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PARAMETRIC OPTIMIZATION FOR IMPROVED SURFACE FINISH IN CNC TURNING OPERATION

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ABSTRACT: -
The parameters affecting the roughness of surfaces produced in the turning process for various materials have been studied by many researchers. Design of experiments were conducted for the analysis of the influence of the turning parameters such as cutting speed, feed rate and depth of cut on the surface roughness.

This paper presents a novel approach for the optimization of machining parameters on turning of the tool work piece combination of the Raw material HCHCr with cemented carbide and CBN tool. The parameters – Speed, Feed and Depth of cut to be maintained for HCHCr were determined in terms of optional values or levels for the tool. Historic data was referred from the records of the company to understand the effect of introducing variation in the input to realize a given output as a 'Response' for surface finish. Statistical data analyzed using ANOVA, DOE and Regression to identify the given machining parameters for the operation. Experimental run conducted for validating the values realized through this Analytical treatment of the data. Experimental outcomes have proved that the responses in turning process can be enhanced efficiently through this fresh approach.

1. INTRODUCTION: -

Turning is an important and widely used machining processes in engineering industries. Surface quality is an important performance characteristic to evaluate the productivity of machine tools as well as machined components. Surface roughness is the critical quality indicator for machined surfaces. A good quality turning surface can lead to improvement in strength properties such as fatigue strength, corrosion resistance, assembly tolerance, wear rate, coefficient of friction, cleanability, thermal resistance and aesthetics etc.

The Taguchi method is statistical tool, adopted experimentally to investigate influence of surface roughness by cutting parameters such as cutting speed, feed and depth of cut. The Taguchi process helps to select or to determine the optimum cutting conditions for turning process.

2. LITERATURE REVIEW:-

Phillip J. Ross[1] Taguchi Techniques Made Easier Than Ever! Regardless of your experience with statistics, the Second Edition of Taguchi Techniques for Quality Engineering, by Saturn quality engineer Phillip J. Ross, shows you step-by-step how to design effective experiments to reduce variation, improve the quality of products and processes, and slash development time and costs. Now organized in the chronological order of the DOE process, this revised and updated edition give you the tools to exploit: the loss function concept--to quantify the cost of product and process variations; orthogonal experiment design--to pinpoint areas where variation may be reduced; parameter and tolerance design--to reduce variations in products and processes at little or no cost.

K. PALANIKUMAR[2] This article discussed the use of Taguchi's method and Pareto ANOVA analysis for optimization of the cutting parameters in turning glass fiber reinforced plastic (GFRP) composites using a poly crystalline diamond (PCD) tool for minimization of surface roughness. The cutting parameters evaluated were cutting speed, feed rate, and depth of cut. An L9 orthogonal array, signal to noise ratio, and Pareto ANOVA analysis were used to analyze the effect of cutting parameters and its interactions. The experimental results suggest that the most significant process parameter was feed rate followed by cutting speed. The study showed that the Taguchi method and Pareto ANOVA were suitable for optimization of the cutting parameters with the minimum number of trials.

Wojciech Zębala [3] The investigation shows the result analysis of the recorded total cutting force components (*Ff, Fp, Fc*) during turning of WC-Co (25 % Co) with tools made of polycrystalline diamond PCD. Turning tests of sintered carbides (WC Co shaft with content of 25% Co) accomplished by the inserts with three different nose radii, each cutting test had been carried out on the distance 54 mm at the constant depth of cut 0.2 mm. it was noticed, the largest growth is for the passive force component *Fp*. In addition, the mathematical models for cutting force value prediction as the cutting path increases are presented. There is presentation of the algorithm of optimization and control of the super hard materials turning process.

