Process Optimization Through Quality Tools

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Abstract- *The important goal in the modern industries is to manufacture the products with lower cost and with high quality in short span of time. There are two main practical problems that engineers face in a manufacturing process. The first is to determine the values of process parameters that will yield the desired product quality (meet technical specifications) and the second is to maximize manufacturing system performance using the available resources. The present work was conducted on a semiautomatic lathe machine. The experimentation involved Aluminum cenosphere MMC as a workpiece material and carbide tip tool as the cutting tool. The current work aims at optimizing material removal rate and forces acting on that. A large number of experiments have to be carried out when the number of process parameters increases. To solve this task, the taguchi method uses a special design of orthogonal arrays to study the entire parameter space with a smaller number of experiments only. In this work, three cutting parameters namely, cutting speed, depth of cut,and feed rate were considered for experimentation and finally obtaining the optimized material removal rat eand forces acting on work piece byusing taguchi's methods and results were analysed by a "minitab-15" software.*

Keywords- s/n ratios, taguchi method, DOE, Aluminium cenosphere material characterization.

I. INTRODUCTION

Today, Metal cutting process places major portion of all the manufacturing processes. Within these metal cutting processes the turning operation is the most fundamental metal removal operation in the manufacturing industry.in turning process there many number of output parameters corresponding to different input variables, so determine a optimum solution for given set of input variables required many no of experiments which consume more time and increases cost of experimentation. To solve this problem taguchi orthogonal array provides a suitable technique to arrive optimal solution with a minimum no of experiments.

II. PROBLEM STATEMENT

The important goal in the modern industries is to manufacture the products with lower cost and with high quality in short span of time. There are two main practical problems that engineers face in a manufacturing process. The first is to determine the values of process parameters that will yield the desired product quality (meet technical specifications) and the second is to maximize manufacturing system performance using the available resources.

III. OBJECTIVES

1) To obtain optimal process parameters
2) To obtain material removal rate.
3) To obtain various forces acting on work piece

Quality Definition(s):

1) Quality is fitness for use (JURAN)
2) Quality is conformance to requirements (CROSBY)
3) Quality is the loss that a product costs to the society after being shipped to the customer (TAGUCHI)

IV. MACHINING PARAMETERS

The machining process depends upon several parameters such as the work piece material, the cutting tool material, the rigidity of the machine, the rigidity of the work piece, cutting speed, feed, depth of cut, chatter, tool wear etc.

Cutting Speed

Cutting speed of a cutting tool can be defined as that which its cutting edge passes over the surface of the work piece in unit time. It is normally expressed in terms of surface speed in "mm/min" It is a very important aspect in machining since it considerably affects the tool life and efficiency of machining. Selection of a proper cutting speed has to be made very judiciously. If it is too high, the tool gets over heated and its cutting edge may fail, needing regrinding. If it is too low, too much time is consumed in machining and full cutting capacities of the tool and machine are not utilized, which results in lowering of productivity and increasing the production cost.

FEED

The feed rate determines the rate of advancement of the cutting tool. The tool can be moved in three directions with respect to the axis of the work. Hence there are three types of feeds. Those are

1. **Longitudinal feed:** The movement of the tool parallel to the axis of work is called longitudinal feed. This is used in turning ,drilling operations
2. **Cross feed:** The movement of the tool perpendicular to the axis of the work is called Cross feed such as in facing operation.
3. **Angular feed:** The movement of the tool at angular direction to the work axis is called angular feed such as in taper turning operation

For example, in turning operation on a lathe it is equal to advancement of the tool corresponding to each revolution of the work. However, it is computed and mentioned in different machine tools and different operations

Units are expressed in “mm/min” or “mm/rev”.

The cutting speed and feed of a cutting tool is largely influenced by the following factors.

1) Material being machined
2) Material of the cutting tool
3) Geometry of the cutting tool
4) Required degree of surface finish.

Rigidity of the machine tool being used

Depth of Cut:

It is the depth or distance perpendicular to axis of the work (in case of turning),By which the tool penetrates into the work.This is expressed in “mm”

Depth of cut in turning = (d1-d2)/2
Where d1= Diameter of work piece before machining.
d2= Diameter after machining.

