Multi Objective Optimization and Comparission of Process Parameters in Turning Operation

Jino Joy Thomas
Department of Mechanical Engineering
Musaliar College of Engineering And Technology
Pathanamthitta, Kerala, India

Assistant Professor Vishnu Prasad V N
Department of Mechanical Engineering
Musaliar College of Engineering And Technology
Pathanamthitta, Kerala, India

***Abstract*— It is an important task to select cutting parameters for achieving high cutting performance (cutting speed, feed rate and depth of cut). Considering the machining process, it deals with the surface finish and material removal rate. For improved productivity, the condition is minimum surface roughness with maximum material removal rate at minimum tool wear rate. The surface roughness plays an important role in quality (wearing rate, surface friction) of the product and material removal rate is dealing with productivity. The material selected for this work is EN 31 steel (AISI 52100). The tool selected for the experimental study is CARBIDE tool. Here it aim is to optimize the process parameters in turning operation of AISI 1024 steel for minimum surface roughness and maximum material removal rate. The methods selected for the optimization are ANOVA method and REGRESSION ANALYSIS. The software selected for the analysis is MINITAB 17.**

Keywords—EN 31, surface roughness, material removal, ANOVA, REGRESSION ANALYSIS.

I. INTRODUCTION

The optimization of cutting parameter is the key component in planning of machining processes. The manufacturing processes are characterized by a multiplicity of dynamically interacting process variables. Optimization of machining parameter not only increases the utility for machining economics, but also the product quality to a great extent. However, deep analysis of cutting involves certain costs, particularly in case of small series. In case of individual machining it is particularly necessary to shorten as much as possible the procedure for determination of the optimum cutting parameters, otherwise the cost of analysis might exceed the economic efficiency which could be reached if working with optimum conditions. From optimization of the machine operations the quantitative methods have been developed with consideration of a single objective, such as minimization of cost or maximization of profit etc. For the process of the single objective optimization several different techniques have been proposed, such as the differential calculus, regression analysis, linear programming, geometric and stochastic programming, computer simulating. While most researches hitherto are based on the single-objective optimization, there have been some successful attempts also with the multi-objective optimization. In many real applications the process designers face on regular basis the problem of simultaneous optimization of several objectives. This project involves hard turning operation. It is an important task to select cutting parameters for achieving high cutting performance. However, this does not ensure that the selected cutting parameters (cutting speed, feed rate, depth of cut) have optimal or near optimal cutting performance of CNC machine and environment. In this experiment, the design is developed by Taguchi technique. Taguchi method is used to determine the desired cutting parameters more efficiently.

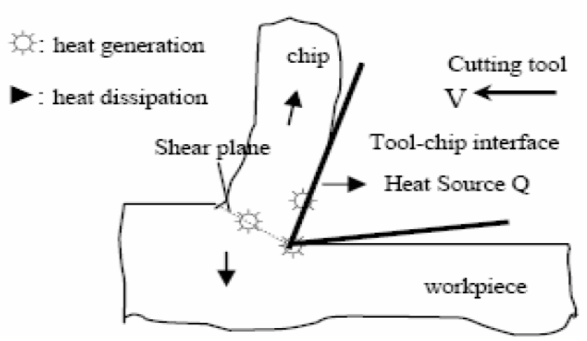

Fig.1. Turning Process

A. Objectives

The objective of this work is to achieve high material removal rate (MRR) and low surface roughness in turning process by settings of optimal/near-optimal process parameter (cutting speed, feed, depth of cut) through Taguchi method with multiple performance characteristics.

- The major steps involved in multi objective optimization problem in turning process.
- To set the levels for the process parameter values with in the variable bounds range. The experiments were conducted based on L27 Taguchi orthogonal array.
- To predict optimal process parameter in turning process by using Taguchi method with multiple performance characteristics.
- To predict, which parameter significantly affects the overall performance characteristics.
- To develop mathematical model for the objective function using Regression analysis.

B. *Multi Objective Optimization*

Multi objective optimization involves minimizing or maximizing multiple objective functions subject to a set of constraints. Example problems include analyzing design tradeoffs, selecting optimal product or process designs, or any other application where you need an optimal solution with tradeoffs between two or more conflicting objectives.

- Goal attainment: reduces the values of a linear or nonlinear vector function to attain the goal values given in a goal vector. The relative importance of the goals is indicated using a weight vector. Goal attainment problems may also be subject to linear and nonlinear constraints.
- Minimax: minimizes the worst-case values of a set of multivariate functions, possibly subject to linear and nonlinear constraints.
- Multi objective genetic algorithm: solves multi objective optimization problems by finding an evenly distributed set of points on the Pareto front. This approach is used to optimize smooth or non smooth problems with or without bound and linear constraints.

