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Optimization of Tool life and MRR on CNC Drilling Machine for E350 HT Steel: A Minimum Quantity of Lubricant (MQL)

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Abstract: **Drilling is the fundamental operation of making a cylindrical hole in metal cutting industry. This dissertation report focuses on a productivity as well as sustainability project taken up in a "KEC International ltd, Jaipur". KEC International Limited is manufacturer of electric power transmission towers. The objective of present work is to optimize process parameter to be specific cutting speed, Feed and Hole diameter of E350 HT Steel. Experimentation was completed according to Taguchi trial. The L9 orthogonal array be utilize to study the control of different combinations of process parameter on the drilling quality. Two responses are found first one is material removal rate (MRR) and second is tool life. Minimum quantity lubrication (MQL) technique is use in this work. MQL fluid application method (for mineral and vegetable oils) is compared with Dry condition in this research. Analysis of variance (ANOVA) and single to noise ratio is to use to determine the importance of every process parameter on drilling.**

Keywords: **ANOVA, DOE, MQL, Tool Life.**

I. INTRODUCTION

Nowadays numerically control machines (CNC machines) are mainly used in production to obtain good surface area, close tolerance, complex geometric shapes, as well as high precision and precision that cannot be achieved with conventional machines. This thesis report focuses on a productivity and sustainability project that was launched in a "KEC International Ltd., Jaipur". The objective is to optimize the process parameters in terms of cutting speed, feed rate and hole diameter of the E350 HT Steel. The experiment was completed according to the Taguchi trial. The L9 orthogonal matrix is used to study the control of various combinations of process parameters on drilling quality. Three responses were found: the material removal rate (MRR) life of the tool. In this work, the Minimum Quantity Lubrication (MQL) technique is used. The method of application of the MQL fluid (for mineral and vegetable oils) is compared with the dry state in this study. The Minimum Quantity Lubrication Technique (MQL) is one of the most important methods for environmentally friendly production. As consider the green manufacturing aspects here experimental work is conducted on the environment friendly machining which refers to vegetable oil (Canola) as cutting fluids. This vegetable based cutting fluids medium compared with mineral oil and dry condition.[17]

This Work is focus on productivity improvement project taken up in a "KEC International Ltd, Jaipur", which is headquartered in Mumbai and manufacturer of power electric transmission towers.

The problem faced by production department in drilling process is that they knows only range of processing parameters within which the machine can do work on HT sections but they don't know the best value of parameters and combination of parameters. If no accurate data available, the operator need more time to setting up processing parameter to get holes. For this study spindle speed, feed rate and Hole diameter parameters involved in producing holes.

Green manufacturing is an element of sustainability. Green manufacturing is committed to preserving the environment, optimizing recycling, avoiding wastage or reducing consumption, conserving raw materials, reducing energy consumption and eliminating non-environmentally friendly manufacturing processes. A traditional manufacturing is only focus on the productivity and a green manufacturing focus on sustainability along with customer satisfaction.[16] There are various objective of green manufacturing like minimize the production of green house gases, maximize recycling, increase product life cycle, eliminate waste, conserve energy and raw materials and eliminating non eco friendly process. At the economic, ecological and social levels, these three pillars constitute sustainable production. The social field of sustainable production concerns human security and its benefits for society. Workers provide a safe and healthy environment with due regard for their safety, workplace lighting and noise levels [16]. There are several dangers such as hypertension, cardiovascular effects due to intense noise, aerosol concentration, etc.

Examples of sustainable green production activities include reducing hazardous emissions, eliminating waste of resources and recycling, industrial energy use and industrial pollution, extending the life cycle of the product and adopting a lighter approach.[17]

In this research, ecological production in the field of drilling processes is used. Drilling was considered in this study as a "single manufacturing process" and the green focus data were collected using the unit method. Minimum Quantity Lubrication (MQL) is a process in which small droplets of oil are sprayed into the jet of compressed air. Lubricant is dispensed directly into the cutting area and provides effective lubrication. It is a substitute for the immense flow of coolant. When using the MQL method, special adjustments and precautions are necessary to allow the fluid to effectively puncture the cutting area [16]. Most researchers have shown that MQL is one of the most environmentally friendly manufacturing techniques and alternative cutting fluids, such as the use of canola oil in a drilling process.[17].

