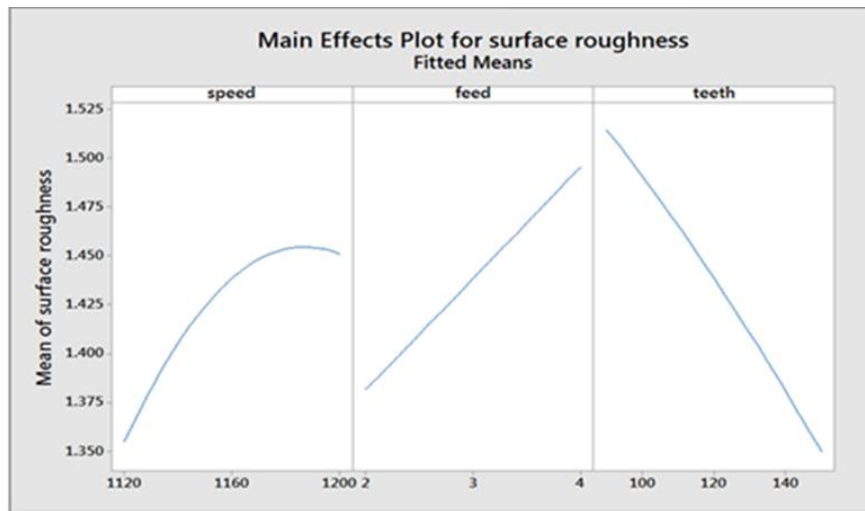


2(a)

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2(b)

Fig 2: (a) Contour plot of surface roughness (b) Main effects plot for surface roughness

The table 4 represents analysis of variation of the process parameters for surface roughness conducted through the software. It also shows the corresponding F-value & P-value which are within the permissible range.

Source	DF	Adj SS	Adj MS	F – value	P – value
Model	9	0.10730	0.01192	5.49	0.038
Linear	3	0.09805	0.03268	15.05	0.006
Speed	1	0.01833	0.01833	8.44	0.034
Feed	1	0.02576	0.02576	11.86	0.018
Teeth	1	0.05395	0.05395	24.84	0.004
Square	3	0.00464	0.00154	0.71	0.585
speed* speed	1	0.00456	0.00456	2.10	0.207
feed* feed	1	0.00000	0.00000	0.00	0.997
teeth* teeth	1	0.00014	0.00014	0.06	0.809
2-way Interaction	3	0.00460	0.00153	0.71	0.588
speed*feed	1	0.00000	0.00000	0.00	0.992
speed*teeth	1	0.00129	0.00129	0.60	0.475
feed*teeth	1	0.00330	0.00330	1.52	0.272
Error	5	0.01085	0.00217		
Lack-of-fit	3	0.00559	0.00186	0.71	0.630
Pure error	2	0.00526	0.00263		
Total	14	0.11816			

Table 4: Analysis of variation for surface roughness

The following table 5 shows the coded coefficients obtained for the surface roughness values. It formulates various combinations of the process parameters and the resulting values of the combinations are shown in the table.

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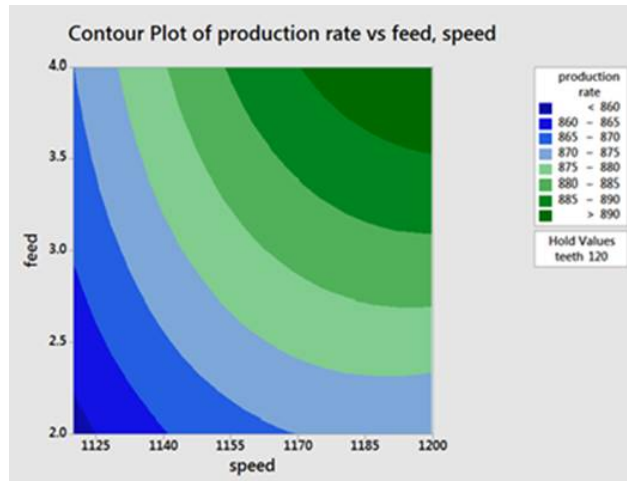
Term	Effect	Coef	SE Coef	T – value	P – value	VIF
Constant		1.4383	0.0269	53.46	0.000	
Speed	0.0958	0.0479	0.0165	2.91	0.034	1.00
Feed	0.1135	0.0568	0.0165	3.44	0.018	1.00
Teeth	-0.1642	-0.0821	0.0165	-4.98	0.004	1.00
Speed* speed	-0.0703	-0.0352	0.0243	-1.45	0.207	1.01
Feed* feed	0.0002	0.0001	0.0243	0.00	0.997	1.01
Teeth* teeth	-0.0123	-0.0062	0.0243	-0.25	0.809	1.01
Speed* feed	0.0005	0.0003	0.0233	0.01	0.992	1.00
Speed* teeth	-0.0360	-0.0180	0.0233	-0.77	0.475	1.00
Feed* teeth	-0.0575	-0.0287	0.0233	-1.23	0.272	1.00

