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R_a Modelling & Optimization of Honda Bike Cylinder Liner in Honing using RSM & RMSE Technique

[A.] Mr. B.N.Tripathi, [B.] Dr. N.K. Singh, [C.] Dr. U.K.Vates

[A.] Mr. B.N.Tripathi is Research Scholar, Deptt. of Mech. Engg., ISM Dhanbad India; braj.tripathi96@gmail.com
[B.] Dr. N.K. Singh is Associate Professor (Workshop) Deptt. of Mech. Engg, ISM Dhanbad India; nks_221@yahoo.co.in
[C.] Dr. U.K.Vates is Associate Professor and Head, Deptt. of Mech. Engg, AIMT, G.Noida, u.k.vates@gmail.com

Abstract

Attempt has been made to optimize surface roughness (R_a) of SCM 420H steel in honing process. `Taguchi Orthogonal Array L27(3**5)` Design of Experiment has been used at three levels having five input variables to conducting the experiment. The suitable surface finish influencing parameters were selected on the basis of available literature of distinguish researchers. Second order response surface methodology (RSM) approach have been applied to develop a suitable model with honing process having five input and single out put parameters (R_a). The effect of input parameters has been analyzed using Analysis of Variance (ANOVA). The RSM modelling for the honing process able to give significant correlation coefficient (R^2) is 99.38 % and adjusted correlation coefficient $(R_{adj})^2$ is 99.4 %. The minimum surface roughness has been found by optimal parametric combinations using root mean square error (RMSE) approach.

Keywords: Honing Process, R_a, SCM 420H steel, RSM, ANOVA and RMSE.

1. INTRODUCTION

Honing is an important fine finishing operation, often used for internal cylindrical surfaces such as gun barrels, hydraulic cylinders, bearings and engine cylinder bores (Armerego and Brown, 1969). Excess material is removed by means of slow moving abrasive sticks pressed against the surface to be machined. Two kinds of motion, namely rotational and reciprocating, are imparted by the honing machine to the hone (or honing tool) carrying the abrasive sticks. Honing is a fine finishing operation, designed to remove surface flaws such as indentations, tapering, out-of-roundness and bowing etc. Therefore not much material is removed from the component. The machining depth is limited to just a few microns. Suitable cutting fluids (coolants) are used during the honing process to limit thermal distortion of the workpiece to be minimum. The chips produced during honing are larger than those during grinding because the abrasive grains are in contact with the workpiece over the major portion of the stroke. The cutting speed and feed have to be carefully selected to ensure self dressing action on the abrasive sticks and to avoid their glazing. Surface quality is crucial to the performance of mating parts which have to move relative to each other during service conditions. Examples of such components include connecting rods, piston pins, shafts, bearings and engine cylinders. The automobile industry alone needs such components in ever increasing numbers. Traditionally centre line average or R_a has been the commonly used measure of surface quality. However recent studies have shown that specification of a single R_a value is inadequate to completely characterize the complex surface roughness profile, especially when questions such as contact area, contact mechanics, lubricant retention and wear become important (Malburg and Raja, 1993). Many attempts that have been made to develop a variety of techniques for surface finishing through diverse machining processes and many attempts at modelling the processes and optimizing the process parameters. Wang and Chang (2004) analysed the effect of cutting conditions and tool geometry on surface roughness by regression analysis. An end mill was used as the cutting tool during slitting. The parameters considered as significant were the cutting speed, feed, depth of cut, concavity and axial relief angles of the end cutting edge. Surface roughness models were built using response surface methodology and experimental results. Rumelhart, Hilton and Williams (1986) reported the development of a back propagation algorithm. This method propagates the error information at the output units back to the hidden units using a generalized delta rule. This net is basically a multi-layer, feed-forward net trained by means of back-propagation. Backpropagation net emerged as the most popular learning algorithm for the training of multi-layer perceptron and has been the workhorse for many neural network applications, but ANN technique not widely used for the honing application on surface finish is concern. Kwak et al. (2005) analysed the power expenditure and the surface roughness of the workpiece during external cylindrical grinding of a hardened steel part using response surface methodology. A grinding wheel of diameter 320 mm and width 38 mm was used for conducting experiments on chrome-molybdenum steel which was heat-treated to R_c 60. The factors considered as affecting the power output and surface finish included rotational speed of the workpiece (rpm), depth of cut (µm), and the traverse speed (m/min). Response surface methodology is being concluded as the best suited modelling tool applicable for the honing of cylinder liner.

The surface finishes analysis also the big issue in the process optimization in honing. Benardo and Vosniako (2003) reviewed the prediction of surface roughness in machining processes. They discussed the different methodologies and strategies usually adopted to predict the surface roughness in different machining processes. Their study was based on four categories. First category employed the machining theory to develop analytical models and computer algorithms to represent the machined surface. Second category was based on an approach that examined the effects of various factors through the execution of experiments and analysis of their results. In third category, they discussed approaches that are used for design of experiments. The last and fourth category was based on artificial intelligence approach. Among the different techniques used to surface finish measurements, Atomic Force Microscopy (AFM) is one of the best suitable instrument through which very précised values of surface finish is calculated. The concept of honing process is illustrated in Fig.1.

Fig.1: Typical honing head (De Garmo et al., 1997)

NOMENCLATURE:

HP – *Honing of cylinder liner*
RSM – *Response surface methodology*
F – *Feed*
V – *Speed*
Gs – *Grit Size*
Gn – *Grit Number*
Fn – *Forces*
T – *Temperature*
τ – *Duty Cycle*
T_M – *Machining Time*
R_a – *Surface Roughness*
MRR – *Material Removal Rate*
MSE – *Mean Square Error*

Taguchi Orthogonal Array Design L27 (3**5) is used to conducting the trial experiment on SCM 420 steel cylinder liner during honing. Due to its robustness only L 27 experimental data are suitable to give the conclusion over analysis. Second order RSM hypothetical technique has been used to generate two distinguishes models. Second order RSM has been used for surface finish modelling where independent process variables are Fluid Pressure, Grit size Hone angle, circumferential speed, and Stone and side contact pressure..