II. MATERIAL PROPERTIES OF PLATE AND TOOL

CNC Drilling Machine:-

Computer Numerical Control is a particular sort of sensitive automation.CNC is one in which the limits and developments of a machine gadget are obliged by strategies for a prepared program containing coded data. CNC may be seen as strategies for working a machine utilizing discrete numerical characteristics fed into the machine, where the required data specific information is secured on a kind of data media, for instance, hard circle, DVD, USB flicker drive or Slam card, etc. CNC can control the developments of the work piece or instrument. The input parameters are feed, significance of cut, speed, hub on/off and coolant on/off. CNC system contains the going with 6 essential segments

(i) Input Gadget

(ii) Machine control unit

(iii) Machine instrument

(iv) Driving Framework

(v) Feedback contraptions

(vi) Show unit

Fig 1: FICEP DB – 363 CNC Drilling Machine

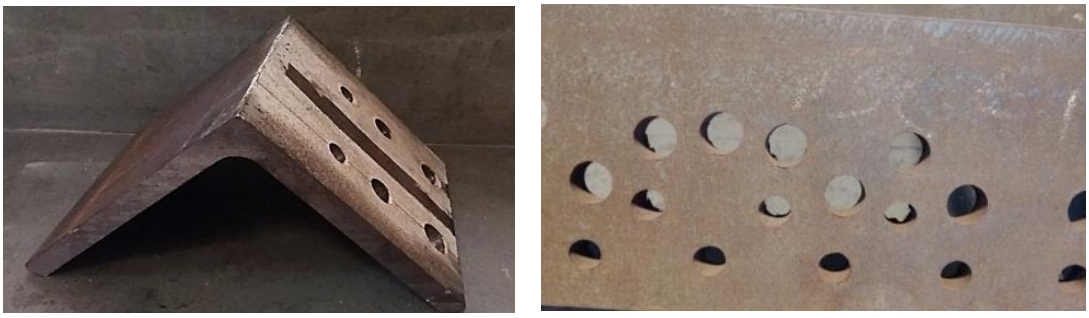

Fig.2: HT 200 x 200 x 16 Angle work piece

Drilling operation will be performed on High Tensile work Piece. The structure of High elastic steel (E350 grade) is C (0.2%), Mn (1.55%), S (0.045%), P (0.045%), Si (0.45%). A HT Steel point evaluation of IS 2062 E 350 of size 200 x 200 x 16 mm is utilized for boring task. Mechanical Properties of HT E350 steel is Tensile (490Mpa), Yield pressure (330 Mpa)

DrillBit Materials

• Steel bits function admirably for exhausting in softwood, however less rapidly in hardwood.

• High-Speed Steel (HSS) bits are more enthusiastically than steel bits. They oppose warmth better and remain sharp more. They can penetrate wood, fiberglass, PVC (polyvinyl chloride) and delicate metals, for example, aluminum.

• Cobalt bits are amazingly hard and scatter heat rapidly. They're generally utilized for exhausting in aluminum and intense metals, for example, tempered steel.

• Black oxide covered HSS bits have a completion intended to help oppose consumption and increment toughness. They last longer than fundamental HSS bits and function admirably on an assortment of materials, including metal, hardwood, softwood, PVC, and fibreglass.

• Titanium covered HSS bits produce less erosion. They're harder than essential HSS bits and remain sharp more. They work for boring wood, metal, fibreglass, and PVC.

• Carbide tipped bits remains sharp any longer than steel, HSS or titanium bits. They're successful for boring tile and brickwork.[9]

Fig.3: HSS Drill Bit

One of our devices for the CNC penetrating activity will be the rapid steel. Fast steel (HSS) are utilized for making boring devices, we utilized drill point edge is 118º. This property permits HSS to bore quicker than high carbon steel. HSS contains high hardness structure are carbon (0.6% to 0.75 %), Tungsten (14% to 20%), Chromium (3% to 5%), Vanadium (1% to 1.5%), Cobalt(5% to 10%) and remaining is iron.

III. DESIGN OF EXPERIMENT (TAGUCHI METHOD)

In this study design of experiment methodology is adopted for cases generation. Taguchi method was developed by the Dr. Genichi Taguchi. It is a statistical method which is used to predict performance of response generated by various input factors and levels. This method applies the conceptual quality loss function known as Signal to Noise (S/N Ratio) ratio which is the measure of performance. Quality Loss Function shown by figure 1

Signal to Noise (S/N Ratio) is the ratio of the mean (signal) and the standard deviation (noise) of the response and depends on the input factors apply for research or study. S/N ratio uses mean data and variability into its calculation three processes having used in study by S/N ratio are following:

- Nominal is best
- Large is Best
- Small is Best

Optimal combination of input factors are always highest values of S/N ratio based data obtained data. Applicable formulas used by S/N ratio are shown below. All notations are carrying their usual meaning.