Both goal attainment and minimax problems can be solved by transforming the problem into a standard constrained optimization problem and then using an active-set approach to find the solution.

II. LITERATURE SURVEY

S.Ganapathy[1] developed optimization of turning process through Taguchi and simulated annealing algorithm, and compared both.

H.M. Somashekara and Dr. N. Lakshmana Swamy[2] an attempt has been made to optimize the process parameters using Taguchi Technique,S/N ratio and ANOVA analysis were also performed to obtain significant factors influencing Surface Roughness.

Saravanan et al**.**[3] applied simulated annealing (SA) and genetic algorithm (GA) to determine the optimal machining parameters for continuous profile machining with respect to the minimum production cost subject to a set of practical constraints.

Kolahan and Abachizadeh [4] also developed a simulated annealing algorithm to optimize machining parameters in turning operation on cylindrical work pieces.

III. METHODOLOGY

A *Machining Operation*

The turning operation is conducting in CNC machine. LMW, Smart Jr CNC Lathe is using for this purpose. Numerical control (NC) is the automation of machine tools that are operated by precisely programmed commands encoded on a storage medium, as opposed to controlled manually by hand wheels or levers, or mechanically automated by cams alone. Most NC today is computer (or computerized) numerical control (CNC),[1] in which computers play an integral part of the control. In modern CNC systems, end-to-end component design is highly automated using computer-aided design (CAD) and computer-aided manufacturing (CAM) programs. The programs produce a computer file that is interpreted to extract the commands needed to operate a particular machine by use of a post processor, and then loaded into the CNC machines for production. Since any particular component might require the use of a number of different tools – drills, saws, etc., modern machines often combine multiple tools into a single "cell". In other installations, a number of different machines are used with an external controller and human or robotic operators that move the component from machine to machine. In either case, the series of steps needed to produce any part is highly automated and produces a part that closely matches the original CAD design. Motion is controlled along multiple axes, normally at least two (X and Y) and a tool spindle that moves in the Z (depth).

Fig.2 LMW, Smart Jr CNC Lathe

B *Turning*

Turing is one of the basic machining processes. It is used to remove the work piece material with the help of the cutting tool. By using the turning process we can produce wide variety of products. The turning operation is performed on the lathe machine.

C. *Material Selection*

Fig.3 EN 31 Steel

It is a steel in which the main industrial alloying constituent is carbon in the range of 0.12-2%. Steel is considered to be carbon steel. As the carbon percentage content rises, steel has the ability to become harder and stronger through heat treating; however, it becomes less ductile. Regardless of the heat treatment, a higher carbon content reduces weldability. In carbon steels, the higher carbon content lowers the melting point. Carbon steel is broken down into four classes based on carbon content.

D. *Tool selection*

The selection of cutting - tool materials for a particular application is among the most important factors in machining operations. Consequently a cutting tool must posses the following characteristics

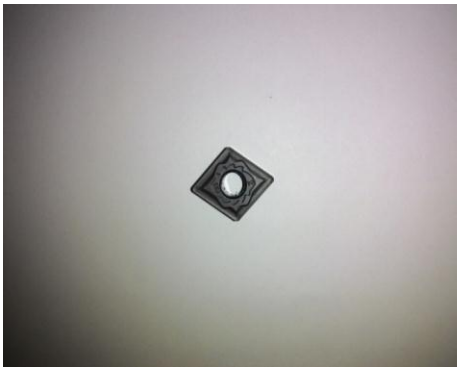

Fig. 4 CNMG 120408-SMR 1105

E. *Design of Experiment*

Taguchi method is a powerful tool for the design of high quality systems. It provides simple, efficient and systematic approach to optimize designs for performance, quality and cost. Taguchi method is efficient method for designing process that operates consistently and optimally over a variety of conditions. To determine the best design it requires the use of a strategically designed experiment. Taguchi approach to design of experiments in easy to adopt and apply for users with limited knowledge of statistics, hence gained wide popularity in the engineering and scientific community. L27 array is selected for the experiment, and the implimented cutting parameters are shown bellow.