The optimum process parameters are essential to achieve better surface finish with adequate material removal rate (MRR). A lot of research techniques have been reported for response optimization but present work uses sum of root mean square error (SRMSE) approach and achieves improvement approx more than 21% in surface smoothness under honing process.

2. EXPERIMENTAL SETUP

2.1 Selection of parameters and work piece materials:

In the present investigation, the honing experiments were conducted on cylinder liner used in the Hero motor corp. SCM 420H steel is used as the material of construction of the cylinder liner.. Work piece material was normalized and shot blasted and its chemical composition of is given in Table 1

The experiments were run on a CNC operated Honing machine, model HONSD,SL NO-210, (F:08:0023:02) having the facilities to hold the work piece within the place provided by the help of fixture. Present experiments are aimed at considering significant effects of several controllable and independent parameters on surface roughness of SCM 420H steel during honing. The requirement of surface finish and rate of material removal are the key factors while selecting a particular grit size. Coarse grits remove high stock of material and are suitable for rough honing (Goetze and Burscheid, 1993). Table 2 shows the relationship between grit number and grit particle size (Boothryod and Knight, 1989). Apart from controllable and independent variables as mentioned inTable.3, there are many parameters which are kept constant. Experiments were carried out randomly using suitable table 5, so that repetitions of the runs were not done throughout. Atomic Force Microscopy (AFM) as Fig 3, used for surface finish measurement.

Table 1: chemical composition of SCM 420H steel

Ingredient	*C*	*Si*	*Mn*	*S*	*P*	*Cr*	*Mo*
Composition	.18-.22	.25-.35	.60-.90	.01-.03	.01-.03	.85-1.20	.14-.32

Table 2: Grit size (µm) and corresponding grit numbers

Grit no.	36	54	80	120	220	320	400	500	600
Size (µm)	710	430	266	142	66	32	23	16	8

Table 3: DOE-factors and its level

Factors/Three Levels(Coding)	**1**	**2**	**3**
Fluid Pressure, P_F (bar)	3	6	9
Grit size, Gs, (µm)	38	53	68
Hone Angle, θ_H (Degree)	10	60	110
Circumferential speed, V_S: (m/min)	35	40	45
Stone and side contact pressure, P_S (N/mm2)	10	30	50

Table 4: Constant Factors during Honing

Factors	Constant values (coded)
Jog Feed	2
Low Jog	7
Duty Cycle	8
Sensitivity	7

Fig.2: Honing Process (Hero motor corp.)

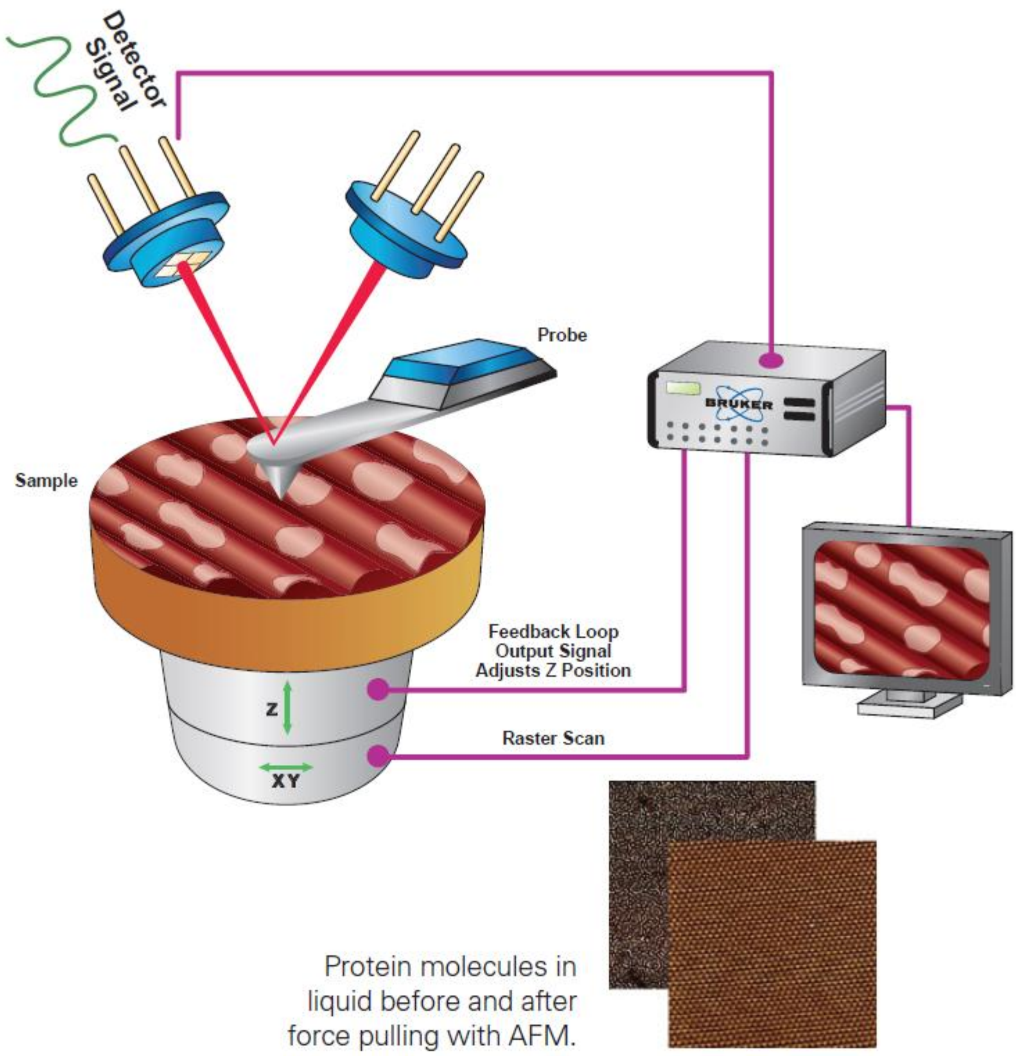

Fig.3: Atomic Force Microscopy (Hero motor corp.)