Table 5: Coded coefficients for surface roughness.

Regression equation in uncoded units

$$\text{Surface roughness} = -31.9 + 0.0540 \text{ speed} + 0.164 \text{ feed} + 0.0192 \text{ teeth} - 0.000022 \text{ speed*speed} + 0.0001 \text{ feed*feed} - 0.000007 \text{ teeth*teeth} + 0.000006 \text{ speed*feed} - 0.000015 \text{ speed*teeth} - 0.000958 \text{ feed*teeth}$$

Analysis of response production rate: The following Fig 3(a) shows the contour plots generated for production rate versus speed, feed. . This helps to verify the value of production rate obtained for corresponding values of speed & feed. Fig. 3(b) shows a graphical representation of obtained production rate values i.e. the total number of components machined within the specified time span, for a specified set of speed, feed, & number of teeth.

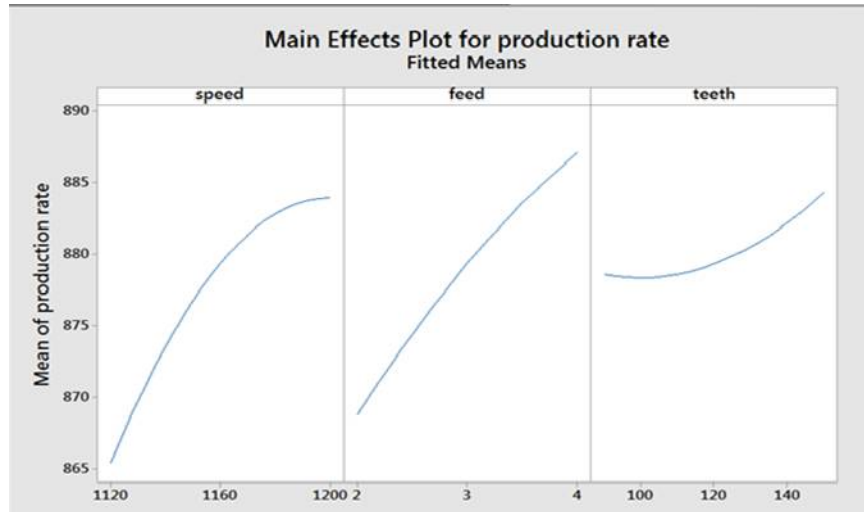


3(a)

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3(b)

Fig 3: (a) Contour plot of production rate (b) Main effects plot for production rate

The table 6 represents analysis of variation of the process parameters for production rate conducted through the software. It also shows the corresponding F-value & P-value which are within the permissible range.

Source	DF	Adj SS	Adj MS	F – value	P – value
Model	9	1568.48	174.276	4.49	0.056
Linear	3	1416.75	472.250	12.1	0.01
Speed	1	684.50	684.500	17.6	0.00
Feed	1	666.13	666.125	17.1	0.00
Teeth	1	66.13	66.125	1.70	0.24
Square	3	108.23	36.078	0.93	0.49
speed* speed	1	80.41	80.410	2.07	0.20
feed* feed	1	7.41	7.410	0.19	0.68
teeth* teeth	1	16.03	16.026	0.41	0.54
2-way Interaction	3	43.50	14.500	0.37	0.77
speed* feed	1	42.25	42.250	1.09	0.34
speed* teeth	1	0.25	0.250	0.01	0.93
feed* teeth	1	1.00	1.000	0.03	0.87
Error	5	193.92	38.783		
Lack-of-fit	3	63.25	21.083	0.32	0.81
Pure error	2	130.67	65.333		
Total	14	1762.4			

Table 6: Analysis of variation for production rate

The following table 7 shows the coded coefficients obtained for the production rate values. It formulates various combinations of the process parameters and the resulting values of the combinations are shown in the table.