S.Sivasankarana et.al [4] This investigation shows the effect of process parameters on surface roughness of glass fiber reinforced polymer (GFRP) composite pipes. On the basis of high speed turning centre (CNC) with poly-crystalline diamond (PCD) tool experiments had been conducted. The cutting speed, feed, depth of cut, and workpiece type (E-Glass mat and E-Glass woven specimen) were considered as process parameter. The pipes used in experiment were fabricated using the filament winding process. It consists of 70 percent epoxy polyester resin and 30 percent glass fiber. The E-Glass woven and E-Glass mat fiber reinforced composite material had been compared. The mechanical properties had also conducted as per ASTM standards. Based on the results, it has been observed that good machinability had obtained at lower cutting speed; feed rate, depth of cut for mat fiber reinforced GFRP pipe.

B.Singarvela et.al [5] In this experimental analysis Taguchi based utility concept is used coupled with Principal Component Analysis (PCA) on turning of EN25 steel with CVD and PVD coated carbide tools to estimate the optimum machining parameters. For obtaining the simultaneous minimization of surface roughness, cutting force and maximization of material removal rate this method has been employed. The multi SN ratio is calculated by the product of weight factor and SN ratio to the performance characteristics in the utility concept. The weight factors involved for all objectives found by adopting the Principal component analysis. Finally the relative significance of machining parameter in terms of their percentage contribution had found by applying ANOVA concept on multi SN ration.

K. Wonggasema et.al [6] In this investigation there is a demonstration of an optimization of the PCA-based DI based on empirical models of hard turning of AISI 6150 steel in which uncertainties are propagated by model errors. The obtained results are the degree of importance of each performance measure has been adjusted by the integration of the covariance information into the overall performance index.

S.J. Raykara et.al [7] This paper the Grey Relational Analysis (GRA) is used for investigation of High Speed Turning of Al 7075, a high strength aluminium alloy used for aerospace applications. GRA is also used for Multi-objective optimization of surface roughness, power consumption, material removal rate and cutting time which are some important parameters to decide the capability and suitability of high speed turning. By machining Al 7075 at high cutting speeds the investigation of performance of coated and uncoated carbide cutting tool has been done. On the basis of GRA results Suitable cutting parameters with appropriate cutting tool for high speed turning of Al 7075 are suggested at the end.

R. Venkata Rao et.al [8] This paper focused on the primary objective in multi-pass turning operations is to produce products with low cost and high quality, with a lower number of cuts. Parameter optimization is the very important process to achieve this goal. It usually involves the optimal selection of cutting speed, feed rate, depth of cut and number of passes. Recently developed advanced optimization algorithm, named, teaching–learning-based optimization algorithm had been used in this process, for parameter optimization of a multi-pass turning operation. Two different examples attempted previously by various researchers using different optimization techniques, such as simulated annealing, the genetic algorithm, the ant colony algorithm, and particle swarm optimization, etc. had been considered here. The first example is a multi-objective problem and the second example is a single objective multi-constrained problem with 20 constraints. The effectiveness of teaching–learning-based optimization algorithm had been proved over other algorithms.

P. Jayaramana et.al [9] A novel approach was presented for the optimization of machining parameters on turning of AA 6063 T6 aluminium alloy with multiple responses based on orthogonal array with grey relational analysis. Experiments were conducted on AA 6063 T6 aluminium alloy. Turning tests were carried out using uncoated carbide insert under dry cutting condition. Optimization of turning parameters such as cutting speed, feed rate and depth of cut has been done considering the multiple responses such as surface roughness (Ra), roundness (Ø) and material removal rate (MRR). The grey analysis was used to determine grey relational grade (GRG). Based on the values of grey relational grade optimum levels of parameters had identified and then by ANOVA the significant contribution of parameters was determined. Confirmation test was performed to validate the test result. Experimental outcomes had proved that the responses in turning process can be enhanced efficiently through this fresh approach.
Yansong Guoa et.al [10] In this paper, an approach which incorporates both energy consumption and surface roughness was presented for optimizing the cutting parameters in finish turning. Based on a new energy model and a surface roughness model, derived for a given machine tool, cutting parameters were optimized to accomplish a precise surface finish with minimum energy consumption.
Deepak Da et.al [11] This paper focused on the optimization of the process parameter such as cutting speed, depth of cut and feed rate on surface roughness produced on the machined component. Analysis was carried out using Taguchi robust design principles. From the analysis, feed rate was found to be the most influential process parameters which influence the surface roughness followed by cutting speed and depth of cut. Increase in feed rate and depth of cut was found to increase the surface roughness.
M. Durairaja et.al [12] This paper deals with CNC Micro turning of Inconel 600 alloy with titanium carbide coated tool. Machining has been done in DT-110 integrated multiprocessor micro machine tool. Micro turning was carried out with full factorial experiments with various combinations of cutting parameters such as speed (25, 31, and 37 m/min), feed (5, 10, and 15 μm/rev) and depth of cut (30, 50 and 70 μm). For every set of experiments, the output parameters such as the tool wear and the surface roughness were measured. Non-linear regression model was used to represent relationship between input and output variables and a multi-objective optimization method based genetic algorithm was used to optimize the cutting parameters in turning process such as cutting speed, feed and depth of cut. Two conflicting objectives such as tool wear and surface roughness were simultaneously optimized.