2.3 RSM Algorithms:

RSM have been reported on the development of second order multiple regression (RSM) would have its own input output characteristics, and therefore it can only be applied for modelling of some specific honing processes.

$$SR = -7.7966\,\theta_H + 0.08848 * P_F - 0.00212 * G_S - 0.00797 * P_S + 0.00811 * V_S \quad (1)$$

1. **DATA COLLECTION AND ANALYSIS:**

Taguchi Orthogonal Array Design, L27 (3**5), Level 3, Factors: 5, Runs: 27, Columns of L27 (3**13) Array.

Table 5: Experimental observation

Sl	P_F (bar)	Gs, (µm)	θ_H (Deg.)	V_S: (m/min)	P_S (N/mm2)	Observed R_a (µm)	Predicted R_a (µm)
1	3	38	10	35	10	0.7956	0.8053
2	3	38	10	35	30	0.6931	0.6942
3	3	38	10	35	50	1.1816	1.1612
4	3	53	60	40	10	0.7086	0.7023
5	3	53	60	40	30	0.5217	0.5303
6	3	53	60	40	50	1.0391	1.1536
7	3	68	110	45	10	1.1966	1.1962
8	3	68	110	45	30	0.4815	0.4825
9	3	68	110	45	50	0.4746	0.4676
10	6	38	60	45	10	0.5473	0.5502
11	6	38	60	45	30	1.1983	1.1977
12	6	38	60	45	50	0.3416	0.3412
13	6	53	110	35	10	0.7634	0.7644
14	6	53	110	35	30	1.1618	1.1623
15	6	53	110	35	50	1.1792	1.1803
16	6	68	10	40	10	1.1652	1.1589
17	6	68	10	40	30	0.8302	0.8307
18	6	68	10	40	50	1.1607	1.1601
19	9	38	110	40	10	0.6680	0.6676
20	9	38	110	40	30	0.6979	0.6956
21	9	38	110	40	50	0.5126	0.5155
22	9	53	10	45	10	1.1549	1.1570
23	9	53	10	45	30	0.7238	0.7208
24	9	53	10	45	50	0.4387	0.4369
25	9	68	60	35	10	0.6387	0.6385
26	9	68	60	35	30	0.8530	0.8539
27	9	68	60	35	50	0.5473	0.5466

Correlation coefficient (R^2) of observed and predicted Ra:

Fig.4 indicates the relationship between the observed and predicted correlation coefficient (R^2) is 0.9938 which gives excellent result.