Implemented cutting parameters

TABLE 1 Implemented Cutting Parameters

Parameters	Unit	Level 1	Level 2	Level 3
Cutting speed	m/min	100	150	200
Feed	mm/rev	0.05	0.08	0.12
Depth of cut	mm	0.1	0.15	0.2

IV. EXPERIMENTAL STUDY

A. *Turning*

The experimental study was done on LMW, Smart Jr CNC machine. The result is tabulated to the bellow table.

TABLE 2 Experimental results

Sl No	Speed m/min	Feed mm/rev	DOC mm	Time min	Initial weight gm	Final weight gm	MRR gm/min	Ra µm	Rq µm	Rz µm
1	100	.05	0.1	4.8	331.1	325.850	1.25	1.850	2.286	11.126
2	100	.05	0.15	4.10	332.220	324.420	1.9049	2.237	2.761	12.019
3	100	.05	0.2	4.24	334.860	323.4	2.7028	2.065	2.517	11.079
4	100	.08	0.1	2.41	334.930	327.220	3.1991	2.669	3.252	15.118
5	100	.08	0.15	2.45	332.62	324.410	3.3510	2.626	3.263	15.364
6	100	.08	0.2	2.48	330.920	320.810	4.0766	1.773	2.226	10.883
7	100	.12	0.1	1.48	328.543	320.540	5.4074	2.285	2.825	13.234
8	100	.12	0.15	1.49	331.920	323.830	5.4295	2.361	3.010	14.355
9	100	.12	0.2	1.52	334.500	324.020	6.8947	2.509	3.160	14.949
10	150	.05	0.1	3.02	333.210	325.580	2.5264	2.134	2.600	11.220
11	150	.05	0.15	2.52	332.970	325.390	3.0079	2.355	3.050	14.736
12	150	.05	0.2	2.53	330.160	321.360	3.4782	2.379	2.972	13.555
13	150	.08	.1	1.51	333.1	326.11	4.629	2.174	2.650	11.69
14	150	.08	.15	1.48	332.74	325.12	5.148	1.827	2.295	11.55
15	150	.08	.2	1.50	333.53	324.53	6	2.225	2.901	13.09
16	150	.12	.1	1.10	333.45	327.16	5.718	2.152	2.72	13.01
17	150	.12	.15	1.11	335.69	326.4	8.369	2.345	2.851	12.59
18	150	.12	.2	1.16	335.23	325.63	8.275	2.205	2.836	13.95
19	200	.05	.1	2.08	333.98	327.46	3.134	1.754	2.161	9.674
20	200	.05	.15	2.15	333.35	325.07	3.853	2.162	2.678	12.07
21	200	.05	.2	2.13	335.4	325.75	4.530	2.320	2.781	11.55
22	200	.08	.1	1.27	334.17	327.36	5.362	1.979	2.423	11.50
23	200	.08	.15	1.23	332.71	324.79	6.439	1.906	2.345	11.40
24	200	.08	.2	1.25	334.01	324.43	7.664	2.397	2.994	14.53
25	200	.12	.1	0.59	332.47	324.56	13.40	2.581	3.284	16.73
26	200	.12	.15	0.52	334.24	326.78	14.34	2.630	3.236	15.19
27	200	.12	.2	0.54	332.5	324.25	15.27	2.665	3.194	14.1

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 06, June - 2017

B. *Surface Roughness*

Surface roughness is an important measure of product quality since it greatly influences the performance of mechanical parts as well as production cost. Surface roughness has an impact on the mechanical properties like fatigue behavior, corrosion resistance, creep life, 27 etc. It also affects other functional attributes of parts like friction, wear, light reflection, heat transmission, lubrication, electrical conductivity, etc. Before surface roughness, it is also necessary to discuss about surface structure and properties, as they are closely related. The machine which is to be used to measure surface roughness is given bellow in the figure.

Fig.5 MITUTOYO SJ-410 DIGITAL

The surface roughness graph which is to be taken from MITUTOYO SJ-410 DIGITAL is given below in the figure.

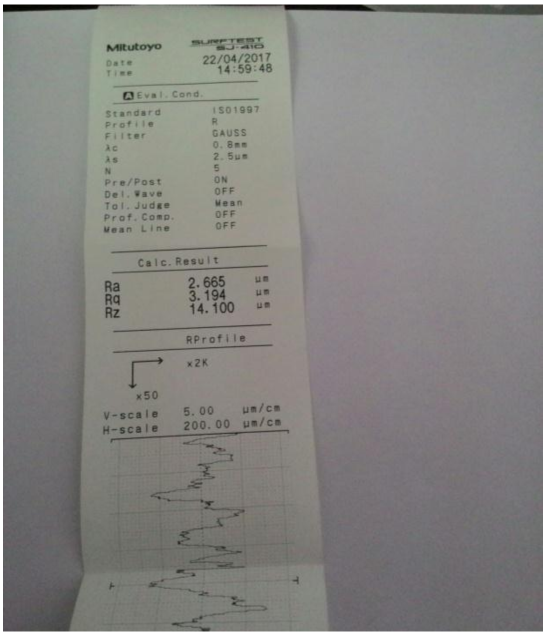

Fig. 6 Surface Roughness Graph.