3. MATERIAL TESTING AND SPECIFICATION:-

Chemical Composition **HCHCr** Material type
Composition in % carbon 2.10, Silicon 0.30, chromium 11.50, Magnesium 0.40, Nickel 0.31.
CNC lathe was used for machining. The tool used is **CBN** tool. **Cubic Boron Nitride** tools used for hard machining applications. Other characteristics of CBN are its abrasion resistance, thermal and chemical resistance and maintaining sharp edges when cutting – which are most effective when machining ferrous materials. The surface roughness was measured using Pocket-sized Surface Roughness tester TR-110. The machining was done under wet cutting condition. The coolant used is **International Compound 1691**. Is an innovative, heavy-duty, very bio-stable, vegetable oil-based machining coolant engineered for use in severe operations utilizing carbon and stainless steel. It provides excellent in-process rust protection for ferrous metals and is non-staining to aluminum. ICC 1691 excels in modern CNC machining operations as a water-soluble coolant for operations like milling, turning, drilling, tapping, sawing and boring. The renewable resource core and ease of disposal make this an environmentally- and fiscally-responsible alternative.

4. EXPERIMENTAL WORK:-

Taguchi's L9 orthogonal array was used to design the experiments with three factors and three levels. Experiments were conducted based on the Taguchi's method which is a powerful tool used in design of experiments [11]. Taguchi advocates use of orthogonal array designs to assign the factors chosen for the experiment. The advantage of Taguchi method is that it uses a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments. Compared to the conventional approach of experimentation, this method reduces drastically the number of experiments that are required to

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model the response functions [12]. The assignment of the levels to the factors and the various parameters used are given in Table 1. The experimental results for L9 orthogonal array are given in Table 2.

Table: 1 Assignment of the Levels to the Factors

S.N	Factors	Unit	Symbols	Level 1	Level 2	Level3
1	Cutting speed	m/min	v	1280	0.12	0.05
2	Feed rate	mm/rev	f	1150	0.09	0.10
3	Depth of cut	mm	d	1000	0.06	0.15

Table: 2 Experimental Results for L9 Orthogonal Array

↓	C1	C2	C3	C4
	Speed, m/min	Feed, mm/rev	DOC,mm	Surface Roughness, Microns
1	1280	0.12	0.05	0.46
2	1280	0.09	0.10	0.51
3	1280	0.06	0.15	0.62
4	1150	0.12	0.10	0.36
5	1150	0.09	0.15	0.47
6	1150	0.06	0.05	0.55
7	1000	0.12	0.15	0.25
8	1000	0.09	0.05	0.34
9	1000	0.06	0.10	0.41

The experimental results were analyzed using Signal to Noise ratio with the Lower the Better criteria as given by the following equation. The relative effect of each process parameter is analyzed by Analysis of Variance (ANOVA).