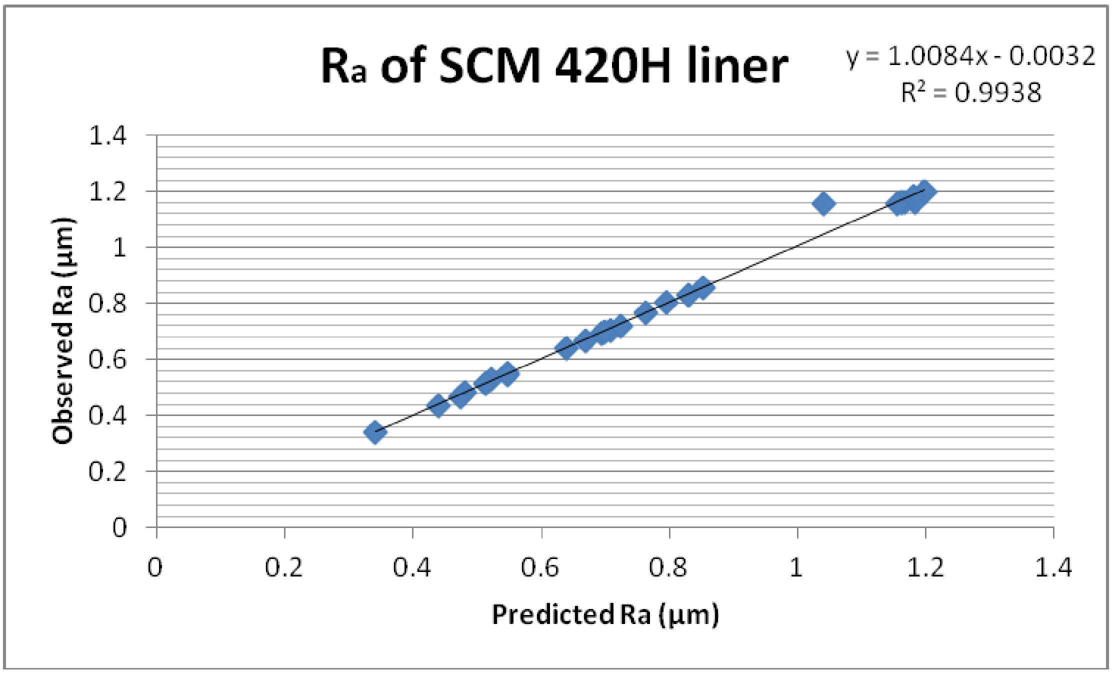

Fig 4: Predicted R_a vs. observed R_a

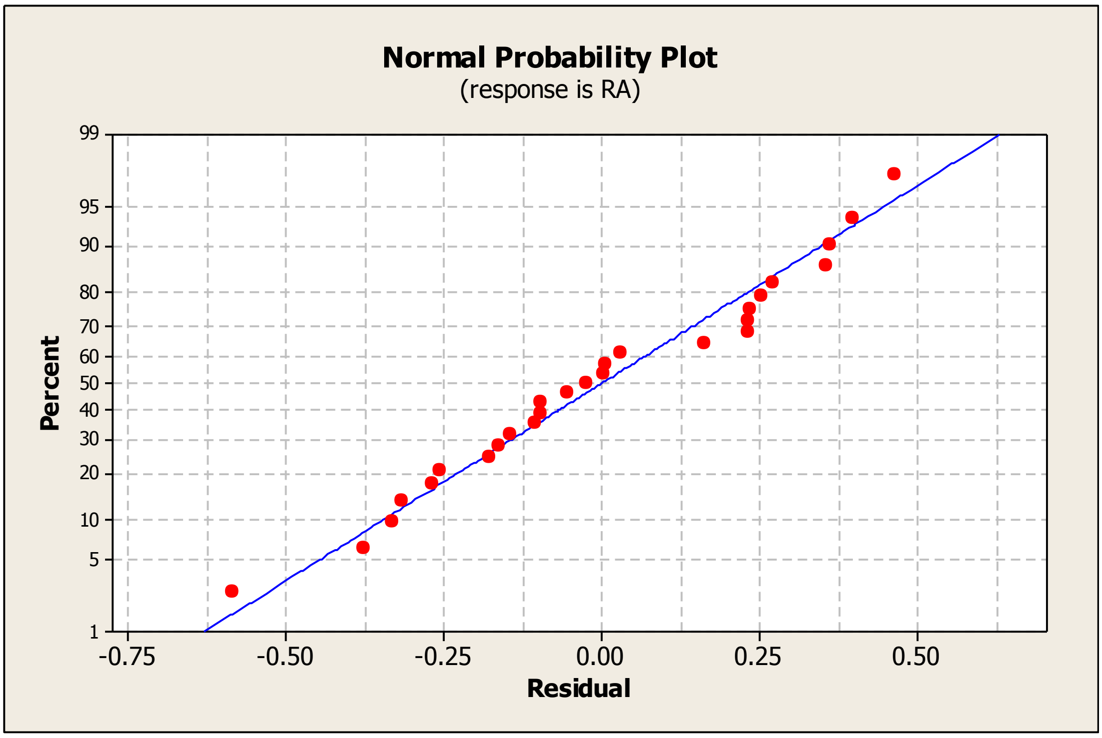

Fig.5: Probability plot of residual from predicted (RSM) R_a

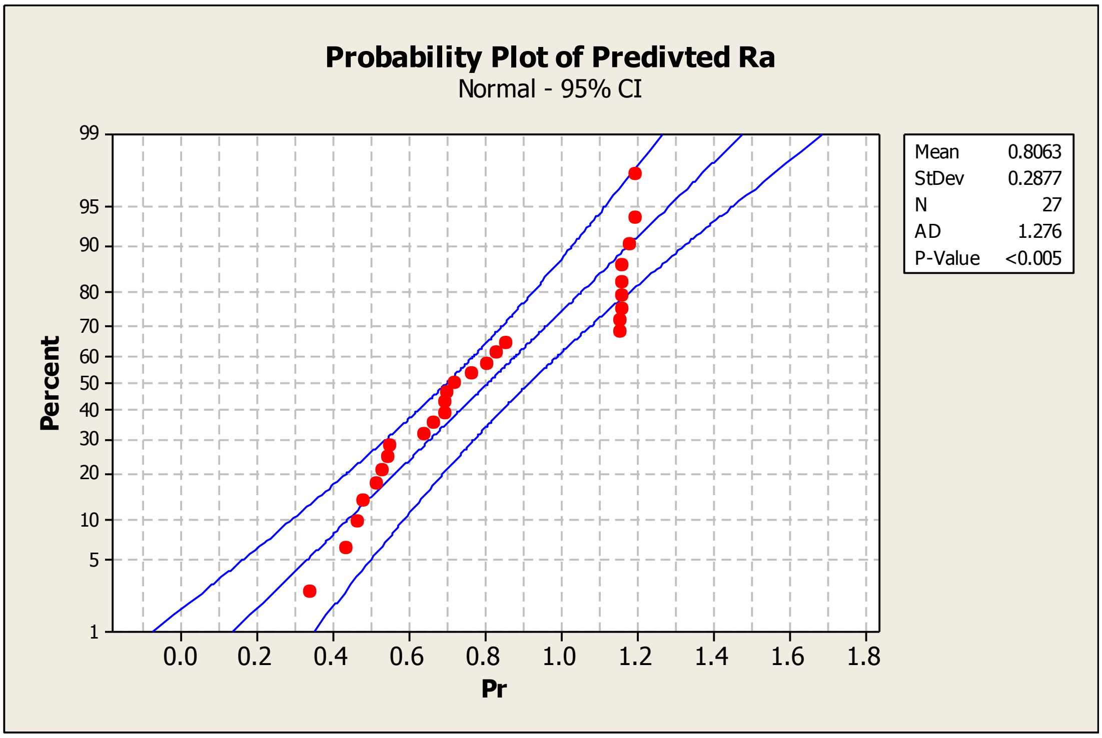

Table.6: Probability plot of residual from predicted (RSM) R_a having P-value

Predicted surface finish data is used to analyse interactions of factors using ANOVA and it is also used for optimization of process parameters. It is also evident that if the factors found significant as per the ANOVA test at 95% confidence level significantly as given in Fig. 7 & Fig.8 consequently. Fig 5 and Fig 6 indicating the P-value of the predicted response less than 0.005 which gives an idea about factor impact of surface finish were significant. Fig.9, Fig 10 & Fig 11 indicates effects of input factors on surface roughness which have been represented graphically using Minitab 16.It indicates that PF, GS, QH, VS, and PS have the most significant effect on surface roughness of SCM 420H steel under honing. It is clear that surface roughness decreases when PF is adequately high and GS decreases, whereas surface finish is proportional to VS and PS. It increases initially and then decreases with increase in the QH.