V. THEORY OF METAL CUTTING

Machining is the process of removing the unwanted material from the work piece in the form of chips. If the work piece is a metal, the process is often called as metal cutting process or chip forming processes. Metal cutting is a machining process by which a work piece is given

1. A desired shape
2. A desired size
3. A desired surface finish

Working principle of turning process

Turning is a machining process for generating external surfaces of revolution. In turning, primary cutting motion is rotational with the tool feeding parallel to axis of rotation. The work is turned straight when it is made to rotate about the lathe axis, and the tool is fed parallel to the lathe axis. The straight turning produces a cylindrical surface by removing excess metal from the work-piece. The machine is started after the work-piece and the tool is properly set and the correct spindle speed and the amount of feed to be given is determined

D^3 methodology

Though there exists various methodologies and techniques to optimize the process there is no uniform solution or a single technique to address the problem completely. Hence it lead to the development of an exclusive methodology called **D^3** which stands for **Describe, Develop and Deliver**. It consists of various tools handpicked from both lean thinking, six sigma and there tools. The significance of this methodology is that no much statistics is required, can provide common solution to multiple problems, it can be implemented within a short span of time and can address up to 95% of any problem.

This methodology consists of the following three steps.

DESCRIBE--> DEVELOP --> DELIVERY

DESCRIBE : Is a tool used in the phase of defining a problem, and understand the process flow and measure the performance.

DEVELOP : Is a tool used in the phase of analysing the problem and establish cause and effect relation and root cause of problem.

DELIVERY : Is a tool used in the phase to improve process and implement the optimal solution and establish a monitoring mechanism

VI. DESIGN OF EXPERIMENTS (DOE)

Design of Experiment (DOE) is a structured, organized method for determining the relationship between factors affecting a process and the output of that process

Design of Experiment Techniques

1)Factorial Design
2)Response Surface methodology
3)Mixture Design
4)Taguchi Design
Among those we had selected Taguchi Design for optimizing the Surface Roughness in Turning Operation.

Introduction to Taguchi Method

Competitive crisis in manufacturing during the 1970's and 1980's that gave rise to the modern quality movement, leading to the introduction of Taguchi methods to the U.S. in the 1980's. Taguchi's method is a system of design engineering to increase quality. Taguchi Methods refers to a collection of principles which make up the framework of a continually evolving approach to quality. Taguchi Methods of Quality Engineering design is built around three integral elements, the loss function, signal-to-noise ratio, and orthogonal arrays, which are each closely related to the definition of quality.

Taguchi method focuses on Robust Design through use of

1) Signal-To-Noise ratio
2) Orthogonal arrays

Signal-To-Noise Ratio

The signal-to-noise concept is closely related to the robustness of a product design. A Robust Design or product delivers strong 'signal'. It performs its expected function and can cope with variations ("noise"), both internal and external. In signal-to-Noise Ratio, signal represents the desirable value and noise represents the undesirable value

There are 3 Signal-to-Noise ratios of common interest for optimization of Static Problems. The formulae for signal to noise ratio are designed so that an experimenter can always select the largest factor level setting to optimize the quality characteristic of an experiment. Therefore a method of calculating the Signal-To-Noise ratio we had gone for quality characteristic.

1) Smaller-The-Better,
2) Larger-The-Better,
3) Nominal-The-Best.

The Smaller-The-Better:

Impurity in drinking water is critical to quality. The less impurities customers find in their in their drinking water, the better it is. Vibrations are critical to quality for a car, the less vibration the customers feel while driving their cars the better, the more attractive the cars are.

The Signal-To-Noise ratio for the Smaller-The-Better is:
S/N = -10 *log (mean square of the response)

$$S/N = -10\log_{10}\left(\frac{\sum y^2}{n}\right)$$

The Bigger-The-Better:

If the number of minutes per dollar customers get from their cellular phone service provider is critical to quality, the customers will want to get the maximum number of minutes they can for every dollar they spend on their phone bills.
If the lifetime of a battery is critical to quality, the customers will want their batteries to last forever. The longer the battery lasts, the better it is.

The Signal-To-Noise ratio for the bigger-the-better is:

S/N = -10*log (mean square of the inverse of the response)

$$S/N = -10\log_{10}\left(\frac{1}{n}\sum\frac{1}{y^2}\right).$$

Nominal-The-Best:

When a manufacturer is building mating parts, he would want every part to match the predetermined target. For instance when he is creating pistons that need to be anchored on a given part of a machine, failure to have the length of the piston to match a predetermined size will result in it being either too small or too long resulting in lowering the quality of the machine. In that case, the manufacturer wants all the parts to match their target. When a customer buys ceramic tiles to decorate his bathroom, the size of the tiles is critical to quality, having tiles that do not match the predetermined target will result in them not being correctly lined up against the bathroom walls.