$$SN_s = -10 \log10(Sy^2/n)$$

Where,
S/N = Signal to Noise Ratio,
n = No. of Measurements,
y = Measured Value

Table: 3 Experimental plan and average results

↓	C1	C2	C3	C4	C6	C7
	Speed, m/min	Feed, mm/rev	DOC,mm	Surface Roughness, Micron	PSNRA1	PMEAN1
1	1280	0.12	0.05	0.46	7.1209	0.454444
2	1280	0.09	0.10	0.51	5.5462	0.514444
3	1280	0.06	0.15	0.62	4.0785	0.621111
4	1150	0.12	0.10	0.36	8.8002	0.361111
5	1150	0.09	0.15	0.47	6.9341	0.464444
6	1150	0.06	0.05	0.55	4.8904	0.554444
7	1000	0.12	0.15	0.25	11.7388	0.254444
8	1000	0.09	0.05	0.34	9.2967	0.341111
9	1000	0.06	0.10	0.41	8.1204	0.404444

5. RESULTS & DISCUSSION:-

- **Effect of process parameters based on SN ratio analysis:-**

The present work investigates the effect of operating parameters such as cutting speed, feed rate and depth of cut. Table 3 shows the surface roughness produced on the work-piece in each replication. To assess the variability of the response, the analysis is carried out by SN ratio using smaller the better criteria as the objective of the work is to minimize the surface roughness. The effect of each process parameter at different levels is calculated using equation (1) and is shown in Table 4. The relative effect of each factor on the response is shown in the form of deltastatistics in the same table. Based on the delta values the ranks are assigned to the factors in the ascending order of their influence.

Table: 4 The mean SN ratio of process parameters

Taguchi Analysis: Surface Roughness, Microns versus Speed, m/min, Feed, mm/rev, DOC,mm

Response Table for Signal to Noise Ratios
Smaller is better

Level	Speed, m/min	Feed, mm/rev	DOC,mm
1	9.719	5.696	7.103
2	6.875	7.259	7.489
3	5.582	9.220	7.584
Delta	4.137	3.524	0.481
Rank	1	2	3

Response Table for Means

Level	Speed, m/min	Feed, mm/rev	DOC,mm
1	0.3333	0.5267	0.4500
2	0.4600	0.4400	0.4267
3	0.5300	0.3567	0.4467
Delta	0.1967	0.1700	0.0233
Rank	1	2	3

Figure 1 shows the main effect plot of SN ratio for the surface roughness (Ra) as response. It is seen from the plot that lowest surface roughness is obtained at the process settings, cutting speed 1000 m/min, Feed 0.12 mm/rev and depth of cut 0.15 mm. This combination of process parameter produces maximum SN ratio and hence the settings can be considered as optimum settings. Further, relative effect of each process parameter is determined by the ANOVA which is a statistical technique. In this technique the total variability of the response is separated with respect to individual contributions of each of the factors and the error. Table 4 shows the ANOVA values for the experimental results. The significance of effect of each factor on the response is evaluated using F test at 95 % confidence levels. It is seen that the effect of cutting speed has highest influence on surface roughness followed by feed rate and depth of cut. Also, the standardized residuals obtained in the ANOVA is shown in figure 1. It is observed from the figure that the residuals shows heteroscedasticity, which means experiments are conducted unbiased.

