Determining Optimal Parameters for Surface Roughness of Cylinder Liners During Honing Process by Taguchi Methodology – A Case Study

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Abstract - Honing is an abrasive machining process that produces a precision surface on a metal workpiece by scrubbing an abrasivestone against it along a controlled path. Honing is primarily used to improve the geometric form of a surface, but may also improve the surface texture. Typical applications are the finishing of cylinders for internal combustion engines, air bearing spindles and gears. In this present work we studied about the honing process used in the manufacturing of cylinder liners at Kusalava Internation ltd., Agiripalli and identified the various factors affecting the surface roughness of a cylinder liner during the process. By applying Taguchi methodology we determined the optimal parameters for obtaining a good surface finish for cylinder liners bore surface.

Key words: Honing, Taguchi methodology.

I. INTRODUCTION

Honing is a finishing process, in which a tool called hone carries out a combined rotary and reciprocating motion while the workpiece does not perform any working motion. Most honing is done on internal cylindrical surface, such as automobile cylindrical walls. The honing stones are held against the workpiece with controlled light pressure. The honing head is not guided externally but, instead, floats in the hole, being guided by the work surface. It is desired that Honing stones should not leave the work surface and Stroke length must cover the entire work length.

The honing stones are given a complex motion so as to prevent every single grit from repeating its path over the work surface. The critical process parameters are . Rotation speed, Oscillation speed, Length and position of the stroke and Honing stick pressure.

II. IMPORTANCE OF SURFACE FINISH

Cylinder liners are among the most critical engine components when it comes to oil consumption and frictional losses. Researchers have estimated that as much as 40% of the frictional losses in an engine arise from the friction between the cylinder liner and the piston ring. Therefore, high demands are set on the surface finish of the liner.

III. NOMENCLATURE OF SURFACE ROUGHNESS

In order to produce cylinder liners for engines with high demands regarding emissions and fuel consumption, the surface need to be characterized. There are multiple surface parameters that can be used to define the surface. Some of the most frequently used are the mean parameters. The most common one is the average roughness, Ra. This is, as the name states, an average of the surface roughness over the sample length.

$$Ra = \frac{1}{l}\int_0^l \left|Z(x)\right| dx \quad (1)$$

Where (x) is the distance between the profile curve and the mean line and l the sample length. Another parameter that is widely used in the industry is the *Rq* or RMS parameter. This is the root mean square of the surface roughness over the sample length and is calculated according to Equation

$$Rq = \frac{1}{l}\int_0^l \left|Z^2(x)\right| dx \quad (2)$$

- **Core roughness depth (R_k):** Depth of roughness core profile.
- **Material portion (*Mr1*):** Material portion, a level in percent (%), determined from the intersection line that separates the protruding peaks from the roughness core profile.
- **Material portion (*Mr2)*:** Material portion, a level in percent (%), determined for the intersection line that separates the deep valleys from the roughness core profile.
- **Reduced peak height (*Rpk)*:** Average height of the protruding peaks above the roughness core profile
- **Reduced valley depths (*Rvk)*:** Average depth of the profile valleys projecting through the roughness core profile.
- **Roughness average (*Ra*):** The mean roughness is the arithmetic average of the absolute values of the roughness profile ordinates.
- **Mean roughness depth (Rz):** The mean roughness depth is the arithmetic mean value of the single roughness depth of consecutive sampling lengths
- **Maximum roughness (Rmax):** The maximum roughness depth is the largest single roughness depth within the evaluation length

IV. TAGUCHI METHODOLOGY

Genichi Taguchi has been identified with the advent of what has come to be termed quality engineering. The goal of quality engineering is to move quality improvement efforts upstream from the production phase to the product/process design stage.

Steps Involved in Taguchi Method

The use of Taguchi's parameter design involves the following steps

- Identify the main function and its side effects.
- Identify the noise factors, testing condition and quality characteristics.
- Identify the objective function to be optimized.
- Identify the control factors and their levels.
- Select a suitable Orthogonal Array and construct the Matrix
- Conduct the Matrix experiment.
- Examine the data; predict the optimum control factor levels and its performance.
- Conduct the verification experiment.