The S/N equation for the Nominal-The-Best is:

S/N = 10 * log (the square of the mean divided by the variance)

$$S/N = 10\log_{10}\left(\frac{y^2}{s^2}\right).$$

VII. LITERATURE SURVEY

W.H. Yang, Y.S. Tarng(Journal of Materials Processing Technology 1997) worked on turning process. In their research, the Taguchi method, a powerful tool to design optimization for quality, is used to find the optimal cutting parameters for turning operations. An orthogonal array, the signal-to-noise (S/N) ratio, and the analysis of variance (ANOVA) are employed to investigate the cutting characteristics of S45C steel bars using tungsten carbide cutting tools. Through this study, not only can the optimal cutting parameters for turning operations be obtained, but also the main cutting parameters that affect the cutting performance in turning operations can be found.

M.Anthony Xavior, M. Adithanw (Journal of Materials Processing Technology 2008) did research on the influence of cutting fluids on tool wear and surface roughness during turning. The objective of this work is to determine the influence of cutting fluids on tool wear and surface roughness during turning of AISI 304austenitic stainless steel with carbide tool. Further an attempt has been made to identify the influence of coconut oil in reducing the tool wear and surface roughness during turning process. The performance of coconut oil is also being compared with another two cutting fluids namely an emulsion and a neat cutting oil (immiscible with water). The results indicated that in general, coconut oil performed better than the other two cutting fluids in reducing the tool wear and improving the surface finish. Coconut oil has been used as one of the cutting fluids in this work because of its thermal and oxidative stability which is being comparable to other vegetable-based cutting fluids used in the metal cutting industry

D. Nageswara Raoa, P. Vamsi Krishna(International Journal of Machine Tools & Manufacture 2007) worked on solid lubricants. The heat generated in the cutting zone during turning is critical in deciding the work piece quality and tool life. Though cutting fluids are widely employed to carry away the heat in metal cutting, their usage poses threat to ecology and the health of workers. Hence, there arises a need to identify eco-friendly and user-friendly alternatives to conventional cutting fluids. Modern tribology has facilitated the use of solid lubricants. Their work features a specific study of the application of solid lubricant in turning. The process performance is judged in terms of cutting force tool temperature, tool wear and the surface finish of work piece, keeping the cutting conditions constant. The results obtained from the experiment show the effectiveness of the use of the solid lubricant as a viable alternative to dry and wet machining.

Alakesh Manna,Sandeep Salodkar(Journal of Materials Processing Technology 2007) did their research on effective turning of E0300 alloy steel. Their research describes the procedure to obtain the machining conditions for turning operation considering unit cost of production as an objective function. The optimality conditions for single point cutting operations are determined based on the objective function using dynamic programming technique. The optimal policy of machining conditions is determined for evolution of minimum cost considering the important cost related machining criteria such as actual machining time, tool reuse time, set up time, tool life, and tool changing time. They also developed mathematical models by considering the Krononberg's data used for standard turning operation. The effects of different constraints on the objective functions are analyzed through various graphical representations. In their study, the Taguchi method a powerful tool for experiment design is also used to optimize the cutting parameters to achieve better surface finish and to identify the most effective parameter for cost evolution during turning. Taking significant cutting parameters into consideration and using multiple linear regressions, mathematical model relating to the surface roughness height *R*ais established to investigate the influence of cutting parameters during turning. The developed optimality condition affects the economics of machining conditions. The graphical representations also help to understand and analyze the effects of various input constraints at the optimum point and their significant influences on production cost. The analysis can propose an effective methodology in advance for proper setting of machining parameters in practice, which may reduce the cost of unit production

Heena Sharma, and Dr. N.M Suri (2017): In this his study applied Quality control tools in production process to reduce the rejection and rework by identifying highest rejection occurring in the production process and gave suggestions for improvement. This study is conducted from one of the Leading Manufacturing industries in Noida which manufactures Low voltage Panel boad products. The approaches used in this study are such as Pareto chart, Fishbone diagram which have been applied to improve the quality of the products and minimize rejections. It has been founded that the company has many problems especially there is highly rejection and rework in the production processing lines. Which have influence of the quality of final products have to be controlled in order to reduce the wastage and also there have been observed a need of improvement by using the quality control tools [1].