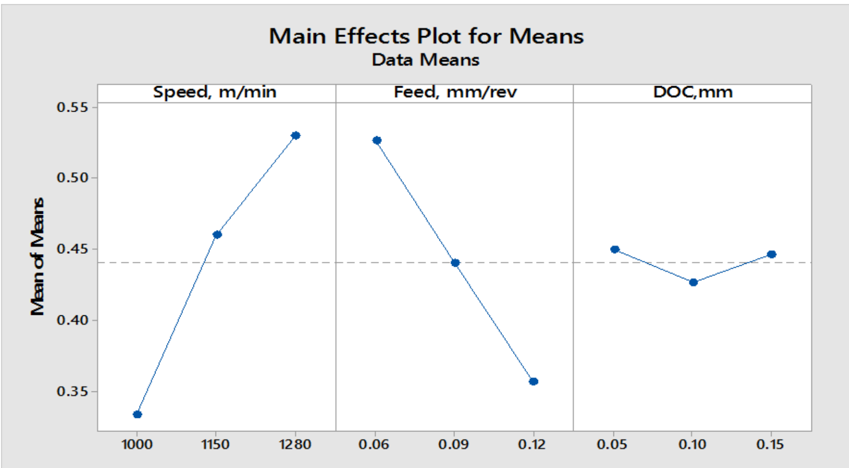

Figure 1: Plot of SN ratio for the surface roughness

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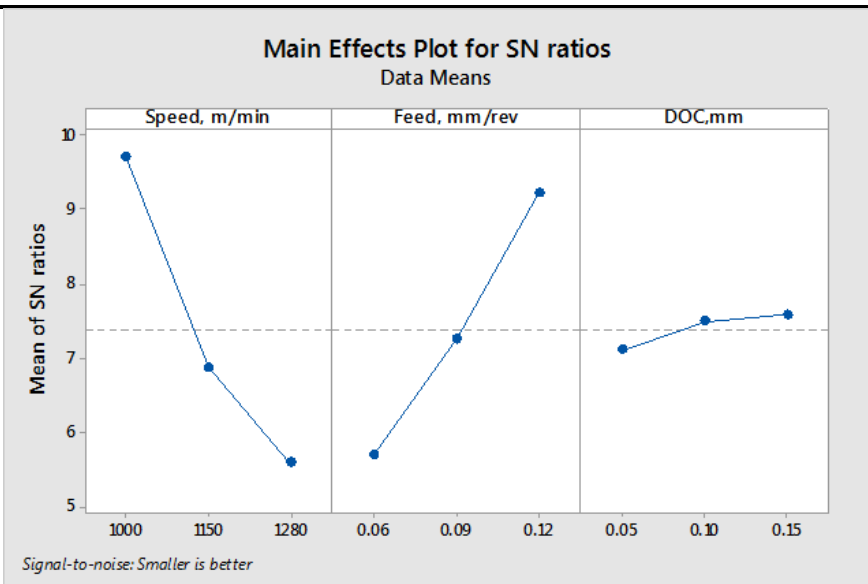

Figure 2: Plot of SN ratio for the surface roughness

Table: 5 One way ANOVAs

One-way ANOVA: Surface Roughness, Microns versus Speed, m/min

Factor Information

Factor	Levels	Values
Speed, m/min	3	1000, 1150, 1280

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Speed, m/min	2	0.05962	0.029811	4.02	0.078
Error	6	0.04447	0.007411		
Total	8	0.10409			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0860878	57.28%	43.04%	3.88%