Nominal is Best:

$$\eta = 10\log_{10}\frac{1}{n}\sum_{i=1}^{n}\frac{\mu^2}{\sigma^2} \quad (1)$$

Smaller is best:

$$\eta = -10\log_{10}\frac{1}{n}\sum_{i=1}^{n}{y_i}^2 \quad (2)$$

Larger is best:

$$\eta = -10\log_{10}\frac{1}{n}\sum_{i=1}^{n}\frac{1}{{y_i}^2} \quad (3)$$

In this study small is better S/ N ratio method is used. Taguchi method is dependent on data which is coming out from designed experiments using taguchi made orthogonal arrays which uses fixed specific combinations of factors and their levels so all input factor and their levels are discussed in detail shown in below.

Factor and Levels

Design of Taguchi orthogonal array is only possible by proper selection of factors and their levels. In this study four factors are used for orthogonal array, every factor has four levels. Available DOE table is L9.

TABLE 1: FACTOR AND THEIR LEVALS

Factor/ Level	**Spindle speed (in**	**Feed rate (in mm/min)**	**Hole dia (in mm)**
1	217	50	18.5
2	260	70	22.5
3	310	100	26.5

TABLE 2: EXPERIMENTS ACCORDING TGUCHI METHOD

Sr. No.	**Spindle Speed (in rpm)**	**Feed Rate (in mm/min)**	**Hole Dia (mm)**
1	217	50	18.5
2	217	70	22.5
3	217	100	26.5
4	260	50	22.5
5	260	70	26.5
6	260	100	18.5
7	310	50	26.5
8	310	70	18.5
9	310	100	22.5

TABLE 3: EXPERIMENTAL DATA RECORD DURING RESEARCH WORK

No. of trial	Spindle Speed	Feed Rate	Hole Dia	Mass = (density * volume) gm	Cutting Time	No. of holes drilled
1	217	50	18.5	33.61	22	62
2	217	70	22.5	49.72	16	49
3	217	100	26.5	68.97	14	43
4	260	50	22.5	49.72	21	62
5	260	70	26.5	68.97	17	50
6	260	100	18.5	33.61	13	42
7	310	50	26.5	68.97	20	65
8	310	70	18.5	33.61	15	47
9	310	100	22.5	49.72	14	47

Three responses material removal rate, surface roughness and tool life are solved in present study.S/N analysis performed for tool life and regression analysis performed for MRR & surface roughness using MINITAB 17. All steps are presented in next section

TABLE 4: MRR AND TOOL LIFE FOR ALL 9 EXPERIMENTS

Sr No.	Spindle speed rpm	Feed rate mm/min	Hole Dia. mm	MRR (gm/sec)			Tool life min
				Dry	MQLm	MQLv	
1	217	50	18.5	1.528	1.495	1.595	23
2	217	70	22.5	3.107	3.212	3.124	13
3	217	100	26.5	4.926	3.54	3.214	10
4	260	50	22.5	2.368	2.428	2.318	22
5	260	70	26.5	4.057	3.254	3.354	14
6	260	100	18.5	2.586	2.827	2.627	9
7	310	50	26.5	3.448	3.504	3.238	22
8	310	70	18.5	2.241	2.239	2.349	12
9	310	100	22.5	3.551	3.419	3.518	11

IV. RESULT AND DISCUSSION

Result Analysis for Tool Life

Tool life is define as the time interval for which the works satisfactorily (defined by failure criterion). It is use to evaluate the performance of tool materials; assess mach inability of the work piece materials and about cutting condition. Tool life depending upon the situation, such as no. of pieces of work machined, cutting speed, and feed rate, depth of cut, tool geometry, tool materials, and volume of material removed etc.

There are three ways to expressing tool life

Time Period

No. of components machined

Vol. of materials removed

Practically tool life calculated by –

Tool life = Total numbers of holes drilled * Time taken in one hole

Therefore to drill 62 holes in case 1and cutting time 22 sec. it takes:

62*22= 1364seconds, 1364/60= 23 minutes.