LubicaSimanova and PavolGejdo (2015) : The main aim of the article is to illustrate the use of tools of operative quality management to prevent a decrease in quality during production, supportive and operational processes by the furniture manufacturing. There are more tools for achieving operative quality management targets and the most frequent method is probably measurement and evaluation of the capability of processes through capability indexes. In addition to other histogram and Ishikawa diagram are the next frequently used tools for quality improvement processes [2].

AyonChakrabarty and Kay ChuanTan (2014) : In this present study in the paper provides empirical evidence on Six Sigma implementation in service industries in Singapore. A questionnaire survey is done involving 250 service organizations.. The use of tools and techniques represent similarities across services in their usage at different stages of DMAIC (Define, Measure, Analyze, Improve and Control) methodology. Efficient service and customer satisfaction emerged as most important key performance indicators followed by reduced cost and reduced variation. Some service organizations also felt that Six Sigma is not relevant to their organization. These reasons will probably help in understanding the still limited application of Six Sigma in services. Finally, the survey also shows that there are certain organizations which are planning to implement Six Sigma in near future. Overall, the results help in understanding the status of Six Sigma in service organizations. [5]

VIII. EXPERIMENTAL WORK

EXPERIMENTAL PROCEDURE

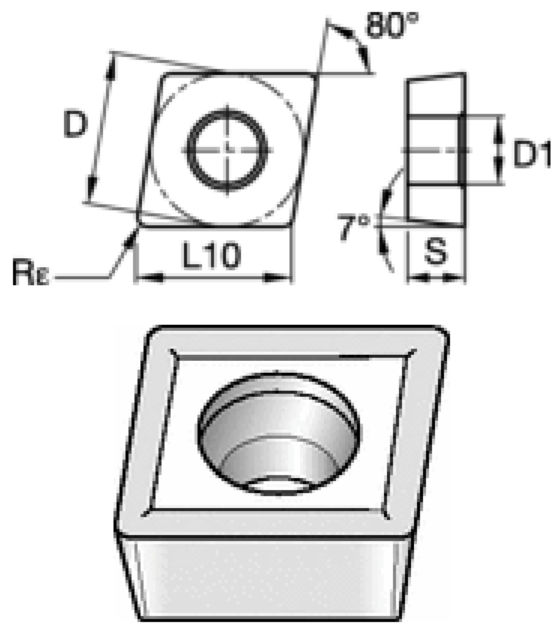
A Lathe (TURBO LX 175) was used for conducting the experiments. Composite material was used as the work material and carbide tool was used as the cutting tool. The experimentation for this work was based on Taguchi’s design of experiments (DOE) and orthogonal array. A large number of experiments have to be carried out when the number of the process parameters increases. To solve this task, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only. In this work, three cutting parameters namely, cutting speed, depth of cut and feed rate were considered for experimentation. Accordingly there are four input parameters and for each parameter three levels were assumed. For a four factors, three level experiment ,Taguchi had specified L27 (3)4 orthogonal array for experimentation. The response obtained from the trials conducted as per L27 array experimentation was recorded and further analysed. Table shows the parameters and their levels considered for the experiments.

Process parameter	Levels
Spindle speed	3
Feed	3
Depth of cut	3

Specifications of semi-automatic lathe

Made : TURBO
Swing over bed : 350 mm
Admit between centers : 550 mm
Spindle variable speed : 45-900 rpm

Specifications of tool



MADE : WIDIA

It's an uncoated carbide grade for steel (P25) composition is the sum of Ti (Titanium), Ta (Tantalum) and Nb (Niobium) in each substrate Ti+Ta+Nb = 15,9%

SPECIFICATIONS OF WORK PIECE

2% Al cenosphere material

Raw materials used:-

Aluminum is a soft, lightweight, malleable metal with appearance ranging from silvery to dull gray, depending on the surface roughness. The yield strength of pure aluminum is 7–11 MPa, while aluminum alloys have yield strengths ranging from 200 MPa to 600 MPa

Cenosphere is a light weight, inert, hallow sphere made largely of silica and alumina and filled with air or inert gas, typically produced as a by-product of coal combustion at thermal power plants.