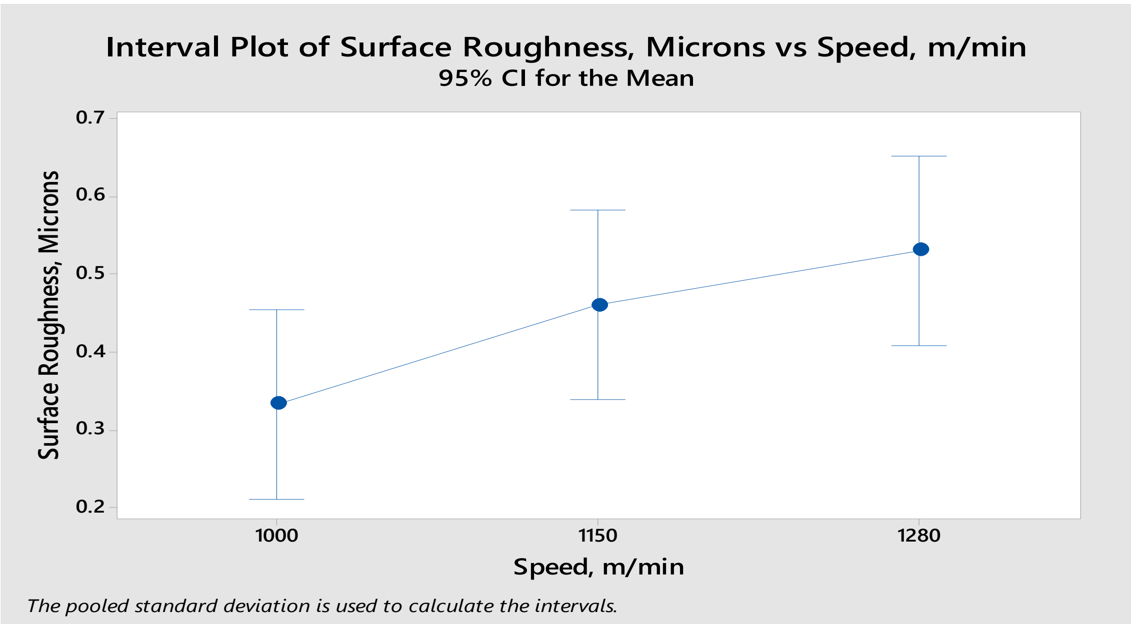

Figure 3: Interval plot of surface Roughness, Micron Vs Speed, m/min

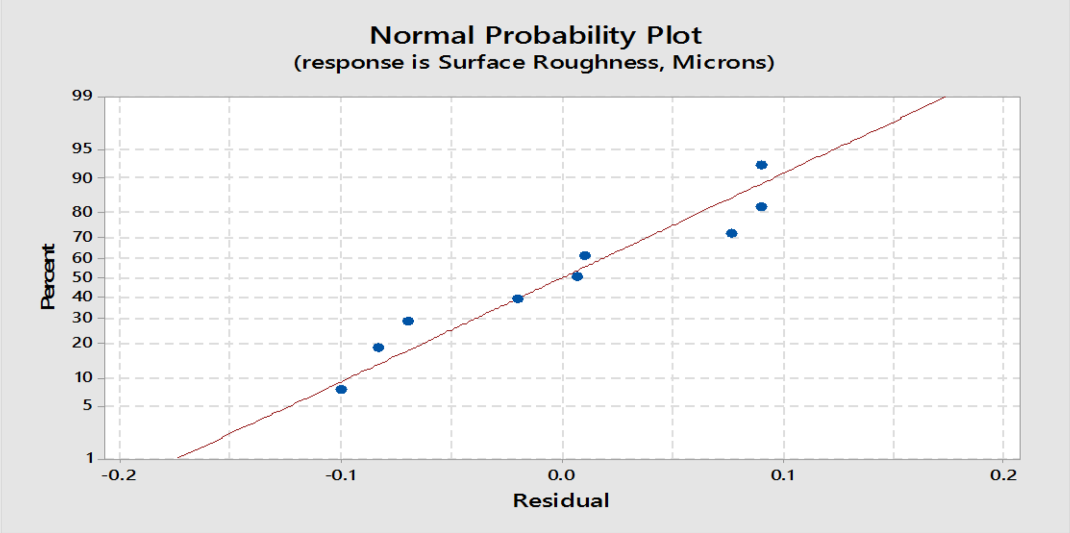

Figure 4: Normal Probability Plot for the surface roughness

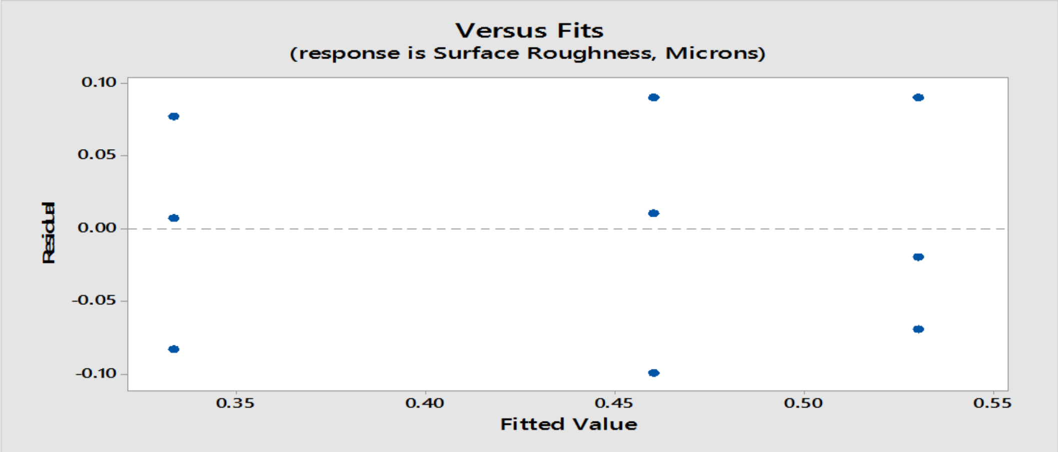

Figure 5: Versus Fits for the surface roughness

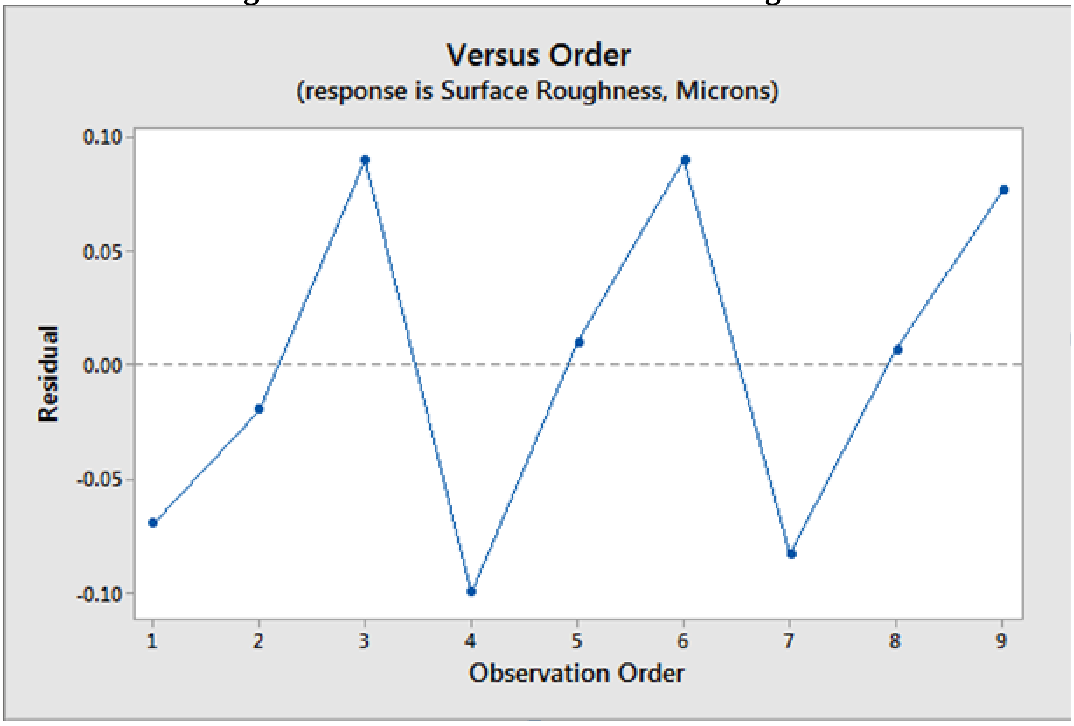

Figure 6: Versus Order for the surface roughness

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- **REGRESSION EQUATION**

The goal of regression analysis is to determine the values of parameters for a function that cause the function to best fit a set of data observations that you provide. In *linear regression*, the function is a linear (straight-line) equation. The relationship between cutting parameters (speed, feed and depth of cut) and the response (Surface roughness) was modeled by linear regression using the MINITAB-16 91 software.