Signal to Noise Ratios

- In the parameter design stage Taguchi makes use of designed experiments and signal to noise ratios to determine the optimal parameter settings. The signal to noise ratios are derived from the Taguchi loss function. While Taguchi has proposed a large number of signal to noise ratios in which three are the most widely used.

Nominal is Best : $SN_N = 10\log\left(\frac{y^{-2}}{s^2}\right)$ **Larger is Better :** $SN_L = 10\log\left(\frac{\sum_{i=1}^{n} 1/y_i^2}{n}\right)$

Smaller is Better : $SN_S = 10\log\left(\frac{\sum_{i=1}^{n} y_i^2}{n}\right)$

V. CASE STUDY

Identify the main function and its side effects

Main function:Honing Operation on Cylinder Liner using Honing machine.

Side effects: Variation in surface finish.

Identify the noise factors, testing condition and quality characteristics

The “Factors” that affect honing operation on a machine are listed in the table below.

Control parameters	Noise parameters
Cutting Speed	Vibration
Load	Raw material variation
Number of strokes	Machine condition
Noise radius	Temperature
Coolant	Operator skill

Table-1

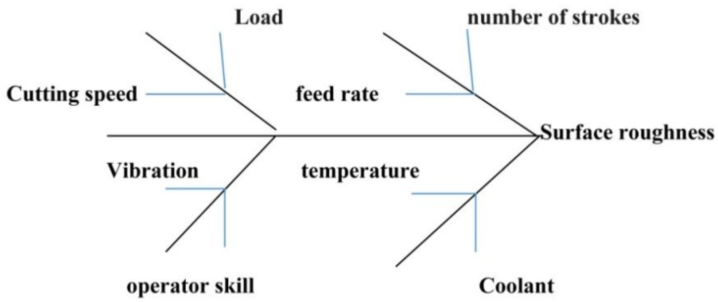


Fig.1 : Fish bone diagram representing the control and noise factors

Identify the objective function to be optimized

Objective Function: Smaller-the-Better

S/N Ratio for this function: $\eta = -10 \log_{10}(1/n \sum y_i^2)$

Where, n= Sample Size, and y= Surface Roughness in that run.

Identify the control factors and their levels

The factors and their levels were decided for conducting the experiment, based on a “brain storming session” that was held with a group of people and also considering the guide lines given in the operator’s manual provided by the manufacturer of the lathe machine. The factors and their levels are shown in table below.

FACTORS	LEVELS		
Cutting speed(rpm)	115	125	140
Load for finish(kg/sq.cm)	12	15	17
Number of strokes(stroke/piece)	7	10	12

Table-2 : Table with Selected Factors and their Levels

Select a suitable Orthogonal Array and construct the Matrix

If we consider three factors and three levels we should take L9 array as mentioned in Orthogonal array table below.

Test case	Parameter1	Parameter2	Parameter3
1	1	1	3
2	1	2	2
3	1	3	1
4	2	1	2
5	2	2	1
6	2	3	3
7	3	1	1
8	3	2	3
9	3	3	2

Table-3: L9 orthogonal array

VI. CONDUCTING THE MATRIX EXPERIMENT

In accordance with the above, experiments were conducted with their factors and their levels as mentioned in table. The experimental layout with the selected values of the factors is shown in Table. Each of the above 9 experiments were conducted 3 times (27 experiments in all) to account for the variations that may occur due to the noise factors. The surface roughness was measured using the surface roughness tester. The tables shows the measured values of surface roughness obtained from different experiments.

