AN INVESTIGATION ON CNC POCKET MILLING OF HSLA BY USING TAGUCHI

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ABSTRACT-- Present work includes understanding the effect of Computerised Numerical Control (CNC) milling parameters such as spindle seed, feed rate and depth of cut (DOC) on the surface roughness (SR), corner radius(CR) and side length of finished pockets. Experimentation was done as per Taguchi's L9 orthogonal array (OA) with three factors and three levels for each variable and studying the contribution of each factor on surface roughness, corner radius and side length of pocket. The experiments were conducted on High Speed Low alloy (HSLA) steel work piece material on CNC vertical milling machine using carbide tool. Analysis of Mean (ANOM) is employed for obtaining the optimal combination for minimum surface roughness and minimum deviation in corner radius and side length of finished pockets. The Analysis of Variance (ANOVA) technique is employed to study the significance of each machining parameters on the surface roughness, corner radius and side length of pocket. From the experiment it is concluded that optimal combination of the parameters for surface roughness is A2B2C1, i.e. at spindle speed (A) at 4000rpm, feed rate (B) at 650 mm/min and depth of cut (C) at 0.1 mm similarly the optimal combination for corner radius A3B1C2, i.e.at spindle speed (a) at 7000 rpm,(B) at 500 mm/min (C) at 0.175 mm and optimal combination for side length is A1 B2C2., i.e. at spindle speed (A) 1000 rpm, (B) 650 mm/min, (C) 0.175 mm. The ANOVA results shows that the spindle speed i.e. 62.46%, DOC i.e. 51.786%, spindle speed i.e. 66.39 % is the most important parameter affecting the surface roughness, corner radius and side length of the pockets respectively.

Keywords- Optimization, Parameters, Taguchi's method, ANOVA, HSLA Steel, Pocket milling, Orthogonal Array (OA).

1 INTRODUCTION

Milling is the process of removing additional material from the work piece with a rotating multi-point cutting tool, called milling cutter. Milling is one of the basic machining processes which is widely used in the manufacturing industries like automobile, cycle industries, etc. because it is capable of producing variety of products with complex geometries. Finding the optimum balance between increased production rate and improved quality are the most important. Criterions for the success of the organization. Thus improvement in the quality of a product ensures its demand from the patron and increased profit. In past various authors has proposed the importance of optimum machining parameters in manufacturing surroundings, where economy of machining operation plays a notable role in competitiveness in market. So the present research was aimed at finding the optimal process parameters for pocket milling process. The three key factors of any basic milling operation spindle speed, feed, and depth of cut are taken into account. Obviously factors such as work piece materials and type of tool materials have large influences, but these three factors can be changed easily by the operator by adjusting the controls [1].

Robust design is defined as reducing variation in a product without eliminating the causes of the variation. In other words, making the product or process insensitive to variation to produce high-quality products with low development and manufacturing costs. Taguchi's parameters design is an important tool for robust design. It offers a simple and systematic approach to optimize design for performance, quality and cost. When any critical quality characteristic deviates from the target value, it constitutes a loss. Endlessly practising variability reduction from the target value improves quality and reduces cost [1].

Pocket milling occupies significantly important place in the aeronautic and automotive industries, as it is employed during the roughing stage of moulds and dies manufacturing. In pocket milling the material inside an arbitrarily closed boundary on a flat surface of a work piece is removed to a fixed depth. Generally flat bottom end mills are used for pocket milling [2].This type of machining presents an interesting characteristic: a degree of freedom can be used to optimize the tool path while respecting the boundary of the pocket, cutting conditions related to the tool / material couple and removal of all the material inside the machined area. Surface quality is important performance characteristic to estimate the productivity of machine tools as well as machined elements. Surface roughness is used as the crucial quality indicator for the surface machined.