C. *Material Removal Rate*

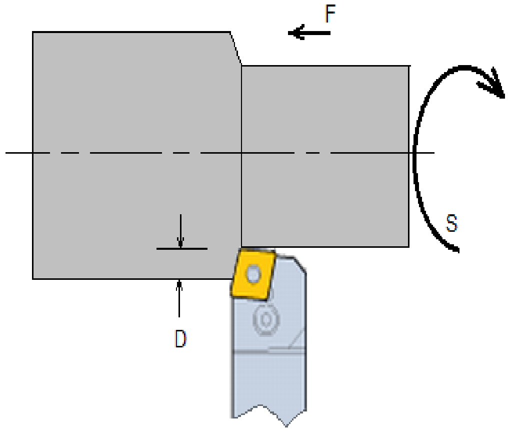

Fig.7 Material Removal Rate

MRR is the volume of material removed per minute. The higher your cutting parameters, the higher the MRR.
MRR = initial weight - final weight/machining time.

V. THEORETICAL STUDY

A *Mini Tab Software*

Minitab is a statistics package developed at the Pennsylvania State University by researchers Barbara F. Ryan, Thomas A. Ryan, Jr., and Brian L. Joiner in 1972. Minitab began as a light version of OMNITAB, a statistical analysis program by NIST; the documentation for OMNITAB was published 1986, and there has been no significant development since then. Minitab is distributed by Minitab Inc, a privately owned company headquartered in State College, Pennsylvania. Today, Minitab is often used in conjunction with the implementation of six sigma, CMMI and other statistics-based process improvement methods. Minitab Inc. produces two other products that complement Minitab.

B *Analysis Of Variance (Anova)*

ANOVA is a statistical technique introduced by prof. RA Fisher frequently used in agricultural scientific research and studies. The purpose of this technique is to examine the significance effects on different varieties of factors in flouncing yields. This is the test of equality of mean of tree or more samples. The total variation in any set of numerical data is due to a number of causes which may be classified as; Assignable causes and Random causes.

C *Regression Analysis*

The experiment is conducted by using Minitab 17 software and regression analysis is conducted in Minitab software. Generates an equation to describe the statistical relationship between one or more predictors and the response variable and to predict new observations. Regression generally uses the ordinary least squares method which derives the equation by minimizing the sum of the squared residuals. Regression results indicate the direction, size, and statistical significance of the relationship between a predictor and response.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 06, June - 2017

VI. RESULT AND DISCUSSION

A Optimization By Anova

Speed, Feed, Doc Versus MRR

TABLE 3 Speed, Feed, Doc Versus MRR

	Df	SS	MS	F -value
Speed	1	88.01	88.006	36.06
Feed	1	182.98	182.983	74.97
DOC	1	11.31	11.308	4.63
Error	23	56.14	2.441	
Total	26	338.44		

Scatter Plot

A scatter plot is a graph that is used to plot the data points for two variables. Each scatter plots has a horizontal axis(X-axis) and a vertical axis. One variable is plotted on each axis.

Scatter plot provide a visual representation of the correlation or relationship between two variables.