Experiment Number	Control Factors		
	Cutting Speed(rpm)	Load for Finish(kg/sq.cm)	No of Strokes(stroke/piece)
1	115	12	7
2	115	15	10
3	115	17	7
4	125	12	10
5	125	15	7
6	125	17	12
7	140	12	7
8	140	15	12
9	140	17	10

Table-4

EXP NO	PARA METER	TRAIL 1	TRAIL 2	TRAIL 3	MEAN
1	**Ra**	0.4375	0.5662	0.3873	0.4636
	Rz	3.89	4.27	3.66	3.94
	Rmax	6.22	5.94	5.22	5.79
	Rk	0.811	1.093	1.041	0.981
	Rpk	0.2811	0.2522	0.3182	0.2838
	Rvk	1.64	1.83	1.55	1.67
	Mr1	7.4	5.83	7.23	6.82
	Mr2	78.9	75.7	79.6	78.06

EXP NO	PARA METER	TRAIL 1	TRAIL 2	TRAIL 3	MEAN
2	**Ra**	0.5133	0.5945	0.4801	0.5293
	Rz	3.97	4.69	4.08	4.25
	Rmax	6.49	6.36	6	6.28
	Rk	0.729	1.328	0.754	0.937
	Rpk	0.2530	0.3350	0.323	0.2736
	Rvk	1.49	2.00	1.68	1.72
	Mr1	7.87	6.21	7.06	7.04
	Mr2	81.9	78.6	78.4	79.6

EXP NO	PARA METER	TRAIL 1	TRAIL 2	TRAIL 3	MEAN
3	**Ra**	0.4166	0.3456	0.3850	0.3824
	Rz	3.86	3.48	3.56	3.63
	Rmax	5.28	5.03	5.20	5.17
	Rk	0.927	0.766	0.759	0.817
	Rpk	0.2645	0.2213	0.2118	0.2325
	Rvk	1.56	1.35	1.11	1.34
	Mr1	6.98	6.88	6.63	6.83
	Mr2	79.2	80.9	81.1	80.4

EXP NO	PARA METER	TRAIL 1	TRAIL 2	TRAIL 3	MEAN
4	**Ra**	0.4413	0.5325	0.4847	0.4861
	Rz	4.09	4.85	4.11	4.35
	Rmax	6.37	7.36	6.48	6.73
	Rk	1.446	0.996	1.32	1.25
	Rpk	0.407	0.313	0.337	0.352
	Rvk	1.84	2	10.9	1.91
	Mr1	7.11	6.91	6.24	6.75
	Mr2	80.5	78.3	79.08	79.29

EXP NO	PARA METER	TRAIL 1	TRAIL 2	TRAIL 3	MEAN
5	**Ra**	0.4675	0.5245	0.5841	0.5253
	Rz	4.41	4.59	5.34	4.79
	Rmax	7.40	6.22	7.78	7.12
	Rk	0.9296	0.686	0.704	0.772
	Rpk	0.269	0.36	0.38	0.336
	Rvk	1.7	1.8	2.12	1.87
	Mr1	7.07	6.53	6.42	6.88
	Mr2	78.7	79.86	78.52	78.02

EXP NO	PARA METER	TRAIL 1	TRAIL 2	TRAIL 3	MEAN
6	**Ra**	0.5321	0.4706	0.4422	0.4483
	Rz	4.19	6.38	4.22	4.93
	Rmax	5.20	5.63	6.74	5.85
	Rk	0.773	0.992	0.694	0.819
	Rpk	0.227	0.424	0.295	0.315
	Rvk	1.70	1.43	1.89	1.67
	Mr1	6.41	7.02	7.03	6.82
	Mr2	79.86	77.07	77.87	78.26

EXP NO	PARA METER	TRAIL 1	TRAIL 2	TRAIL 3	MEAN
7	**Ra**	0.4501	0.3638	0.4793	0.4310
	Rz	4.91	4.50	3.58	4.33
	Rmax	10.18	7.70	6.38	8.08
	Rk	0.895	1.181	0.832	0.969
	Rpk	0.344	0.357	0.272	0.324
	Rvk	1.71	1.68	1.36	1.58
	Mr1	7.79	7.96	6.58	7.41
	Mr2	79.51	78.56	81.07	79.79

EXP NO	PARA METER	TRAIL 1	TRAIL 2	TRAIL 3	MEAN
8	**Ra**	0.4375	0.5945	0.3873	0.4731
	Rz	4.91	4.41	4.09	4.47
	Rmax	6.22	6.49	5.28	5.99
	Rk	0.737	0.686	0.740	0.721
	Rpk	0.225	0.300	0.289	0.271
	Rvk	1.70	1.89	2.00	1.86
	Mr1	8.81	6.20	8.89	7.96
	Mr2	79.36	80.40	80.10	79.95