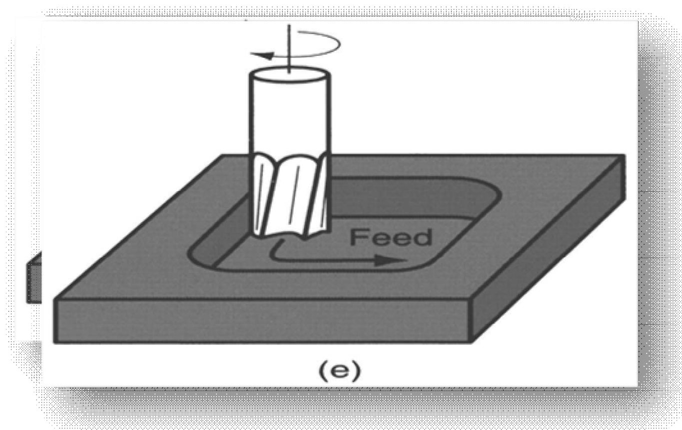

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Figure 1: Pocket milling operation

2 LITERATURE REVIEW

Literature has revealed an increasing interest of researchers in pocket milling in recent times.

Prajapati et al. [3] investigated the effect and optimization of machining parameters (spindle speed, feed rate and depth of cut) on SR and Material removal rate (MRR). L27 Orthogonal array, ANOVA and grey relation analysis is used. Chandrasekaran et al. [4] studied the machinability of AISI 410 on CNC lathe for SR using Taguchi's method. L27OA, ANOVA is used in this investigation. Zhang et al. [5] investigated the Taguchi's design application to optimize surface quality in a CNC face milling operation. An orthogonal array of L9 was used. Gologlu et al. [6] studied about pocket milling which is often encountered in plastic mould manufacture. The aim of this study is to investigate optimum cutting characteristics of DIN 1.2738 mould steel using high-speed steel end mills. Joshi et al. [7] investigated the SR response on CNC milling by Taguchi technique. ANOVA was used in this investigation. Mohd.et al. [1] studied the effect of CNC milling machine parameters on depth of pocket. EN31 steel is used as a work material and L9 OA is used for investigation. Yang et al. [9] in his research, construct the prediction model of surface roughness based on gene expression programming (GEP). Reddy et al. [10] optimized the parameters such as nose radius, cutting speed, feed, axial depth of cut and radial depth of cut for surface roughness using response surface methodology and genetic algorithm. The experiments were conducted using Taguchi's L50 OA. Kromanis et al. [11] developed a technique to predict the surface roughness of part to be machined. In result of the study, the mathematical model of end-milling is achieved and qualitative analysis is maintained. Thakkar et al. [12] optimized process parameters for SR and MRR for SS 410 Material. Experiments were conducted on CNC turning and machined parameters (MRR & SR) were predicted by ANOVA. Kopac and Krajnik [13] presented the robust design of flank milling parameters dealing with the optimization of the cutting forces, milled surface roughness and the MRR in the machining of an Al-alloy casting plate for injection moulds. In light of the above reviewed literature present work is aimed at estimating the significance of SR, CR and side length of milled pockets based on the all important machining parameters of CNC milling.

3 EXPERIMENTAL WORK

3. 1 Material and Machine used

3.1.1 Work piece Material

HSLA steel is used in present work as it offers better mechanical properties and increased resistance to corrosion as compared to other steels i.e. carbon steel etc. . Application of HSLA steels include construction and farm machinery, oil and gas pipelines, heavy-duty highway and off-road vehicles, industrial equipment, storage tanks, mine and railroad .The chemical composition of HSLA Steel is shown in Table 1.

Table 1: Chemical Composition of Steel

Elements	Composition in weight of %
Carbon	0.048
Manganese	0.62
Phosphorus	0.10
Silver	0.27
Chromium	0.52
Niobium	0.020
Copper	1.47
Vanadium	0.11
Sulphur	0.004

3.1.2 Machine

The pocket milling operation is carried out on a Vertical CNC milling machine .The machine is shown in Figure 2.