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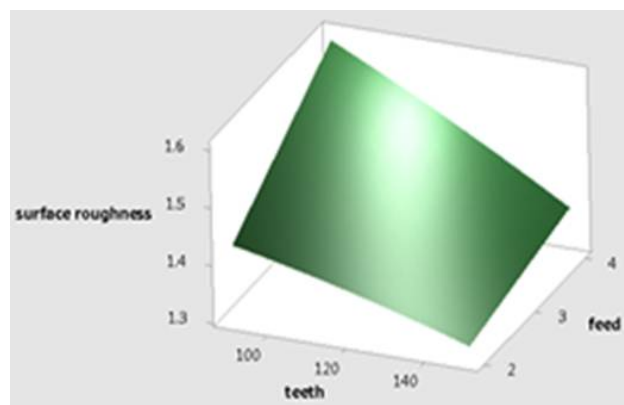
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Term	Effect	Coef	SE Coef	T – value	P – value	VIF
Const-ant		879	3.6	244	0.00	
Speed	18.5	9.25	2.2	4.20	0.008	1.0
Feed	18.2	9.13	2.2	4.14	0.009	1.0
Teeth	5.75	2.88	2.2	1.31	0.248	1.0
Speed*speed	-9.33	-4.67	3.2	-1.44	0.209	1.0
Feed* feed	-2.83	-1.42	3.2	-0.44	0.680	1.0
Teeth* teeth	4.17	2.08	3.2	0.64	0.549	1.0
Speed* feed	6.50	3.25	3.1	1.04	0.344	1.0
Speed* teeth	-0.50	-0.25	3.1	-0.08	0.939	1.0
Feed* teeth	-0.0575	0.50	3.1	0.16	0.879	1.0

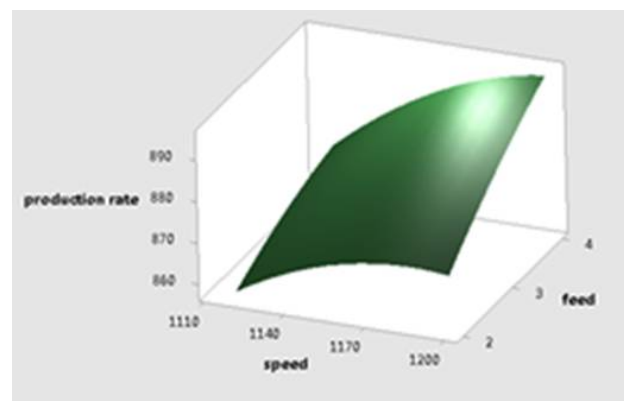
Table 7: Coded coefficients for production rate.

Regression equation in uncoded units

$$\text{Production rate} = -3072 + 6.78 \text{ speed} - 78.6 \text{ feed} - 0.27 \text{ teeth} - 0.00292 \text{ speed*speed} - 1.42 \text{ feed*feed} + 0.00231 \text{ teeth*teeth} + 0.0812 \text{ speed*feed} - 0.00021 \text{ speed*teeth} + 0.017 \text{ feed*teeth}$$



4(a)



4(b)

Fig.4 (a) Surface plots for surface roughness (b) Surface plots for production rate

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The above Fig 4 (a) represent the surface curve generated for various values of surface roughness with respect to the different combinations of the process parameters whereas Fig 4 (b) represent the surface curve generated for various values of production rate with respect to the different combinations of the process parameters. Through this graph, set of process parameters can be selected for desired values of surface roughness and production rate.

VII. OPTIMIZATION USING RESPONSE SURFACE METHODOLOGY

The following figure shows optimum parameters set of speed, feed and number of teeth which give relevant response values of surface roughness and production rate. This graph shows the predicted values for low, medium and high values of surface roughness and production rate. It focuses on the overall effect of the process parameters on each output parameters. The highlighted lines and values shows the values of speed, feed and number of teeth required for obtaining optimum values of surface roughness and production rate.