variable factors and level values

Controllable factors	Level1	Level2	Level3
Speed(rpm)	120	250	400
Feed rate (mm/rev)	0.2	0.3	0.4
DOC (mm)	0.1	0.15	0.2

L_{27} Input Parameters

Exp no	Speed(rpm)	Feed(mm/rev)	Doc(mm)
1	120	0.2	0.1
2	250	0.3	0.15
3	400	0.4	0.2
4	120	0.2	0.15
5	250	0.4	0.2
6	400	0.2	0.1
7	120	0.4	0.2
8	250	0.2	0.1
9	400	0.3	0.15
10	400	0.3	0.1
11	120	0.4	0.15
12	250	0.2	0.2
13	400	0.4	0.15
14	120	0.2	0.15
15	250	0.3	0.1
16	400	0.2	0.2
17	120	0.3	0.1
18	250	0.4	0.15
19	250	0.4	0.1
20	400	0.2	0.15
21	120	0.3	0.2
22	120	0.2	0.15
23	400	0.3	0.2
24	120	0.4	0.15
25	250	0.3	0.2
26	400	0.4	0.2
27	120	0.2	0.15

Formulas

MRR =3.142*doc*N*f*D(i)

Where

MRR= Material removal rate in mm^3/rev
Doc= depth of cut in mm
F= feed in mm/rev
N=spindle speed in rpm
D(i)= initial dia in mm

Results of the L_{27} for 2% cenosphere aluminum composite material

trial	Speed (rpm)	Doc (mm)	D(i) (mm)	D(f) (mm)	Fx (kgf)	Fy (kgf)	Fz (kgf)	Mrr	Fr (kgf)	feed
1	120	0.1	14	13.8	8	35	20	105	41	0.2
2	250	0.15	13.8	13.5	20	30	14	487	38	0.3
3	400	0.2	13.5	13.1	6	25	10	1357	27	0.4
4	120	0.15	12.1	12.8	15	40	9	148	43	0.2
5	250	0.2	12.8	12.4	17	37	14	804	43	0.4
6	400	0.1	12.4	12.2	16	40	14	311	45	0.2
7	120	0.2	12.2	11.8	30	80	20	367	87	0.4
8	250	0.1	11.8	11.6	20	37	10	185	43	0.2
9	400	0.15	11.6	11.3	10	24	7	356	26	0.3
10	400	0.1	11.3	11.1	19	45	15	426	51	0.3
11	120	0.15	11.1	10.8	19	85	17	251	88	0.4
12	250	0.2	10.8	10.4	42	75	15	339	76	0.2
13	400	0.15	10.4	10.1	10	68	16	784	70	0.4
14	120	0.15	10.1	9.8	32	90	21	114	97	0.2
15	250	0.1	9.8	9.6	28	70	23	230	78	0.3
16	400	0.2	9.6	9.2	9	76	38	486	85	0.2
17	120	0.1	9.2	9.0	17	98	48	104	110	0.3
18	250	0.15	12	11.7	25	102	30	565	109	0.4
19	250	0.1	11.7	11.5	5	20	6	367	21	0.4
20	400	0.15	11.5	11.2	15	50	17	433	54	0.2
21	120	0.2	11.2	10.8	12	70	30	253	77	0.3
22	250	0.15	10.8	10.5	7	83	35	254	90	0.2
23	400	0.2	10.5	10.1	5	49	25	791	55	0.3
24	120	0.15	10.1	9.8	3	29	19	328	34	0.4
25	250	0.2	9.8	9.4	9	42	17	467	46	0.3
26	400	0.2	9.4	9.0	15	71	27	244	7	0.4
27	120	0.15	9	8.7	2	18	6	101	9	0.2

Results and discussion

The tests was developed with the aim of relating the influence of the cutting speed, feed and depth of cut with cutting forces(F_x,F_y,F_z) in work piece, and the material removal rate.The statistical treatment of the data was made in two phases. The first phase was concerned with MRR and the effect of factors. The second phase was determination of optimal cutting force. The third phase allowed us to obtain the correlations between the parameters.