Graphs plotted with Speed, Feed, DOC vs MRR is shown below

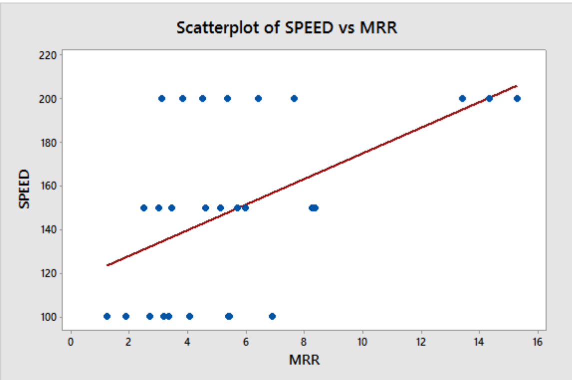

Fig. 8 speed vs MRR

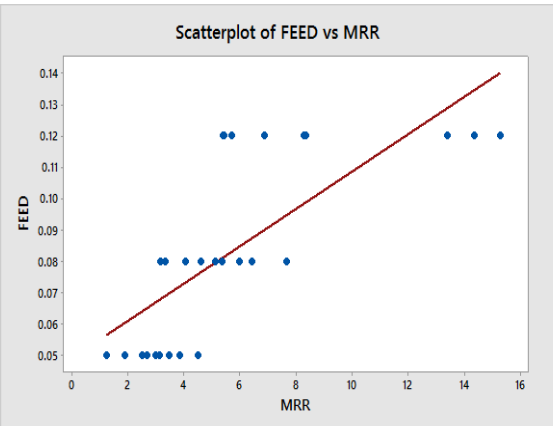

Fig.9 feed vs MRR

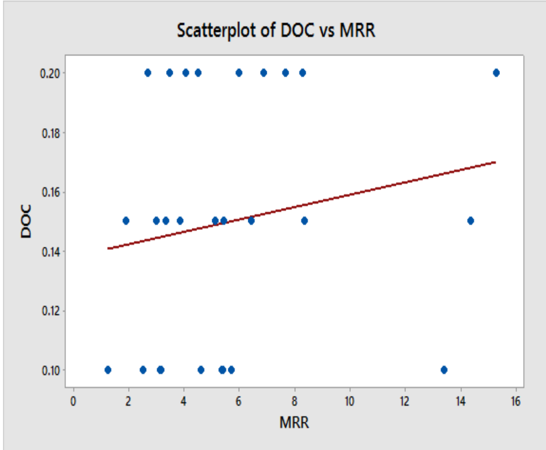

Fig.10 DOC vs MRR

Speed, Feed, Doc Versus Ra

TABLE 4 Speed, Feed, Doc Versus Ra

	Df	SS	MS	F -value
Speed	1	0.00002	0.000020	0.04
Feed	1	0.36289	0.362895	5.39
DOC	1	0.05120	0.051200	0.76
Error	23	1.54944	0.067367	
Total	26	1.96356		

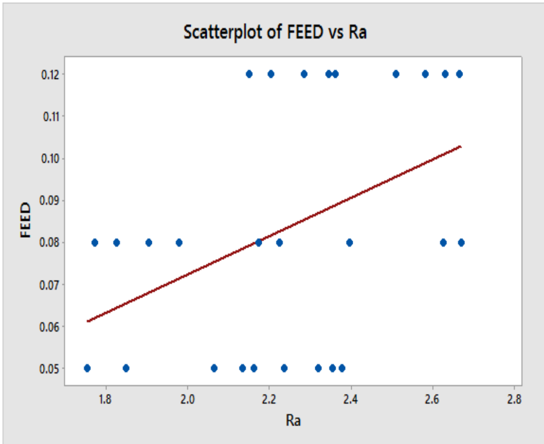

Fig. 11 feed vs Ra

Speed, Feed, Doc Versus Rq

TABLE 5 Speed, Feed, Doc Versus Rq

	Df	SS	MS	F -value
Speed	1	0.00513	0.005134	0.05
Feed	1	0.68019	0.680194	6.75
DOC	1	0.09074	0.090738	0.90
Error	23	2.31872	0.100814	
Total	26	3.09478		

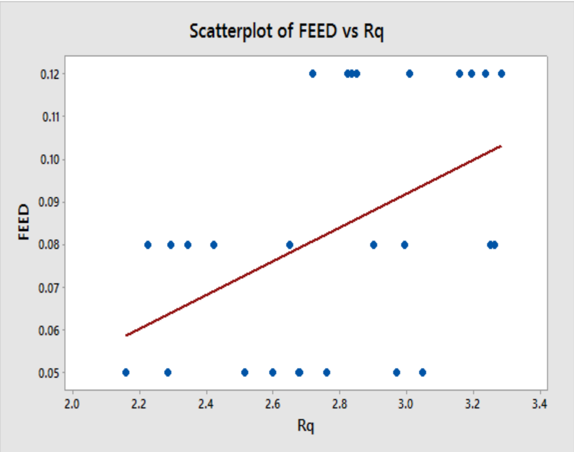

Fig.12 feed vs Rq

Speed, Feed, Doc Versus Rz

TABLE 6 Speed, Feed, Doc Versus Rz

	Df	SS	MS	F value
Speed	1	0.1008	0.1008	0.04
Feed	1	25.0999	25.0999	10.57
DOC	1	1.0707	1.0707	0.45
Error	23	54.6332	2.3754	
Total	26	80.9046		