Figure 2: CNC Vertical Milling Machine

3.1.2.1 Machine Specification

Specification of Vertical CNC Milling Machine shown in Table 2.

Table 2: Specification of Vertical CNC Milling Machine

Machine Tool Builder Name	Bharat Fritz Werner Ltd.
Model	Chandra
SI. No	7139
Year of Manufacturing	2003
PMC & NC Name	FOIMATE-MC SAI/RAI
PMC Prog. No	001
Edition No.	000
Date of Programming	21-06-2006
Bed Size	1060 mm
X-Axis Drive	800 mm
Y-Axis Drive	350 mm
Z- Axis Drive	380 mm
Capacity	7.5 KVA
Working Voltage	415 V
Rated Current	6 Kg/m square

3.1.3 Cutting Tool

The pocket milling operation is done by using solid carbide (8mm) as shown in figure 3.

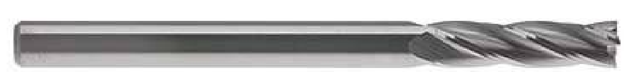

Figure 3: Carbide end milling tool

3.2 Experimental Procedure

1. Work piece plate was sized to required dimension of 200×200×18mm by Power Hacksaw.
2. Face milling is done on CNC milling machine using face milling cutter.

3. A program on different parameters is developed by using Unigraphics software.
4. Milling operation is started after setting the work material.
5. Pocket shape is formed with End milling cutter (8mm) as shown in figure 4.
6. Nine such pockets are formed on work material.
7. Measuring the SR, CR and side length by surface roughness tester and stereo zoom microscope using caliper pro software.
8. Taguchi's experimental design is used for analysis.

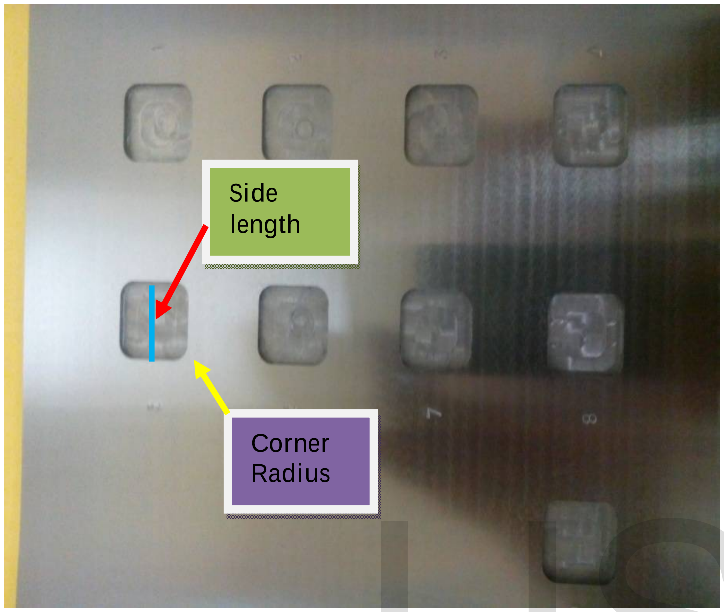

Figure 4: Plate after milling pocket

3.2.1 Taguchi Method

Taguchi defines the quality of a product, in terms of the loss imparted by the product to the society from the time the product is shipped to the customer [1]. The overall aim of Taguchi method is to make products that are robust with respect to all noise factors .The uncontrollable factors which cause the functional characteristics of a product to deviate from their target values are called noise factors, which can be classified as external factors (e.g. temperatures and human errors), manufacturing imperfections (e.g. unit variation in product parameters) and product deterioration. Taguchi used the signal-to-noise (S/N) ratio as the quality characteristic of choice [1]. S/N ratio is used as a measurable value instead of standard deviation due to the fact that as the mean decreases, the standard deviation also decreases and vice versa. Usually, analysis of the S/N ratio is based on three categories of performance characteristic: the lower-the- better, higher-the-better and nominal the better. A larger S/N ratio corresponds to better performance characteristics. Therefore, the optimal level of the process parameters is the level with the highest S/N ratio.