Similarly all values obtained which shown in Table 5.1

Calculation of S/N Ratio for Tool life

The Taguchi robust design method is to identify control factors that reduce the variability of a product or process by minimizing the effects of uncontrollable factors (noise factors). This analysis identifies the factors that have the most influence on the response and also provides a series of input factor levels that provide the desired result. The resulting tool life is used to calculate the signal-to-noise ratio (S/N) to obtain the best setting. The signal-to-noise ratio (S/N) is calculated according to Table 5.2. The life expectancy should be high for better productivity. Therefore, the larger is better the calculated S/N ratio. To calculate the signal-to-noise ratio in this case, it is better to have an equation. The equation for obtaining S / N values is shown below.

S/N = -10log10 (MSD)

For larger is better

$$\mathrm{MSD} = \frac{1}{n}\sum_{i=1}^{i=n}\frac{1}{{y_i}^2}$$

MSD = Mean Square Deviation

y = Tool Life

n = No. of repetitions

S/N Ratio for trial no. 1

n = 1, y1 = 23

$$S/_{N1}\ \mathrm{Ratio} = -10\log_{10}\frac{1}{1}\left(\frac{1}{23^2}\right)$$

$$S/_{N1}\ \mathrm{Ratio} = 27.2346$$

S/N Ratio for trial no. 2

n = 1, y2 = 13

$$S/_{N2}\ \mathrm{Ratio} = -10\log_{10}\frac{1}{1}\left(\frac{1}{13^2}\right)$$

$$S/_{N2}\ \mathrm{Ratio} = 22.2789$$

S/N Ratio for trial no. 3

n = 1, y3 = 10

$$S/_{N3}\ \mathrm{Ratio} = -10\log_{10}\frac{1}{1}\left(\frac{1}{10^2}\right)$$

$$S/_{N3}\ \mathrm{Ratio} = 20.0000$$

Similarly S/N ratio for other trials is obtained and shown in Table 5.2

TABLE 5: S/N RATIO FOR TOOL LIFE IN EACH TRIAL

Trial	Spindle Speed (rpm)	Feed Rate (mm/min)	Hole Dia (mm)	Tool life (min.)	S/N Ratio
01	217	50	18.5	23	27.2346
02	217	70	22.5	13	22.2789
03	217	100	26.5	10	20.0000
04	260	50	22.5	22	26.8485
05	260	70	26.5	14	22.9226
06	260	100	18.5	9	19.0849
07	310	50	26.5	22	26.8485
08	310	70	18.5	12	21.5836
09	310	100	22.5	11	20.8279

Calculation of S/N Ratio for Each Level of Each Factor

S/N ratio of level 1 for spindle speed 217 rpm is obtained as follows

$$\text{ForLevel } 1 = \frac{(27.2346 + 22.2789 + 20.0000)}{3} = 23.17$$

S/N ratio of level 1 for Feed Rate 50 mm/min is obtained as follows

$$\text{ForLevel } 1 = \frac{(27.2346 + 26.8485 + 26.8485)}{3} = 26.98$$

S/N ratio of level 1 for Holedia 18.5mm. is obtained as follows

$$\text{ForLevel } 1 = \frac{(27.2346 + 19.0849 + 21.5836)}{3} = 22.63$$

Similarly the S/N ratio for each level of each factor is obtained, and the results of S/N ratio for each level are shown in table 5.3

TABLE 6: RESPONSE TABLE OF S/N RATIO FOR EACH LEVEL OF EACH FACTOR

Level	**Spindle Speed (rpm)**	**Feed Rate (mm/min)**	**Hole Dia. (mm)**
1	23.17	26.98	22.63
2	22.95	22.26	23.32
3	23.09	19.97	23.26
Delta	0.22	7.01	0.68
Rank	**3**	**1**	**2**

The Tool Life data is also analyzed by using the Minitab software. The results obtained by Minitab are shown in Fig 4