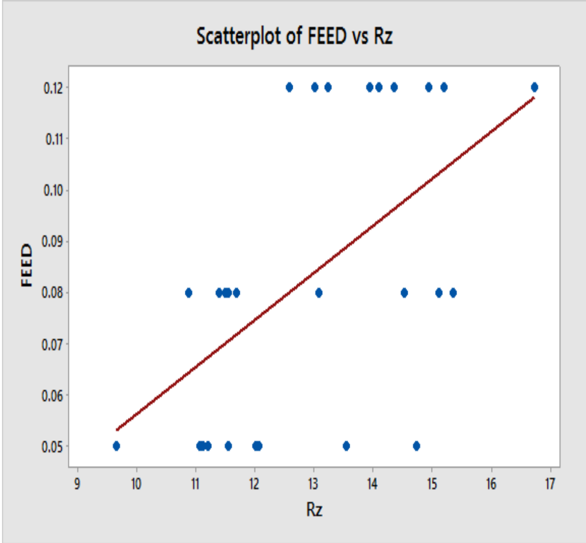

Fig.13 feed vs Rz

Summary Of ANOVA

TABLE 7 Summary Of ANOVA

	MRR	Ra	Rq	Rz
F- value of Speed	131.620	0.04	0.05	0.04
F- value of Feed	285.02	5.39	6.75	10.57
F- value of DOC	28.30	0.76	0.90	0.45

From the above table f- value of feed shows the highest value in all the cases that is MRR, Ra, Rq, Rz. So this concluded that feed is the significant factor that influencing the values of MRR, Ra, Rq, Rz.

D. Regression Analysis(validation)

SPEED, FEED, DOC versus MRR
Coefficients

TABLE 8 Coefficients in regression equation

Term	Coefficients
Constant	-10.82
Speed	0.04422
Feed	90.8
Depth of cut	15.85

Regression Equation
MRR = -10.82 + 0.04422 SPEED + 90.8 FEED + 15.85 DOC

TABLE 9 Validation of MRR

Sl no	Speed Mm/min	Feed Mm/rev	Doc mm	Actual MRR mm³/min	Theoretical MRR mm³/min
1	100	0.05	0.1	1.25	-0.273
2	100	0.05	0.15	1.90493	0.5195
3	100	0.05	0.2	2.70283	1.312
4	100	0.08	0.1	3.19917	2.451
5	100	0.08	0.15	3.35102	3.2435
6	100	0.08	0.2	4.076613	4.036
7	100	0.12	0.1	5.407432	6.083
8	100	0.12	0.15	5.42953	6.8755
9	100	0.12	0.2	6.894737	7.668
10	150	0.05	0.1	2.52649	1.938
11	150	0.05	0.15	3.007937	2.7305
12	150	0.05	0.2	3.478261	3.523
13	150	0.08	0.1	4.629139	4.662
14	150	0.08	0.15	5.148649	5.4545
15	150	0.08	0.2	6	6.247
16	150	0.12	0.1	5.718182	8.294
17	150	0.12	0.15	8.369369	9.0865
18	150	0.12	0.2	8.275862	9.879
19	200	0.05	0.1	3.134615	4.149
20	200	0.05	0.15	3.853488	4.9415
21	200	0.05	0.2	4.530516	5.734
22	200	0.08	0.1	5.362205	6.873
23	200	0.08	0.15	6.439024	7.6655
24	200	0.08	0.2	7.664	8.458
25	200	0.12	0.1	13.40678	10.505
26	200	0.12	0.15	14.34615	11.2975
27	200	0.12	0.2	15.27778	12.09
				155.3847	155.4435

Actual MRR/Theoretical MRR = 1
155.3847/155.4435 = 0.999621

From the experiment it is found that the ratio of actual and calculated values of MRR, Ra, Rq and Rz are almost equal to unity.

This confirms the competency of experiment and hence the accuracy of the physical measurements taken.

This implies the optimal conditions of the cutting parameters on surface roughness physically obtained with the analytical method.

VII. CONCLUSION

By increasing Speed, Feed, DOC the Material Removal Rate (MRR) and Surface Roughness also increases. The significant factor influencing the values for Ra, Rq, Rz and MRR is Feed rate. The next optimal parameter for MRR is Speed and for Ra, Rq, Rz are Depth of Cut. Validation of the experiment has been successfully conducted. Regression Analysis & ANOVA is performed by using MINITAB 17.

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