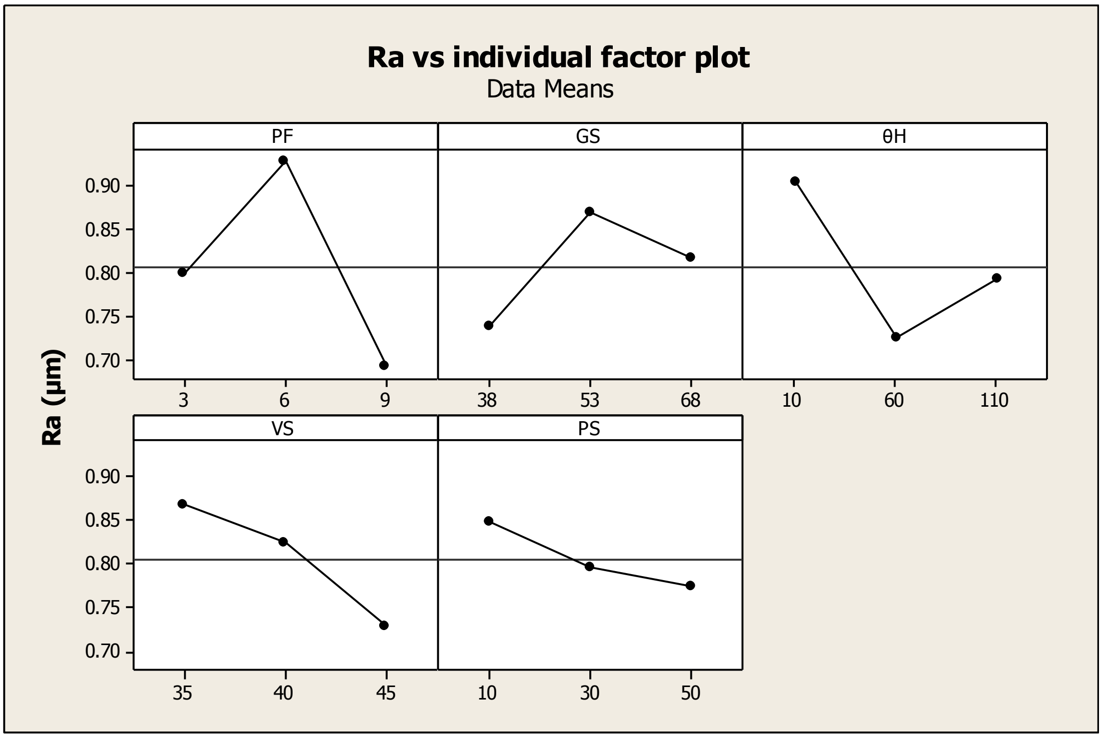

Fig.7: Main Effects Plot for R_a

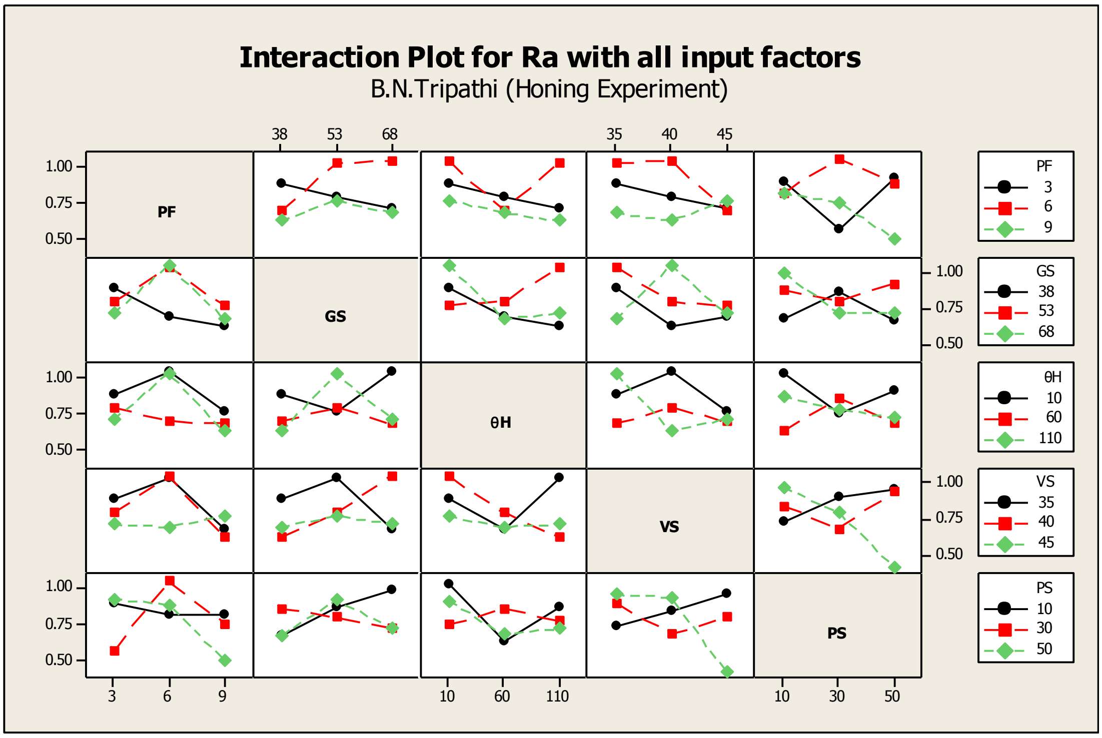

Fig 8: Factors Interaction plot using predicted response

Table.5 indicates nested ANOVA for surface roughness and it shows that all the five input factors have significant interaction with each other.