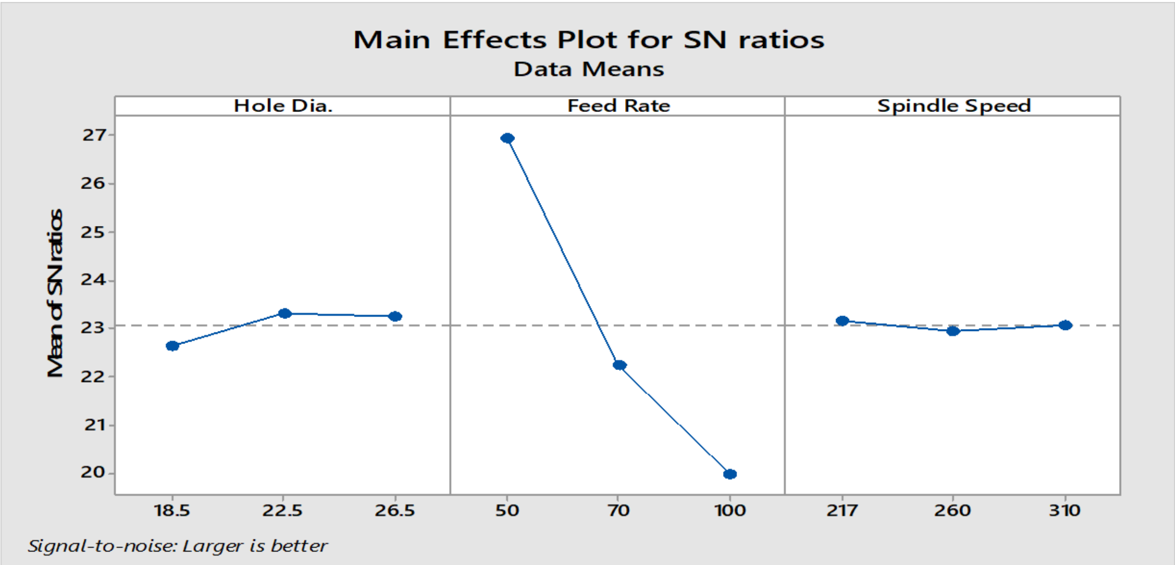

Fig.4: Main effect plot for S/N ratio for Tool Life

From the S/N ratio response as shown in Table 5.3 and Fig 5.1 the best combination of parameters are spindle speed (A) followed by feed rate (B) and hole dia. (C) can be represented by A1B1C2. Table 5.4 shows the summary of best combinations of parameters setting.

TABLE 7: BEST PARAMETERS SETTING FORTOOL LIFE

Factors	**Values**
Spindle Speed	217 rpm
Feed rate	50 mm/min
Hole Dia.	22.5 mm

Result Analysis for Martial removal rate (MRR)

As seen in table 5.1 MRR and Ra for all 9 experiments are presented. Theoretically MRR is calculatedwith the help of simple formula

MRR (mm3/min) = (πD2 / 4)* (f)

D = Hole diameter (mm)

f = feed rate (mm/min)

But here in this work MRR calculated by

MRR = Mass of material removed / Cutting time

In case 1(Dry Condition)

Material thickness or depth of cut (h) = 16mm

Density = 0.0078 gm/mm3

Volume = πD2h/4 (mm3) = 4309.34

Mass of material removed = Density * Vol. = 33.61gm

Cutting Time for case 1 = 22sec

MRR = 33.61/22 = 1.528gm/sec

In case 1(MQLm)

Mass of material removed = Density * Vol. = 33.61gm

Cutting Time for case 1 = 22.4sec

MRR = 33.61/22 = 1.495 gm/sec

In case 1(MQLv)

Mass of material removed = Density * Vol. = 33.61gm

Cutting Time for case 1 = 21.7sec

MRR = 33.61/22 = 1.595 gm/sec

Similarly all values obtained which shown in Table 5.1

ANOVA Analysis for MRR

ANOVA calculation gives information about the significance of parameters. By using ANOVA method we can get most significant parameter as well as percentage contribution of that parameter on output variables. Here for empirical system use multiple linear regressions. The corresponding ANOVA table for multiple regressions is shown below. For p explanatory variables and N total no of experiment.

TABLE 8: ANOVA TABLE FOR MULTIPLE REGRESSION

Source	Degrees of Freedom	Sum of squares	Mean of Square	F value
Regression	P	SSM = (SSA + SSB + ...+ SS_N)	SSM/DFM	MSM/MSE
Error	N - p– 1	SSE = SST – (SSA + SSB +.....+ SS_N)	SSE/DFE	
Total	N– 1	$SS_T = (Y_{S1}^2 + Y_{S2}^2 + \cdots + Y_{SN}^2) - \frac{(Y_{S1} + Y_{S2} + \cdots + Y_{SN})^2}{N}$	SST/DFT	

n multiple regression, the MSM / MSE test statistic has a distribution F (p, N-p-1). The null hypothesis indicates that μ1 = μ2 = ... = μp = 0, and the alternative hypothesis simply states that at least one of the parameters μj is 0, j = 1, 2 ... p. The big values of the test statistics speak against the null hypothesis. The test F does not indicate which of the parameters μj is different from zero, except that at least one of them is linearly related to the response variable. Table 5.5 presents the analysis of variance for

Where,

DF = Degree of freedom

SS = Sum of squares

MS =mean squares

F = F- Value, Calculate by dividing the factor MS by the error MS.