For 2% of cenosphere Al composites

TAGUCHI ANALYSIS: MRR VERSUS ,SPEED, FEED, DEPTH OF CUT

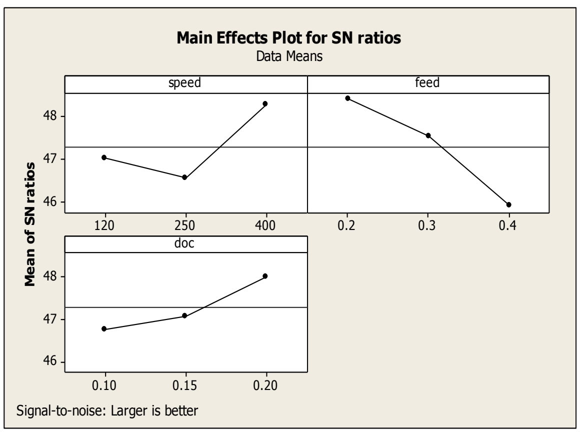
response table for s/n ratio

Level	speed	feed	doc
1	47.01	48.41	46.78
2	46.56	47.55	47.08
3	48.30	45.91	48.01
delta	1.74	2.50	1.24
rank	2	1	3

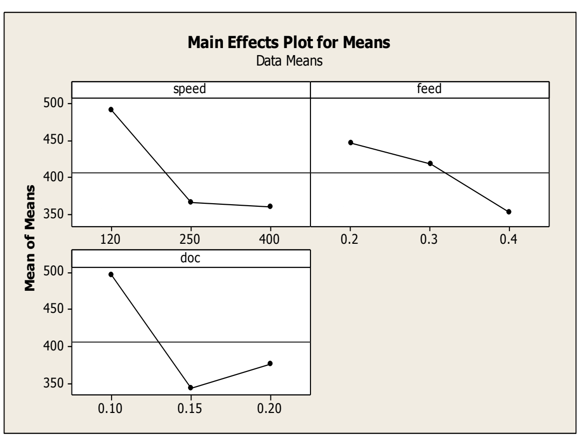
response table for means

Level	speed	feed	Doc
1	491.5	446.8	497.5
2	366.5	418.7	343.9
3	360.5	352.9	377.0
delta	131.0	93.9	153.5
rank	2	3	1

S/N ratio of MRR



means of MRR



TAGUCHI ANALYSIS: F_X VERSUS SPEED, FEED, DEPTH OF CUT

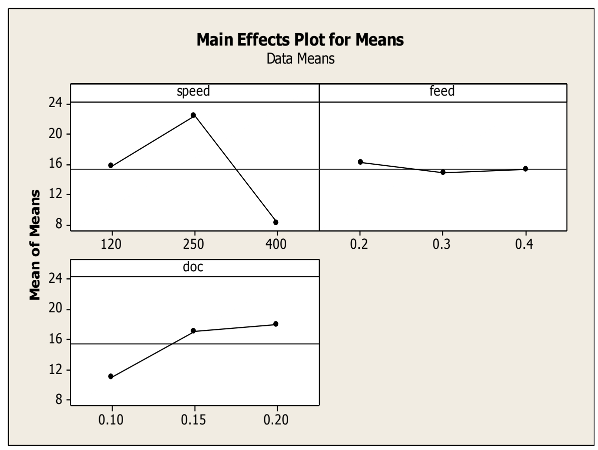
Signal to Noise Ratios of F_X

Level	speed	feed	doc
1	-24.33	-24.20	-20.62
2	-27.48	-22.18	-24.47
3	-18.58	-24.01	-25.30
delta	8.89	2.01	4.69
rank	1	3	2

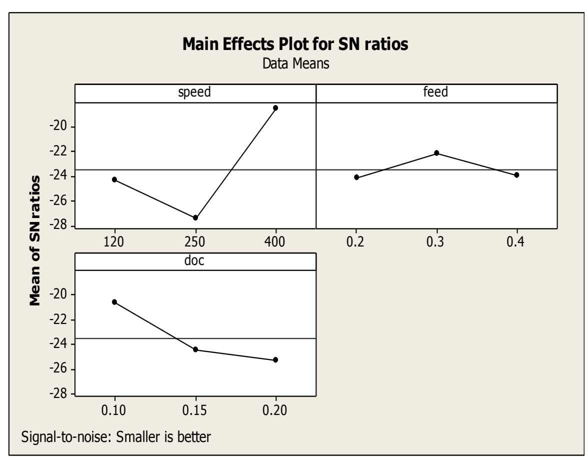
Means of Fx

level	speed	feed	doc
1	15.778	16.22	11.111
2	22.333	14.778	17.111
3	8.111	15.22	18.000
Delta	14.22	1.444	6.889
rank	1	3	2