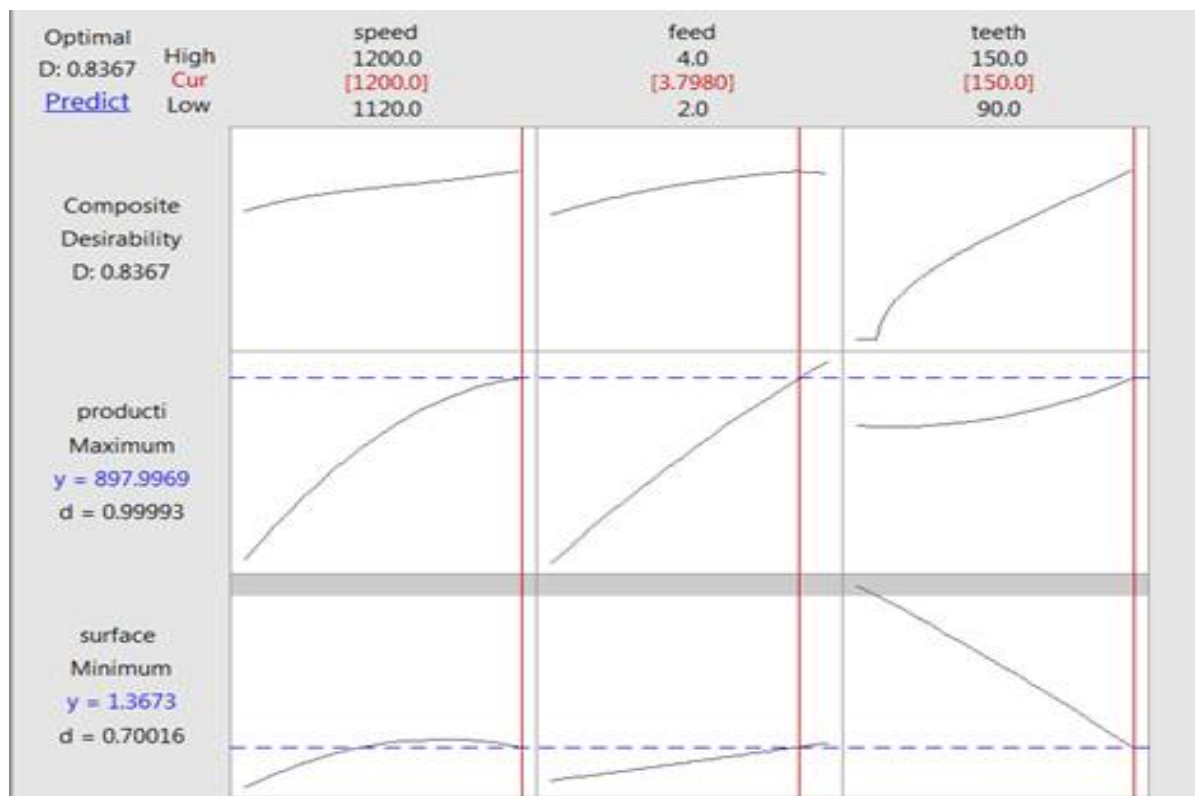


Fig.5: Multi Optimization plot using RSM

VIII. CONCLUSION

The special purpose machine is built with the objective to increase the productivity. Although productivity is governed by many parameters, here we have concentrated on certain parameters as speed, feed and number of teeth on circular saw.

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The following conclusions can be drawn ,

- 1.As the cutting speed increases from 1120 rpm to about approximately 1180 rpm, the surface roughness increases gradually from points 1.350 to 1.450. After 1180 rpm, the surface roughness becomes steady and eventually decreases then after.
- 2.As the feed increases, the surface roughness goes on increasing gradually.
- 3.As the number of teeth goes on increasing, the surface roughness is highly affected. For maximum number of teeth on circular saw, the surface roughness obtained is minimum.
- 4.As the speed increases, the production rate also increases. After the speed of 1180 rpm, the production rate remains steady up to a certain limit.
- 5.As the feed increases, the production rate increases gradually. For maximum feed, maximum production rate is obtained and vice versa.
- 6.The number of teeth on circular saw from 120 to 140 help to increase the production rate.

Thus the solution is as,

The following multi optimization result table shows the final values of the process parameters to achieve minimum surface roughness and maximum production rate.

Input parameters			Output parameters	
Speed (rev/ min)	Feed (mm/ sec)	No. of Teeth	Surface roughness (μ)	Production rate (components / shift)
1200	3.798	150	1.36	898

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