EXP NO	PARAMETER	TRAIL 1	TRAIL 2	TRAIL 3	MEAN

9	**Ra**	0.4166	0.5325	0.3850	0.4447
	Rz	6.38	4.59	4.85	5.27
	Rmax	5.49	6.00	5.03	5.50
	Rk	1.110	0.874	0.825	0.936
	Rpk	0.301	0.352	0.256	0.303
	Rvk	1.65	1.30	1.62	1.52
	Mr1	7.39	5.83	6.76	6.66
	Mr2	76.80	80.46	77.17	78.14

Tables-5: Measured values of surface Roughness by Experimentations

Examination of Data of Ra

The following are the experimental results of the work carried out.

Experimental Details

Since the objective function (Surface Finish) is smaller-the-better type of control function, was used in calculating the S/N ratio. S/N Ratio for this function : $\eta = -10 \log_{10}(1/n \sum y_i^2)$
The S/N ratios of all the experiments were calculated and tabulated as shown in Table

Exp No.	1	2	3	4	5	6	7	8	9
S/N Ratio	6.562	5.49	8.324	6.238	5.555	6.319	7.254	6.3523	6.951

Table-6

The S/N ratio for the individual control factors are calculated as given below:

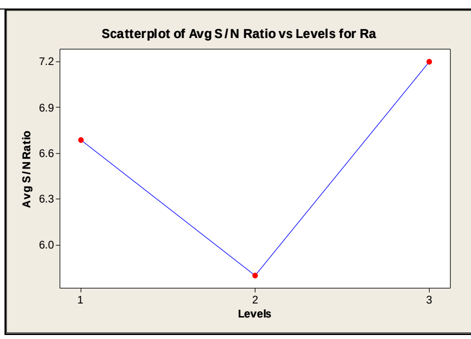
$S_{s1} = \eta_1 + \eta_2 + \eta_3$ $S_{L1} = \eta_1 + \eta_4 + \eta_7$ $S_{N1} = \eta_1 + \eta_5 + \eta_9$
$S_{s2} = \eta_7 + \eta_8 + \eta_9$ $S_{L2} = \eta_2 + \eta_5 + \eta_8$ $S_{N2} = \eta_2 + \eta_6 + \eta_7$
$S_{s3} = \eta_7 + \eta_8 + \eta_9$ $S_{L3} = \eta_3 + \eta_6 + \eta_7$ $S_{N3} = \eta_3 + \eta_4 + \eta_8$
For selecting the values of η_1, η2, η3 etc. and to calculate Ss1, Ss2 & Ss3 see table.
ηk is the S/N ratio corresponding to Experiment k.

- Average S/N ratio corresponding to Cutting Speed at level 1 = Ss1/3
- Average S/N ratio corresponding to Cutting Speed at level 2 = Ss2/3
- Average S/N ratio corresponding to Cutting Speed at level 3 = Ss3/3

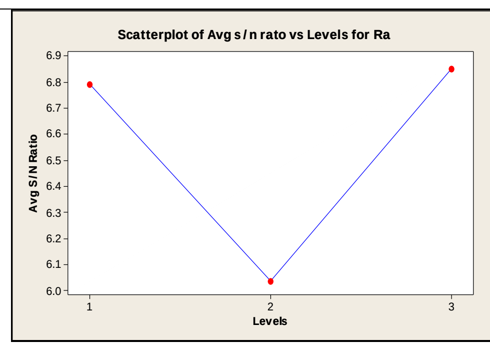
j is the corresponding level each factor. Similarly Sfj and Stj are calculated for feed and depth of cut. The average of the signal to noise ratios is shown in table. Similarly S/N ratios can be calculated for other factors.