means of Fx



S/N ratio of Fx



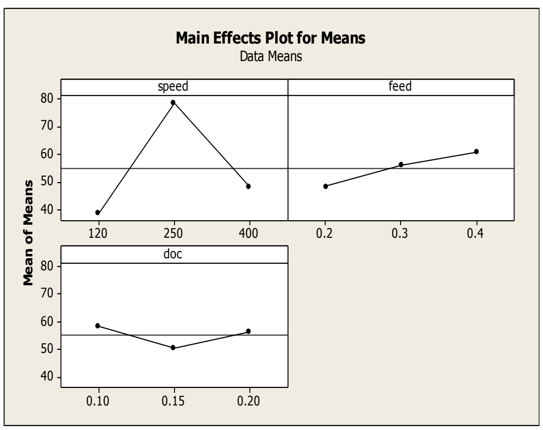
TAGUCHI ANALYSIS: F_Y VERSUS SPEED, FEED, DEPTH OF CUT

Signal to Noise Ratios of Fy

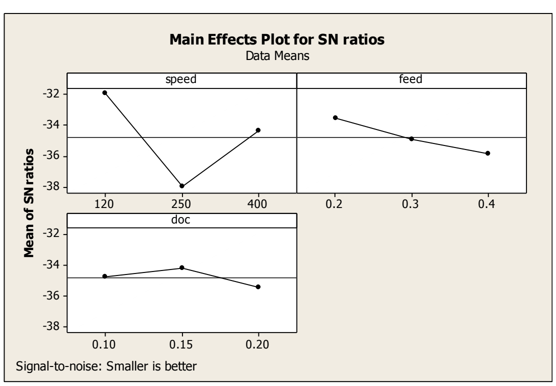
Level	speed	feed	doc
1	-31.96	-33.58	-34.75
2	-38.00	-34.93	-34.18
3	34.40	-35.85	-35.43
delta	6.03	2.27	1.25
rank	1	2	3

Means of Fy

Level	speed	feed	doc
1	38.678	48.33	58.56
2	78.48	56.22	50.33
3	48.00	60.89	56.56
delta	40.11	12.56	8.22
rank	1	2	3



S/N ratio of Fy



TAGUCHI ANALYSIS: F_Z VERSUS SPEED, FEED, DEPTH OF CUT

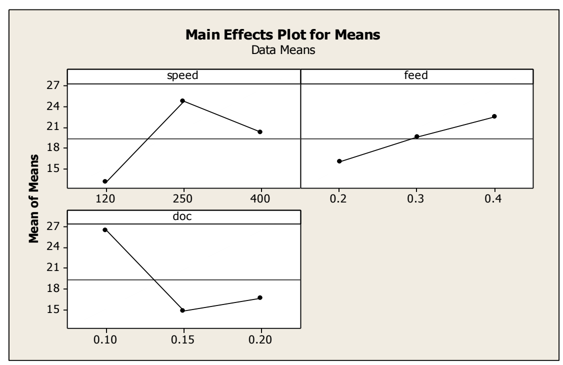
Signal to Noise Ratios of Fz

Level	speed	feed	doc
1	-22.75	-24.56	-28.08
2	-27.31	-25.59	-23.78
3	-26.75	-26.66	-24.95
delta	4.56	2.10	4.29
rank	1	3	2

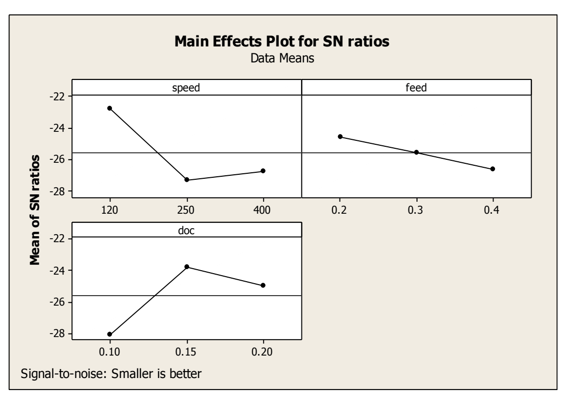
Means of Fz

Level	speed	feed	doc
1	13.11	16.00	26.56
2	24.78	19.56	14.89
3	20.22	22.56	16.67
delta	11.67	6.56	11.67
rank	1	3	2