3.2.1.1 Design of Experiments (DOE) and process parameters

This DOE helps us for conducting experiments in a more methodical way. The process parameters range is specified in Table 2. These ranges are chosen based on limiting conditions of machine, available resources and the available literature.

Table 3: Machining Factors And Their Levels

Factors	Level 1	LEVEL 2	LEVEL 3
Spindle Speed(A) rpm	1000	4000	7000
Feed Rate (B) mm	500	650	800
D.O.C. (C) mm	0.1	0.175	0.25

3.2.1.2 Orthogonal Array (OA)

Orthogonal Array is a numerical method of defining parameters that converts test areas into factors and levels. It allows for the maximum number of main effects to be estimated in an impartial (orthogonal) manner, with a least amount of run in the experiments. In this study,L9 orthogonal was used. This array has eight degree of freedom and it can handle three-level design parameters.

3.2.1.3 ANOVA

ANOVA is the statistical method used to interpret experimental data to make the necessary decisions [1].The purpose of ANOVA is to control the variation of a process, consequently; decisions can be made concerning which parameters affect the performance of the process. Through ANOVA, the parameters can be categorized into significant and insignificant machining parameters.

4 EXPERIMENTAL RESULTS AND ANALYSIS

4.1 Analysis for Surface Roughness of Pockets

4.1.1 Signal to Noise ratio (S/N)

The main objective of the experiment is to optimize the milling parameters (spindle speed, feed rate and depth of cut) to achieve minimum surface roughness and minimum deviation in CR and side length of pocket in order to maximize the finish and accuracy during machining. The experimental data for surface roughness of pocket and calculated signal-to-noise ratio are shown in Table 4. The S/N ratio values are calculated, using the smaller the better characteristics using equation 1.

$$SNs = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^{\,2}\right) \qquad \text{............................ [1]}$$

Table 4: Experimental results and corresponding S/N ratio

Ex. No	A (RPM)	B (Feed)	C (D.O.C)	SR values	S/N ratio
1	1000	500	0.1	1.658	-4.39169
2	1000	650	0.175	1.636	-4.27567
3	1000	800	0.25	1.695	-4.58339
4	4000	500	0.25	1.540	-3.75041
5	4000	650	0.1	1.440	-3.16725
6	4000	800	0.175	1.779	-5.00352
7	7000	500	0.175	1.830	-5.24902
8	7000	650	0.25	1.845	-5.31993
9	7000	800	0.1	1.900	-5.57507

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Table 5: Response Table Mean S/N Ratio

Level	A	B	C
1	-4.417	-4.464	-4.378
2	-3.974	-4.254	-4.843
3	-5.381	-5.054	-4.551
Delta	1.408	0.800	0.465
Rank	1	2	3

Average S/N ratio for each level of experiment is calculated, and shown in Table 5. The different values of the S/N ratio between maximum and minimum (main effect) are also shown in Table 5.The spindle speed and feed rate are two factors with the highest different in values respectively. Based on Taguchi prediction that the bigger different in value of S/N ratio shows a more effect or more significant. Hence, increase changes in spindle speed reduce pocket roughness significantly.The ANOVA results are shown in Table 6. Since the percentage contribution of speed is maximum i.e. 62.46% it is most important and significant factor affecting the surface roughness of the milling pocket. The next important milling parameter is feed rate with percentage contribution of 20.81% followed by DOC having percentage contribution of 6.652%.

Table 6: Results of Analysis of Variance

Source	D.O.F	Ad_jSS	Ad_jMS	P	% Contribution
A	2	3.1079	1.5540	0.140	62.46
B	2	1.0318	0.5159	0.329	20.81
C	2	0.3310	0.1655	0.604	6.652
Error	2	0.5051	0.2525		10.15
Total	8	4.9758			

Where D.O.F =Degree of Freedom;
SS = Sum of Square;
%P = percentage of Contribution.