Level Ra	**Cutting Speed**		**Load for Finish**		**No of Strokes**	
	Sum (Ss)	Avg S/Nratio	Sum(Sl)	Avg S/Nratio	Sum(Sn)	Avg S/Nratio
1	20.376	6.792	20.054	6.684	19.068	6.356
2	18.112	6.037	17.397	5.799	19.063	6.354
3	20.557	6.852	21.594	7.918	20.914	6.971

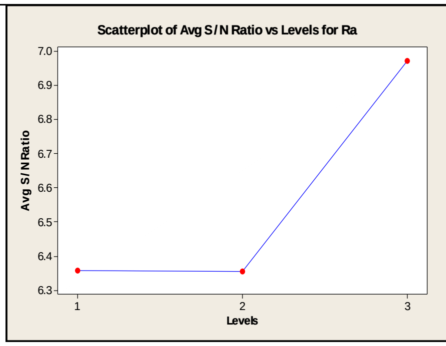
Table-7



Cutting Speed



Load for Finish



No of Strokes

From the graph we found that the control factor cutting speed is optimum at level-2, parameter load for finish is optimum at level-2 and the parameter number of strokes is optimum at level-2, which is represented in the table below.

Fig.2 : Graphical representation of Avg S/N ratio vs Parameter Levels

Optimum values of factors and their corresponding levels

Factors	Optimum Value
Cutting Speed(rpm)	125
Load for Finish(kg/sq.cm)	15
No of Strokes(stroke/piece)	10

Table-8

Examination of Data of Rk

The following are the experimental results of the work carried out.

Experimental Details

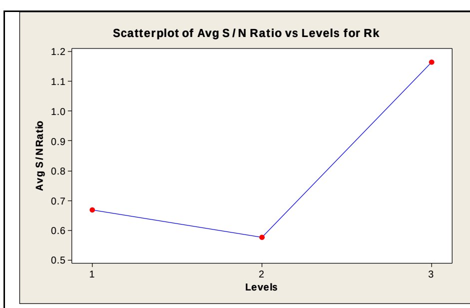
Since the objective function (Surface Finish) is smaller-the-better type of control function, was used in calculating the S/N ratio. S/N Ratio for this function : $\eta = -10 \log_{10}(1/n\sum y_i^2)$
The S/N ratios of all the experiments were calculated and tabulated as shown in Table

Exp No.	1	2	3	4	5	6	7	8	9
S/N Ratio	0.093	0.202	1.713	-2.064	2.162	1.626	0.165	2.836	0.495

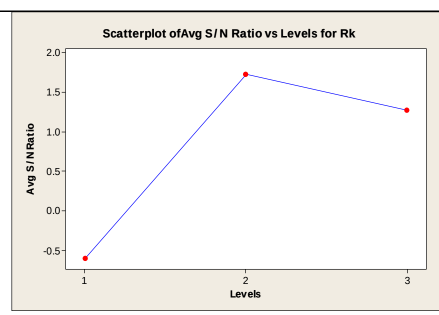
Table-9

Level Rk	Cutting Speed		Load for Finish		No of Strokes	
	Sum (Ss)	Avg S/Nratio	Sum(Sl)	Avg S/Nratio	Sum(Sn)	Avg S/Nratio
1	2.008	0.669	-1.806	-0.602	2.75	0.917
2	1.724	0.575	5.2	1.733	1.993	0.664
3	3.496	1.165	3.83	1.27	2.48	0.82

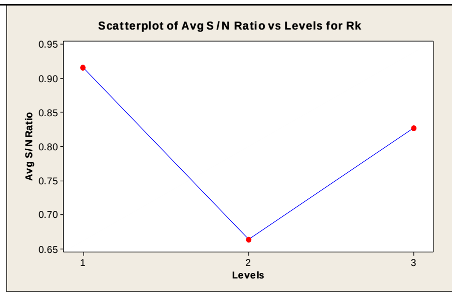
Table-10: Average of the signal to noise ratios



Cutting Speed



Load for Finish



No of strokes

From the graph we found that the control factor cutting speed is optimum at level-2, parameter load for finish is optimum at level-1 and the parameter number of strokes is optimum at level-2, which is represented in the table below.