means of Fz



S/N ratio of Fz



TAGUCHI ANALYSIS: Fr VERSUS SPEED, FEED, DEPTH OF CUT

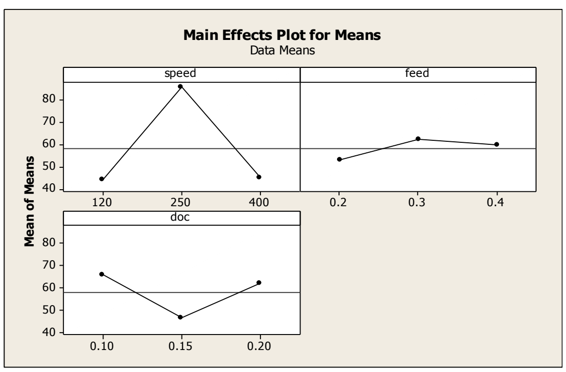
Signal to Noise Ratios of Fr

Level	speed	feed	doc
1	-33.14	-34.51	-35.85
2	-38.66	-35.81	-33.18
3	-33.48	-34.95	-36.24
delta	5.52	1.30	3.07
rank	1	3	2

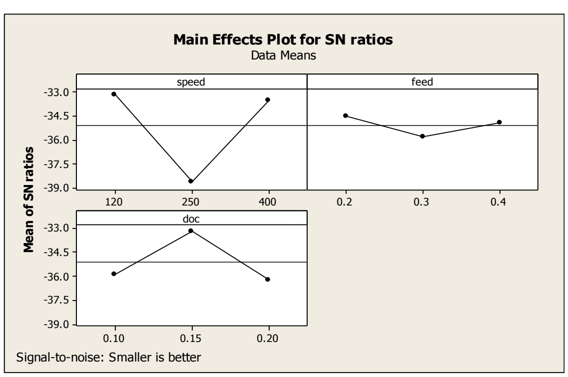
Means of Fr

Level	speed	feed	doc
1	44.13	53.04	65.87
2	85.41	62.16	46.78
3	45.18	59.52	62.07
delta	41.28	9.13	19.08
rank	1	3	2

means of Fr



S/N ratio of Fr



IX. CONCLUSION

On the basis of experimental results, condition for optimal parametric combinations for material removal rate and cutting forces using Taguchi design concept the following points can be concluded as listed below:The main objective of the work is to optimize the material removal rate and cutting forces

The following are the final conclusions of the work

For 2% aluminium composite material

- The Feed in the more significant input variables then the other variables on MRR.
- The optimum material removal rate is at 400rpm for a feed rate of 0.2mm/rev at depth of cut is 0.2mm for signal noise ratio analysis.
- The optimum material removal rate is at 120rpm for a feed rate of 0.2mm/rev at depth of cut is 0.1mm for means analysis.
- The speed in the more significant input variables then the other variables on cutting force Fx.
- The cutting force Fx minimum at speed 250rpm for a feed rate of 0.2mm/rev at depth of cut is 0.2mm for signal noise ratio analysis.
- The cutting force Fx minimum at speed at 400rpm for a feed rate of 0.4mm/rev at depth of cut is 0.1mm for means analysis.
- The speed in the more significant input variables then the other variables on cutting force Fy.
- The cutting force Fy minimum at speed 250rpm for a feed rate of 0.4mm/rev at depth of cut is 0.2mm for signal noise ratio analysis.
- The cutting force Fy minimum at speed at 120rpm for a feed rate of 0.2mm/rev at depth of cut is 0.2mm for means analysis.
- The speed in the more significant input variables then the other variables on cutting force Fz.
- The cutting force Fz minimum at speed 250rpm for a feed rate of 0.4mm/rev at depth of cut is 0.1mm for signal noise ratio analysis.
- The cutting force Fz minimum at speed at 120rpm for a feed rate of 0.2mm/rev at depth of cut is 0.15mm for means analysis.
- speed in the more significant input variables then the other variables on cutting force Fr.
- The cutting force Fr minimum at speed 250rpm for a feed rate of 0.3mm/rev at depth of cut is 0.2mm for signal noise ratio analysis.

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