4.1.2 GRAPHS

Figure 5depicts the main effect plot for S/N ratio. It can be seen from Figure 6 that within the range of investigated input parameters, the optimal combination of the parameters for minimum surface roughness is A2B2C1.Figure 6shows the normal probability plot of the residuals for surface roughness and it reveals that the residuals either fall on a straight line or are very close to the line implying that the errors are distributed normally.

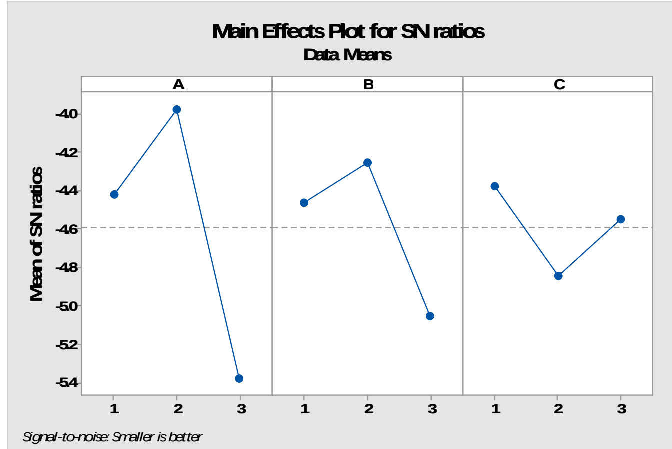

Figure 5: Main Effects Plot for S/N ratios

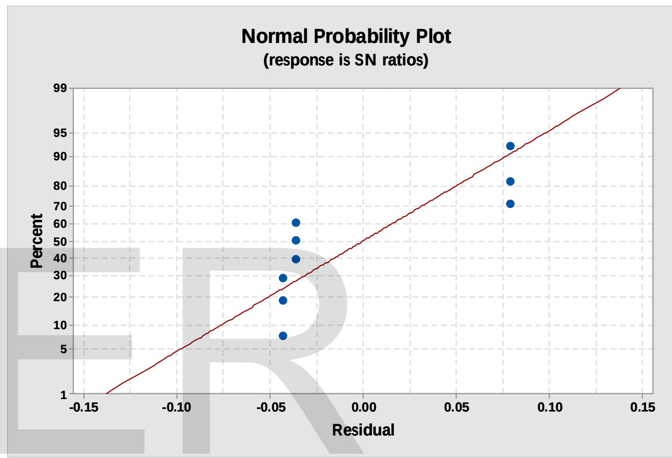

Figure 6: Main Effects Plot for S/N ratios

4.2 Analysis For Corner Radius Of Pockets.

4.2.1 The experimental data for minimum deviation in CR of pockets and calculated S/N ratio are shown in Table 7.

Table 7: Experimental results and corresponding S/N ratio

Ex. No	A (RPM)	B (Feed)	C (D.O.C)	Mean deviation in CR	S/N ratio
1	1000	500	0.1	0.148	16.5948
2	1000	650	0.175	0.145	16.7726
3	1000	800	0.25	0.198	14.0667
4	4000	500	0.25	0.212	13.4733
5	4000	650	0.1	0.254	11.9033
6	4000	800	0.175	0.148	16.5948
7	7000	500	0.175	0.098	20.1755
8	7000	650	0.25	0.231	12.7278
9	7000	800	0.1	0.132	17.5885

Table 8: Response Table Mean S/N Ratio

Level	A	B	C
1	15.81	16.75	15.36
2	13.99	13.80	17.85
3	16.83	16.08	13.42
Delta	2.84	2.095	4.43
Rank	3	2	1

The ANOVA results (Table 9) shows that DOC is the most significant factor affecting the minimum deviation in CR as % contribution of DOC is 51.786% maximum. The next significant factor is feed rate i.e. (25.14%) followed by spindle speed i.e. (21.78%).