Fig.3: Graphical representation of Avg S/N ratio vs Parameter Levels

Optimum values of factors and their levels

Parameter	Optimum Value
Cutting Speed(rpm)	125
Load for Finish(kg/sq.cm)	12
No of Strokes(strokes/piece)	10

Table-11

Examination of Data of RPk

The following are the experimental results of the work carried out.

Experimental Details

Since the objective function (Surface Finish) is smaller-the-better type of control function, was used in calculating the S/N ratio. S/N Ratio for this function : $\eta = -10 \log_{10}(1/n\sum y_i^2)$

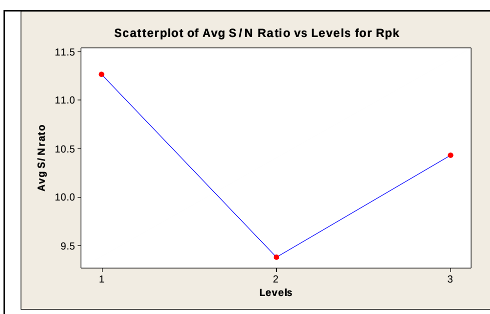
The S/N ratios of all the experiments were calculated and tabulated as shown in Table

Exp No.	1	2	3	4	5	6	7	8	9
S/N Ratio	10.899	10.291	12.628	9.005	9.376	9.742	9.723	11.266	10.299

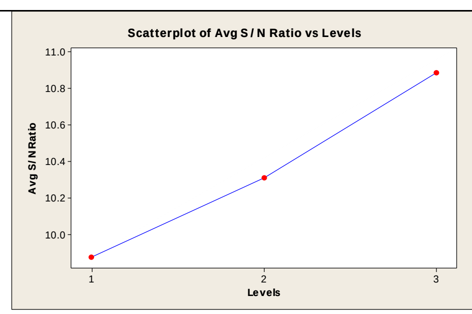
Table-12

Level Rpk	Cutting Speed		Load for Finish		No of Strokes	
	Sum (Ss)	Avg S/Nratio	Sum(Sl)	Avg S/Nratio	Sum(Sn)	Avg S/Nratio
1	33.81	11.27	29.62	9.87	30.57	10.19
2	28.12	9.37	30.93	10.31	29.75	9.91
3	31.28	10.42	32.66	10.88	32.9	10.96

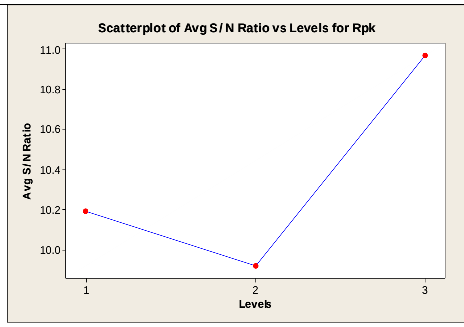
Table-13: The average of the signal to noise ratios



Cutting Speed



Load for Finish



No of Strokes

From the graph we found that the control factor cutting speed is optimum at level-2, parameter load for finish is optimum at level-1 and the parameter number of strokes is optimum at level-2, which is represented in the table below.

Fig.4: Graphical representation of Avg S/N ratio vs Parameter Levels

Optimum values of factors and their levels

Parameter	Optimum Value
Cutting Speed(rpm)	125
Load for Finish(kg/sq.cm)	12
No of Strokes(strokes/piece)	10

Table-14

VII. RESULTS & DISCUSSIONS

In the present work nine experiments each three trails were carried out and optimal parameters for the eight surface roughness characteristics were determined separately. from the above calculations and their corresponding graphs we observed that most of them are indicating level II for cutting speed, level I for load for finish and level II for no of strokes which are indicated in the below table.