P – P- Value is used to rejection of null hypothesis in hypothesis test. The available range of P value is 0 to1.But is compared as alpha value. In this study 95% CI (Confidence interval) use and 0.05 is value for alpha.

TABLE 9: ANALYSIS OF VARIANCE FOR MRR

Source	**DF**	**SS**	**MS**	**F Value**	**P Value**
Regression	5	13.6735	2.7347	23.99	0.000
Spindle Speed (A)	1	0.1810	0.1810	1.59	0.221
Feed Rate (B)	1	3.6596	3.6596	32.11	0.000
Hole Dia (C)	1	9.4605	9.4605	83.00	0.000
Medium	2	0.3724	1.862	1.63	0.219
Error	21	2.3936	0.1140		
Total	26	16.0671			

The P value is use to determine the significant of the factors, typically compare against an alpha value of 0.05. If the p-value is lower than 0.05, then the factor is significant. ANOVA analysis is tell that Hole dia. and feed rate factor has very low p value (0.000), and has acceptable p value for two factors. So it can conclude that MRR are affected by mainly Hole dia. and feed factor. Model equations are generated for three cutting medium but when perform error analysis on model equations these equations show good relation with prediction of same factors. One modele quation is also predicted in this study for MRR which are present in below and this equation is predicted by using ANN. Analysis of variance is calculated for 95%Confidence interval (CI) for linear analysis using Minitab software.

Model equations for MRR are presented in table 5.7.

The ratio SSR/SST = R^2 is known as the squared multiple correlation coefficient. ThisR^2 value is the proportion of the variation in the response variable. The square root of R^2 is called the multiple correlation coefficients, the correlation between the observations. The squared multiple correlationR^2 = SSR/ SST = 13.6735/ 16.0671=0.8510, indicating that 85.10 % of the variability

TABLE 10: REGRESSION EQUATION FOR MRR

Medium	**Regression Equation**
Dry	MRR = -2.867 + 0.00215 Spindle Speed + 0.01792 Feed Rate + 0.1812 Hole Dia.
MQLm	MRR = -3.077 + 0.00215 Spindle Speed + 0.01792 Feed Rate + 0.1812 Hole Dia.
MQLv	MRR = -3.142 + 0.00215 Spindle Speed + 0.01792 Feed Rate + 0.1812 Hole Dia.

The significance of the regression models ought to be checked to affirm that all models have extricated all pertinent data from every single trial case. On the off chance that the after-effects of the relapse conditions are sensible, the appropriation of build-ups ought to be ordinary.

The typical likelihood of MRR is outlined in fig. 5.2. Every single exploratory datum focuses are spoken to by a direct red line with little remaining qualities. Residuals are the contrast between the watched worth and the relating balanced qualities. Leftover worth is valuable for relapse and ANOVA since it demonstrates the degree to which a model records for variety in watched information. It gives great proof of the unwavering quality of model conditions for future application.