Table 9: Results of Analysis of Variance

Source	D.O.F	Adj SS	Adj MS	P	% Contribution
A	2	12.4208	6.2104	0.056	21.78
B	2	14.3319	7.1660	0.049	25.14
C	2	29.5205	14.7603	0.024	51.786
Error	2	0.7311	0.3656		1.28
Total	8	57.0044			

4.2.2 Graphs

Figure 7 depicts the main effect plot for S/N ratio. It can be seen from figure: 7 that the optimal combination of parameters for minimum deviation in corner radius is A3B1C2.Figure 8 shows the normal probability plot of the residuals for corner radius and it reveals that the residuals either fall on a straight line or are very close to the line implying that the errors are distributed normally.

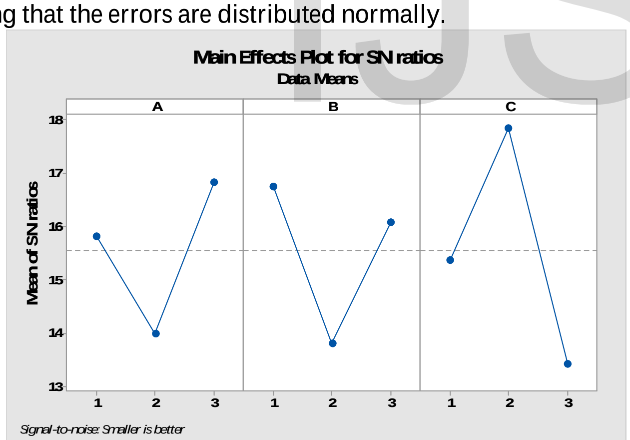

Figure 7: Main Effect plot for SN ratios

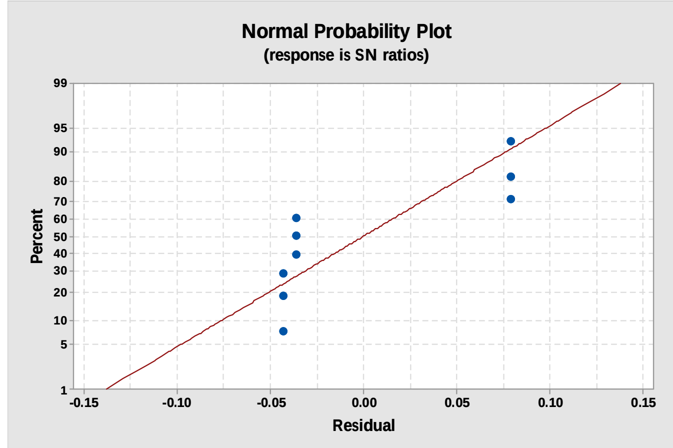

Figure 8: Normal probability plot of the residuals

4.3 Analysis for Pockets Side Length

4.3.1 The experimental data for minimum deviation in side length of pockets and calculated S/R ratio are shown in Table 10.

Table 10 Experimental results and corresponding S/N ratio

Ex. No	A (RPM)	B (Feed)	C (D.O.C)	Mean Deviation in side length	S/N ratio
1	1000	500	0.1	0.320	9.8970
2	1000	650	0.175	0.179	14.9429
3	1000	800	0.25	0.250	12.0412
4	4000	500	0.25	0.4548	6.8589
5	4000	650	0.1	0.250	12.0412
6	4000	800	0.175	0.351	9.0939
7	7000	500	0.175	0.400	7.9588
8	7000	650	0.25	0.600	4.4370
9	7000	800	0.1	0.700	3.0980

Table 11: Response Table Mean S/N Ratio

Level	A	B	C
1	12.294	8.01	8.345
2	9.331	10.00	10.665
3	5.165	8.078	7.779
Delta	7.129	2.396	2.886
Rank	1	3	2

The ANOVA results are shown in Table 12. It can be seen from Table 12 that the spindle speed significantly affects minimum deviation in side length. Based on the percentage contribution, it is found that % contribution of spindle speed is (66.39%) maximum; the next significant factor is feed rate i.e. (9.283%) and another one is D.O.C i.e. (12.20%).