Optimum values of factors and their levels

Parameter	Optimum Value
Cutting Speed(rpm)	125
Load for Finish(kg/sq.cm)	12
No of Strokes(strokes/piece)	10

Table-15

CONFIRMATION TRAIL/VERIFICATION EXPERIMENTATION

EXP	PARAMETER	TRAIL 1	TRAIL 2	TRAIL 3	MEAN
	Ra	0.4166	0.3456	0.3850	0.3824
	Rz	3.86	3.48	3.56	3.63
	Rmax	5.28	5.03	5.20	5.17
	Rk	0.927	0.766	0.759	0.817
	Rpk	0.2645	0.2213	0.2118	0.2325
	Rvk	1.56	1.35	1.11	1.34
	Mr1	6.98	6.88	6.63	6.83
	Mr2	79.2	80.9	81.1	80.4

Table-16: Measured Surface Roughness Values

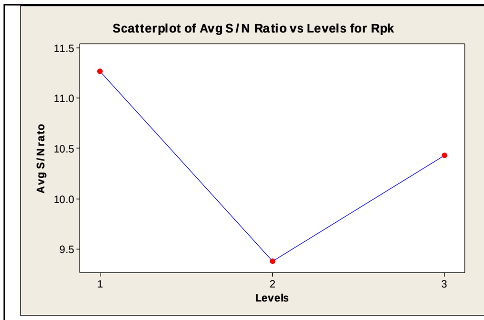
Exp No.	1	2	3	4	5	6	7	8	9
S/N Ratio	10.899	10.291	12.628	9.005	9.376	9.742	9.723	11.266	10.299

Table-17: The S/N ratios of all the experiments were calculated and tabulated

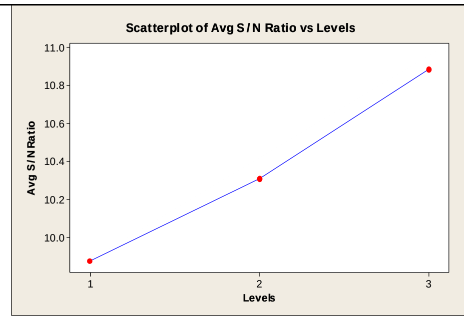
Level	**Cutting Speed**		**Load for Finish**		**No of Strokes**	
	Sum (Ss)	Avg S/Nratio	Sum(Sl)	Avg S/Nratio	Sum(Sn)	Avg S/Nratio
1	33.81	11.27	29.62	9.87	30.57	10.19
2	28.12	9.37	30.93	10.31	29.75	9.91

3	31.28	10.42	32.66	10.88	32.9	10.96

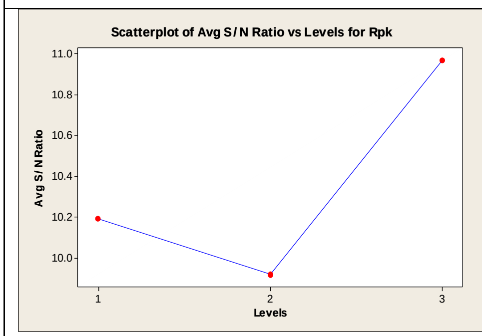
Table-18: The average of the signal to noise ratios



Cutting Speed



Load for Finish



No of Strokes

For calculating the Surface Roughness the objective function, "smaller-the-better" type was used as shown.

$$\eta = -10 \log_{10}(1/n\sum y_i^2)$$

The factor levels corresponding to the highest S/N ratio were chosen to optimize the condition. From these linear graphs it is clear that the optimum values of the factors and their levels are as given in table below.

Fig.5: Graphical representation of Avg S/N ratio vs Parameter Levels:

Optimum values of factors and their levels

Parameter	Optimum Value
Cutting Speed(rpm)	125
Load for Finish(kg/sq.cm)	12
No of Strokes(strokes/piece)	10

Table-19

Hence verification experiment has been done successfully.

VIII. CONCLUSION

In the present work nine experiments each three trails were carried out and optimal parameters for the eight surface roughness characteristics were determined separately. But due to space limitation only few important characteristics and their respective calculations are presented in this paper. From the above calculations and their corresponding graphs we observed that most of them are indicating level II for cutting speed, level I for load for finish and level II for no of strokes which are indicated in the above table.

Employing design of experiments, are important statistical tools for designing high quality systems at reduced cost. Statistical design of experiments is a procedure that allows quick, economical, and accurate evaluation of processes and products that depend upon several variables. It is found that the parameter design of the Taguchi method provides a simple, systematic, and efficient methodology for optimizing the process parameters.

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