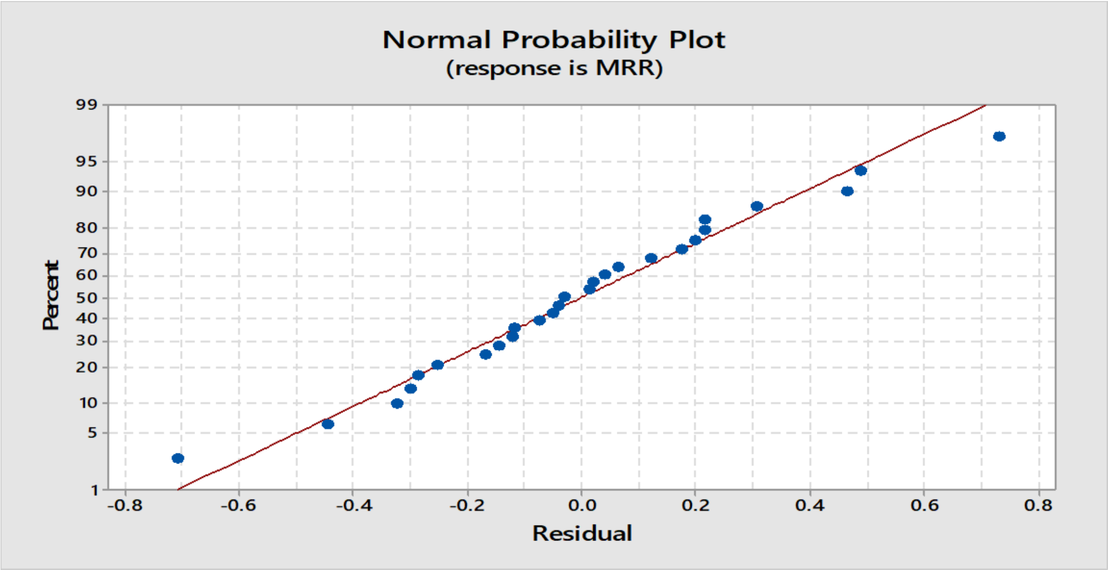

Fig.5: Normal probability for MRR

Time Series graph based on a type of grouping. The goal of time series analysis is to find patterns in the data and use the data for predictions. Minitab creates a graph for each distinct combination for different cutting medium (Dry, MQLM, and MQLV). There is no major change in MRR under different cutting medium.

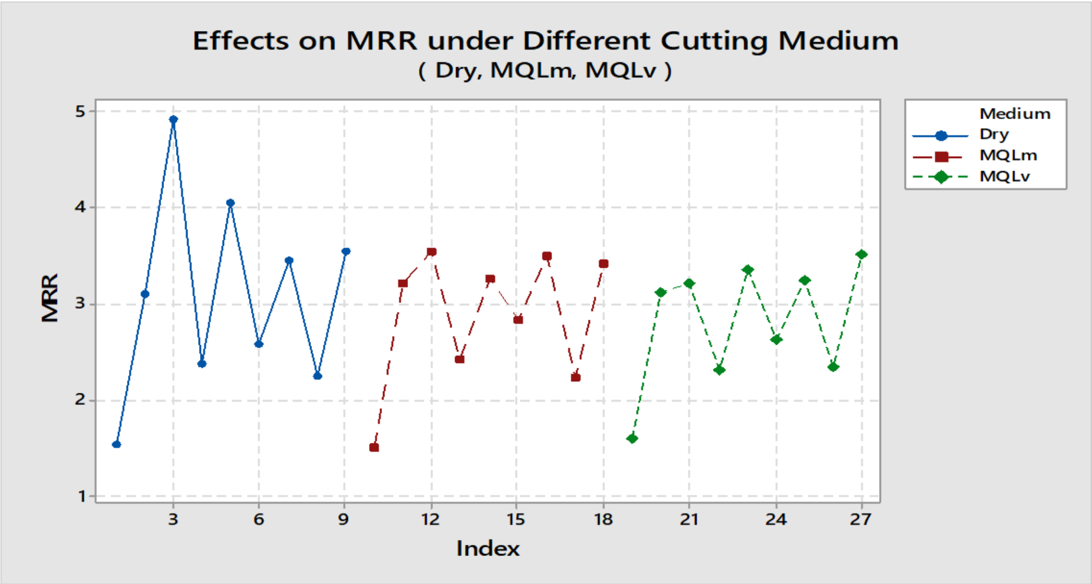

Fig.6: Time Series graph for MRR

V. CONCLUSION

In this study the analysis of drilling operation using MQL technique. Total 9 experiments are designed according to Taguchi methods and consider three cutting medium (Dry, MQLm, and MQLv). In this study three factors are used.

Main conclusions from this study is

S/N ratio analysis is performed for tool life and it is concluded that feed rate is most critical factor for tool life.

Best parameter for tool life:

Factors	Values
Spindle Speed	217 rpm
Feed rate	50 mm/min
Hole Dia.	22.5 mm

Multiple linear regressions modelling apply on MRR and which show Spindle speed and Feed rate is most significant factor for surface roughness and Feed rate and hole dia. is most significant factor for MRR

Model equations are generated for three cutting medium but when perform error analysis on model equations these equations show good relation with prediction of same factors. Which means more attraction is necessary on numerical simulation and design of experiments for future reference.

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