Table 12: Results of Analysis of Variance

Source	D.O.F	Adj SS	Adj MS	P	% Contribution
A	2	76.96	38.481	0.155	66.39
B	2	10.76	5.382		9.283

				0.568	
C	2	14.03	7.016	0.502	12.10
Error	2	14.15	7.075		12.20
Total	8	115.91			

4.3.2 GRAPHS

Figure 9 depicts the main effect plot for S/N ratio. It can be seen that within the range of investigated input parameters, the optimal combination of parameters for minimum deviation in side length is A1B2C2.Figure shows the normal probability plot of the residuals for side length and it reveals that the residuals either fall on a straight line or are very close to the line implying that the errors are distributed normally.

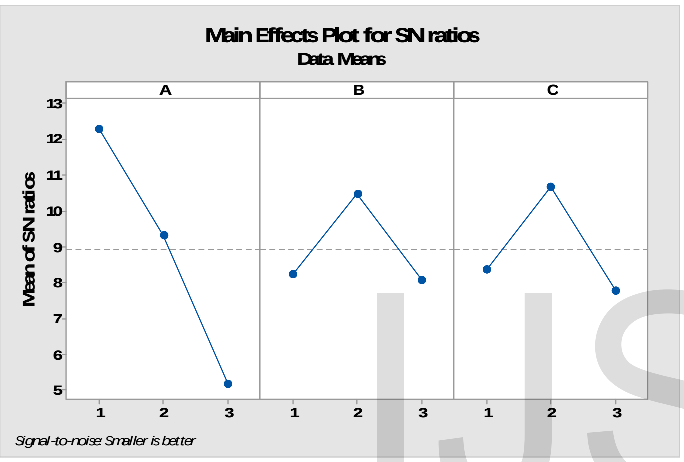

Figure 9: Main Effect plot for SN ratios

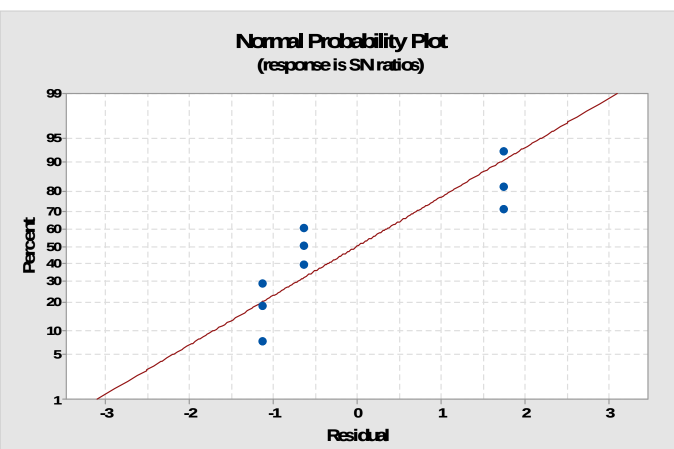

Figure 10: Normal probability plot of the residuals

5. Conclusion

- The optimum combination of machining parameters and their levels for minimum surface roughness and decreasing the deviation in CR and side length of pockets are A2B2C1, A3B1C2, and A1B2C2 respectively.
- Spindle speed significantly effects the surface roughness of pocket .The percentage contribution of spindle speed feed and depth of cut are 62.46%, 20.81% and 6.652% respectively.
- Depth of cut significantly affects the corner radius of pocket. The percentage contribution of depth of cut, spindle speed and feed are 51.786%, 21.78% and 25.14% respectively.
- Spindle speed significantly affects the side length of pocket. The percentage distribution of spindle speed, feed and depth of cut are 66.39%, 9.283% and 12.10% respectively.

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