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Regression Equation

Surface Roughness, Microns = -0.1077 + 0.000706 Speed, m/min - 2.833 Feed, mm/rev
                             - 0.033 DOC,mm

        S    R-sq  R-sq(adj)  R-sq(pred)
0.0200332  98.07%     96.92%      95.44%
```

Inspection of some diagnostic plots of the model was done to test the statistical validity of the models. The residuals could be said to follow a straight line in normal plots of residuals implying that the errors were distributed normally shown in Figure 7. This gives the support that the models prepared were significant and accurate. The residuals were randomly scattered within one constant variance across the residual versus the predicted plot shown in Figures 7 and it indicate that there is no obvious pattern and unusual structure present in the data which implies that the residual analysis does not indicate any model inadequacy.

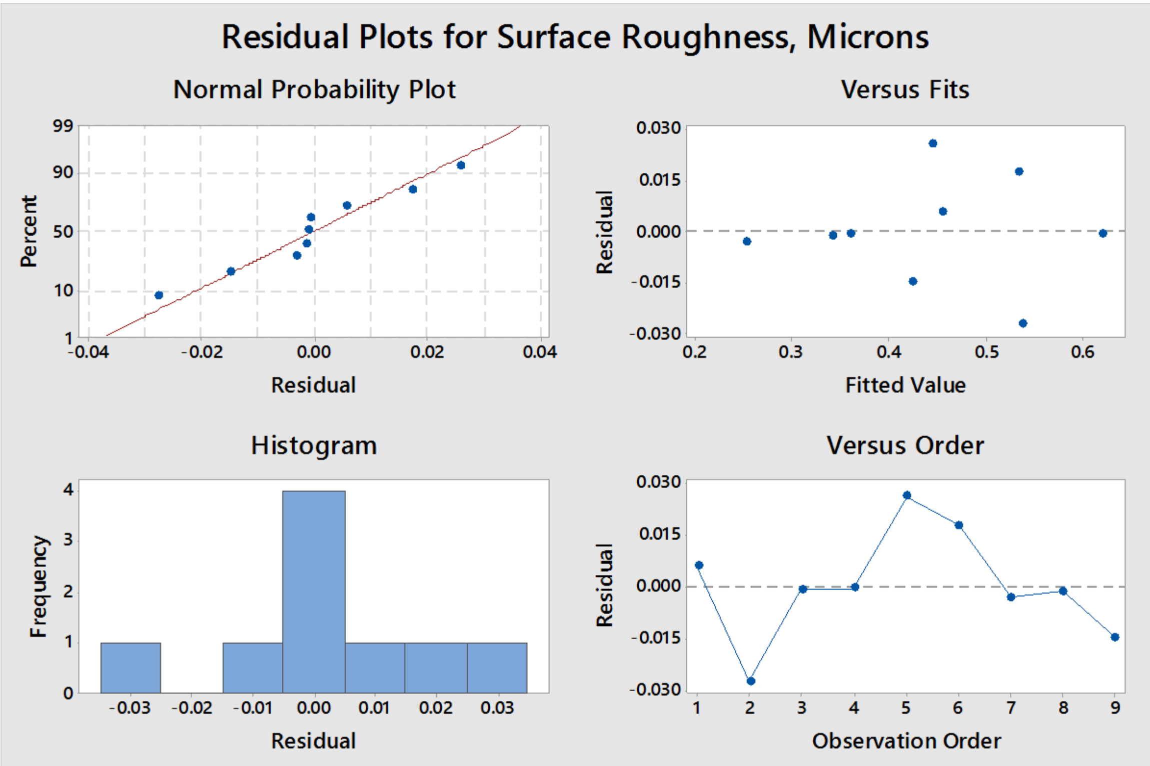

Figure 7: Residual plots for Surface Roughness, Microns

CONCLUSION:

From the experimental and predicted results the following conclusions can be drawn

- The normality plots show that the data collected is uniform and trustworthy in the statistical context
- L9 Array has been used to capture the input data with the response Surface Roughness
- Taguchi Analysis has indicated that the dominant process parameter is Speed followed Feed and further the Depth of Cut
- One-way ANOVA throws light on the extent of contribution of the dominant process parameter i.e. Speed

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- The Regression Analysis prescribes the equation that offers a relation of the input parameters that helps realize the given Response.
- The optimized set for process parameters has been derived and is advocated for use to realize the desired response

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