Table 5: ANOVA Analysis

Source	DF	SS	MS	F-value	P-value
Vg	2	1.4568	0.7284	182.1	0.8618
Fr	7	0.2384	0.0397	9.925	0.0448
Ton	6	0.3648	0.0281	7.025	0.0332
Toff	6	0.2764	0.0115	2.875	0.0129
Wf	3	0.0462	0.0154	3.85	0.0182
Error	2	0.0199	0.0040	-	-
Total	26	2.4246	-	-	-

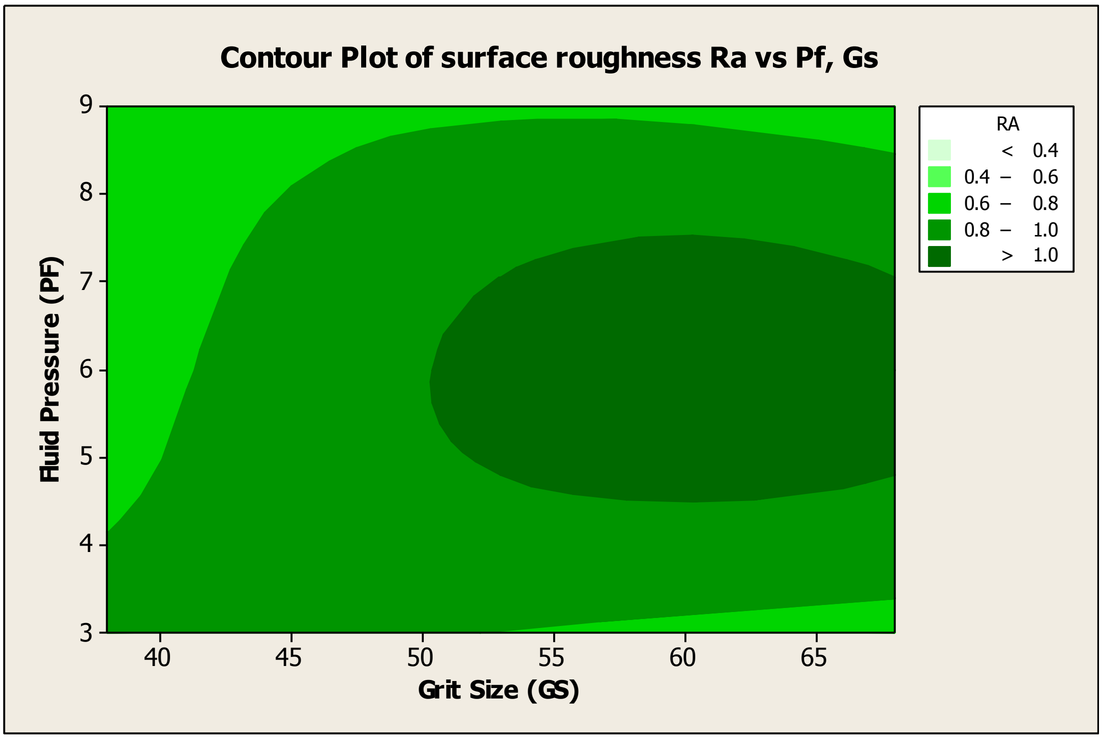

Fig 9: Relation of surface finish with fluid pressure and Grit size

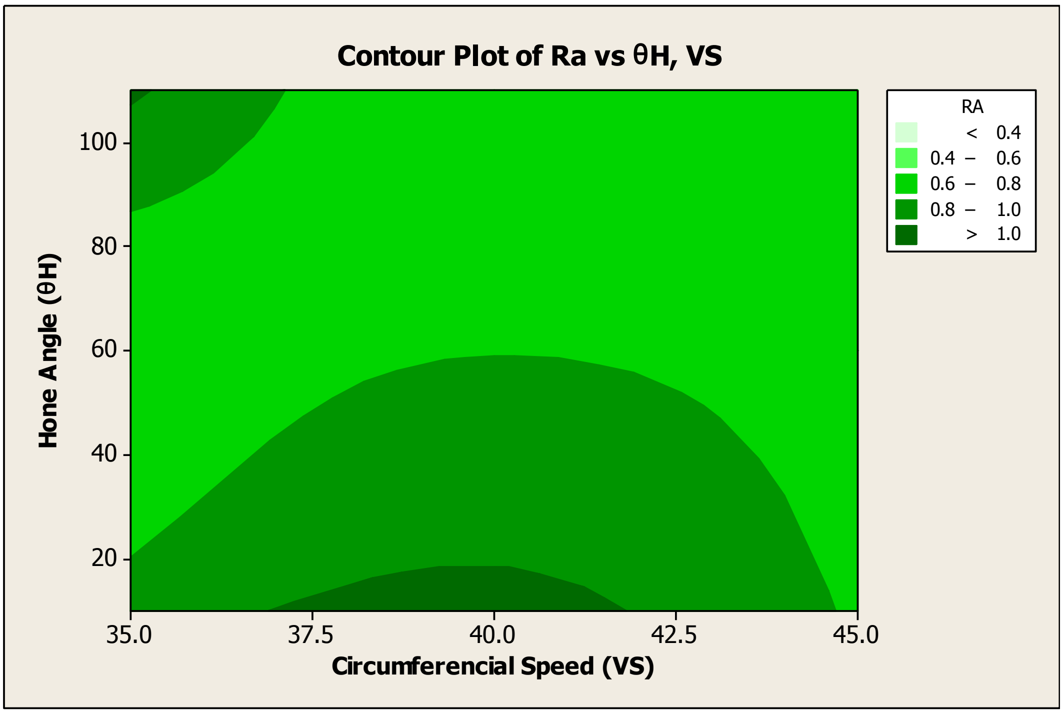

Fig 10: Relation of surface finish with hone angle and circumferential speed

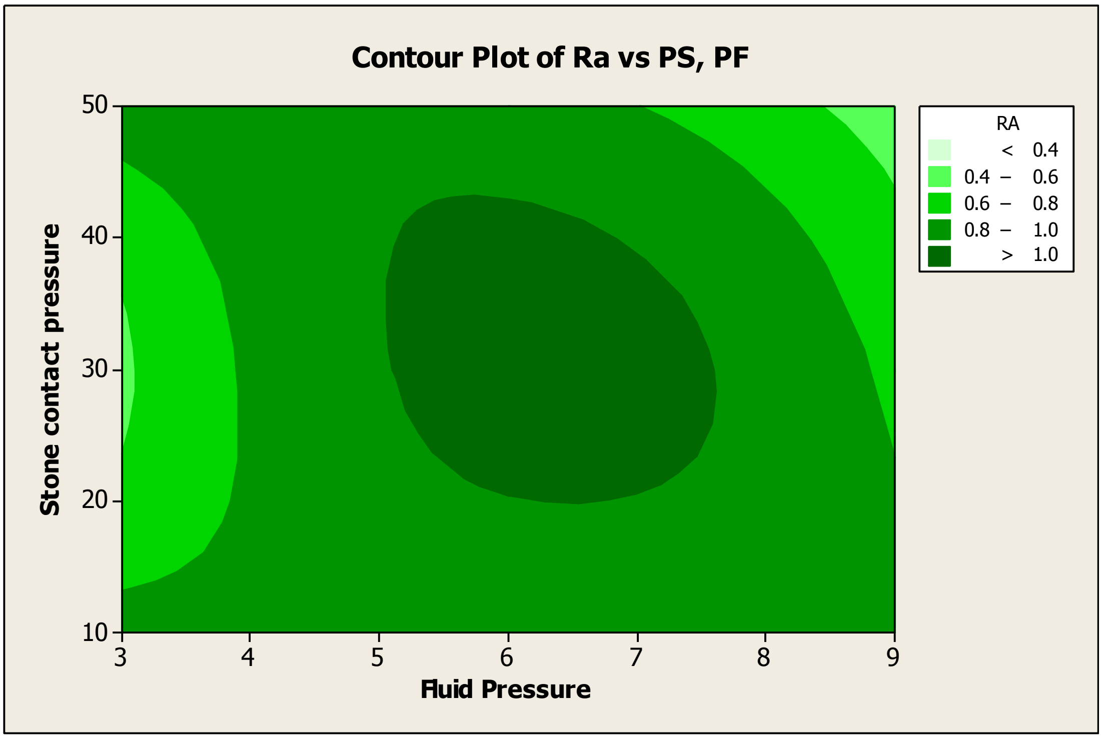

Fig 11: Relation of surface finish with stone contact pressure and fluid pressure

4. OPTIMIZATION OF PROCESS PARAMETERS

It is evident from Table.6 that three values of each independent influencing input parameter have been taken on the basis of their corresponding least possible values of its square of error. However, one values from each level of input parameters have been drawn, corresponding to lowest possible square of errors. One significant point from each input factors have been selected as optimization for surface finish, 3D scatter plot have been also drawn as Fig.12 to Fig 14.

Table 6: ANOVA Analysis

SL	P_F	G_S	Q_H	V_S	P_S	Ob. (Ra)	Pr. (Ra)	Error	$Error^2*100$
1	9	68	60	35	10	0.6387	0.6385	0.031314	0.000981
2	9	38	110	40	10	0.668	0.6676	0.05988	0.003586
3	6	38	60	45	50	0.3416	0.3412	0.117096	0.013711
4	9	53	10	45	50	0.4387	0.4369	0.410303	0.168349
5	3	68	110	45	50	0.4815	0.4825	-0.20768	0.043133

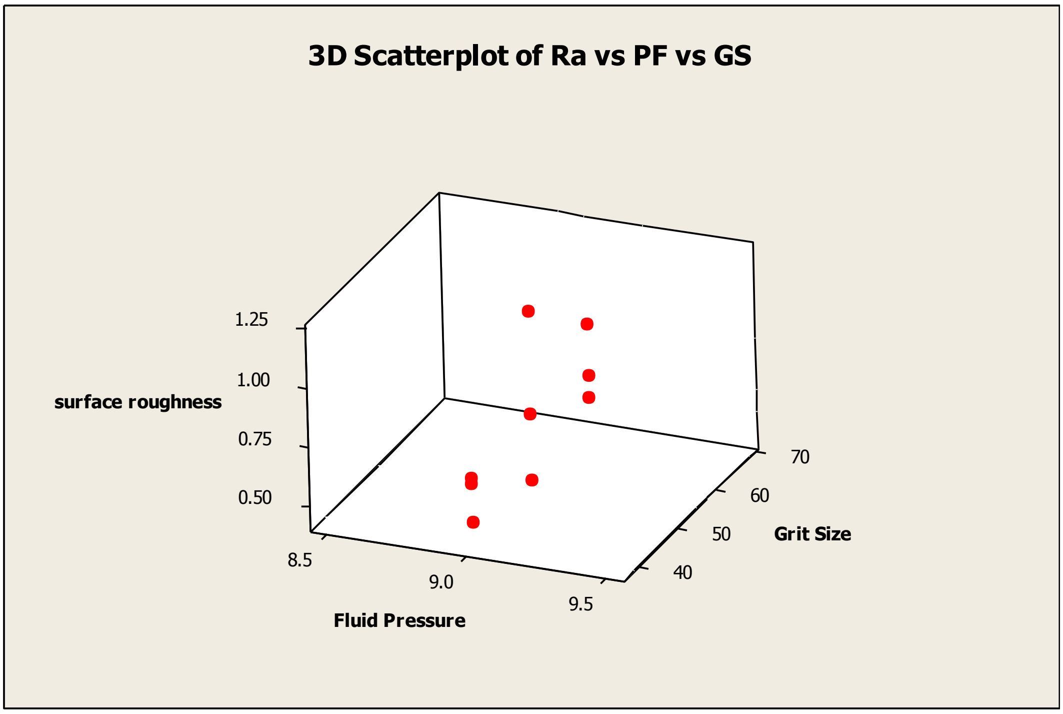

Fig 12: 3D scattered plot between R_a Vs grit size Vs fluid pressure.

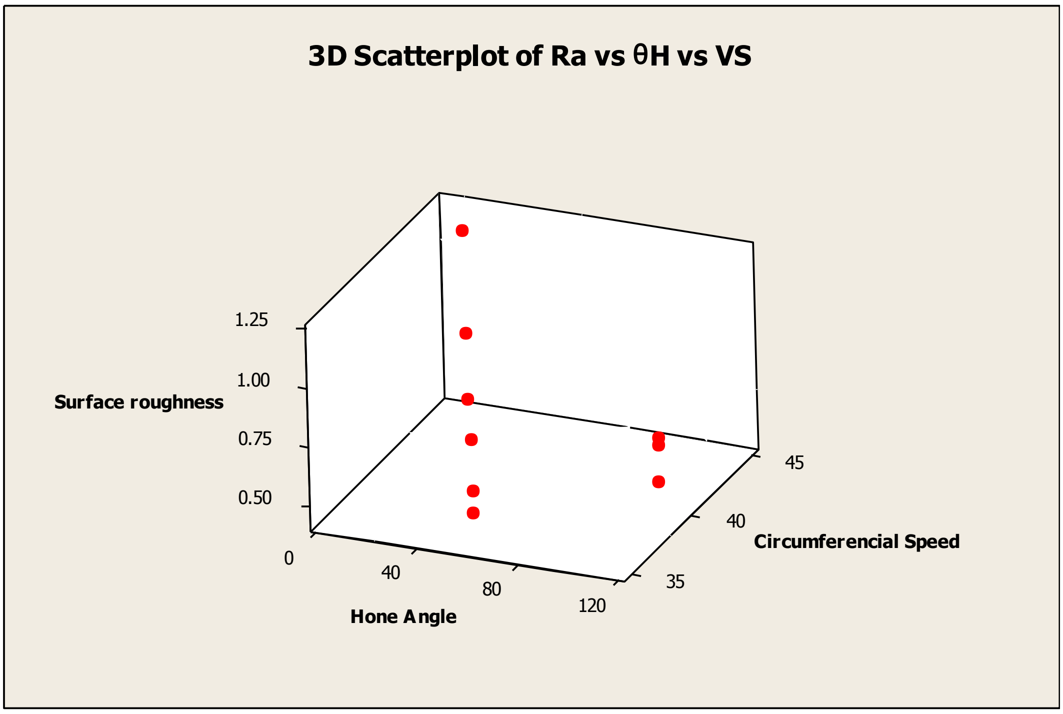

Fig 13: 3D scattered plot between R_a Vs hone angle Vs circumferential speed.

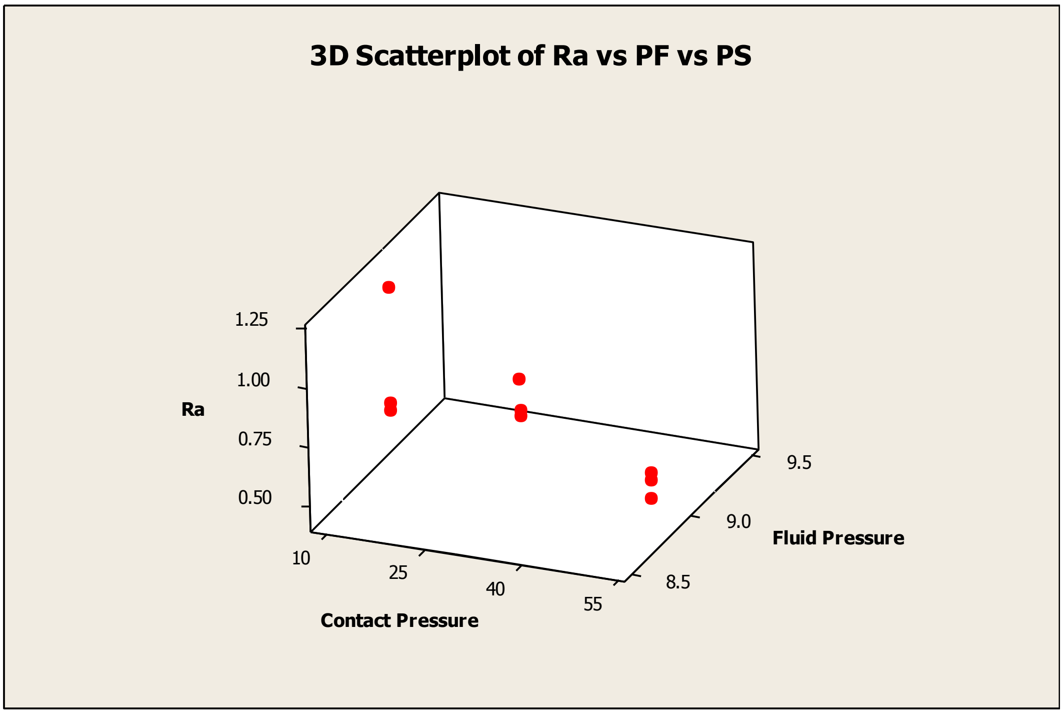

Fig 14: 3D scattered plot between R_a Vs contact pressure Vs fluid pressure.

5. RESULT

Fig 12, Fig 13 & Fig 14 shows the relationship between individual influencing parameter (P_F, G_S, Q_H, V_S & P_S) to their response i.e. surface roughness (R_a). Table.6 indicates that unique value of each influencing parameter (corresponding to serial numbers of table.6) and it gives optimum response.

The prediction has been made surface roughness of liner using honing by setting the individual optimum parameters i.e. P_F, G_S, Q_H, V_S & P_S as 9 bar, 38 μm, 60deg., 45 m/min and 50 N/mm^2 in RSM respectively. The values of R_a= 0.3750 μm have been found by RSM modelling consequently. It is very clear that RSM modelling technique is best fitted for the prediction of surface roughness and is able to successfully minimize R_a by 46.52% from its average value of R_a= 0.8063. Again the experiment were conducted by setting the optimum parametric combination of parameters P_F, G_S, Q_H, V_S & P_S as 9 bar, 38 μm, 60deg., 45 m/min and 50 N/mm^2 during honing and experimental R_a= 0.3825 μm have been found, which was very close to each other.

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Mr. B. N. Tripathi, Research Scolar, ISM/IIT Dhanbad, Teaching & Research Experience-13 years, Research Publications-More than 05

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Dr. N. K. Singh, Associate Professor, ISM/IIT Dhanbad, Teaching & Research Experience-28 years, Research Publications-More than 30.

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Dr. U. K. Vates, (Associate Professor & Head), Department of Mechanical Engineering, AIMT, Greater Noida, U.P., Teaching & Research Experience-11 years Research Publications-More than 18

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