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Impact of Mechanical System in Machining Of AISI 1018 Using Taguchi Design of Experiments

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Abstract: *The imperative objective of the science of metal cutting is the solution of practical problems associated with the efficient and precise removal of metal from work piece. Optimization of process parameters is done to have great control over quality, productivity and cost aspects of the process. Taguchi method stresses the importance of studying the response variation using the signal–to–noise (S/N) ratio, resulting in minimization of quality characteristic variation due to uncontrollable parameter. Orthogonal array was adopted in order to planning the (L9) experimental runs in turning of AISI 1018 by taking the help of software Minitab 16. The MRR and time- machining values measured from the experiments and their optimum value for maximum material removal rate. It is also predicted that Taguchi method is a good method for optimization of various machining parameters as it reduces the number of experiments. Finally present work reviews the conventional and CNC machine in dry-turning, with profound insight to the field of quality and manufacturing from both a statistical and an engineering viewpoint.*
Keywords: *AISI 1018 alloy steel, Taguchi, MRR, shear angle and R- chart.*

I. Introduction

The benefits of civilizations which we enjoy today are essentially due to the improved quality of products available to us. The improvement in the quality of goods can be achieved with proper design that takes into consideration the functional requirement as well as its manufacturing aspects. Manufacturing is involved in turning raw materials to finished products to be used for so purpose in the present age there have been increasing demands on the product performance by way of desirable exotic properties such as résistance to high temperatures high operating speeds and extra loads. This is turn would require a variety of new materials and its associated processing. Also exacting working conditions that are designed in the modern industrial operations make large demands on the manufacturing industry. The principle used in all marching process is to generate the surface require by providing suitable relative motions between the work piece and the tool. In this process material is removed from the unwanted regions of the input material [1].

Metal cutting process consists in removing a layer of metal from blank to obtain a machine part of the required shape and dimensions and with the specified quality of surface finish. A metal cutting tool is the part of a metal cutting machine tool that, in the cutting process, acts directly on the blank from which the finished part is to be made. The metal cutting process accompanied by deformation in compression, tension and shear by great deal of friction and heat generation is governed by definite laws. In order to cut the material from blank the cutting tool should be harder then material to be cut, the tool should penetrate the blank and the tool should be strong enough to withstand the forces developed in cutting [2]

The earliest approach to reducing the output variation was to use the Six Sigma Quality strategy [1,2].So that ±6 standard deviations lie between the mean and the nearest specification limit. Six Sigma as a measurement standard in product variation can be traced back to the 1920s when Walter Shewhart showed that three sigma from the mean is the point where a process requires correction. In the last twenty years, various non-deterministic methods have been developed to deal with design uncertainties. These methods can be classified into two approaches, namely reliability-based methods and robust design based methods. However, the variation is not minimized in the reliability approaches [4], which concentrate on the rare events at the tails of the probability distribution [5].

Ro-bust design improves the quality of a product by minimizing the effect of the causes of variation without eliminating these causes. The objective is different from the reliability approach, and is to optimize the mean performance and minimize its variation, while maintaining feasibility with probabilistic constraints. This is achieved by optimizing the product and process design to make the performance minimally sensitive to the various causes of variation. Taguchi developed the foundations of robust design to meet the challenge of producing high-quality products. In 1980, he applied his methods in the American telecommunications industry and since then the Taguchi robust design method has been successfully applied to various industrial fields such as electronics, automotive products, photography, and telecommunications [6, 7]. Taguchi objective functions for robust design arise from quality measures using quadratic loss functions. In the extension of this definition to design optimization, Taguchi suggested the signal-to-noise ratio (SNR).The use of SNR in system analysis provides a quantitative value for response variation comparison. Maximizing the SNR results in the minimization of the response variation and more robust system performance is obtained. Generally the industries having metal cutting operations have been suffering from various big problems since the optimum operating conditions for the machine tools cannot be easily achieved. The Industrial practitioners and researchers have been dealing with this area to overcome such problems.

II. Literature Survey

Thorough literature survey has been carried out to capture the voice of concerned people and their relevant work as far as machining concerned; a detailed literature survey is carried out as follows. It is nearly impossible to discuss all the works related to Taguchi methods. We have tried to mention the main articles that discuss the pros and cons of Taguchi's contributions. There are several other papers that are listed in the Bibliography but specifically not discussed here [8-14].

2.1 Identified Gaps in the Literature

After a comprehensive study of the existing literature, a number of gaps have been observed in taguchi's method of machining.

1. Most of the researchers have investigated influence of process parameters on the performance measures using Taguchi method.
2. Literature review reveals that the researchers have carried out most of the work on quality developments, monitoring and control but very limited work has been reported on optimization of process variables.
3. The effect of machining parameters has not been fully explored.

4 Both theoretical & statistical optimization of turning process is another thrust area which has been given less attention in past studies.

2.2 Objective of the Project

The objective of the work is to study and discuss the various methods of Taguchi technique and strategies that are adopted in order to find the following parameters by both experimentally and Taguchi's techniques.

1. The use of arrays to study the effect of machining parameters influence on Material removal rate.
2. To understand relationships between the control parameters and response parameters during machining.
3. To optimize turning operations parameters for material removal.
4. To verify the cutting conditions as efficient using chip theory.
5. To validate the Taguchi optimize level-factors using Statistical Quality control charts.

III. Materials and Experimentation Method

Generally every machining system consists of Machine tool, Cutting tool and Work piece.

Machine tool: The experiment was carried out on the precision centre lathe (Turn Master 40) which enables high precision machining and production of jobs. The main spindle runs on high precision roller taper bearings and is made from hardened and precision drawn nickel chromium steel.

Technical Specifications are: centre height: 177.5mm, main motor power: 3hp, 30 longitudinal and transverse feeds.

The Cutting tool: The cutting selected for machining of AISI 1018 alloy steel was Tungsten carbide insert of 0.4 and 0.8 mm nose radii, and 5 degree rake angle.

Work piece: Alloy steels may be defined as steels to which elements other than carbon or added in sufficient amounts to produce improvements in properties [3]. Work piece of standard dimensions was used for machining: work piece diameter: 45mm, work piece length: 400mm (approx.).Especially for 3D-turnng machine the length to diameter ratio (L/D) is less than or equal to 10.

Table 3.1: Process variables and their limits

Factors	Units	Low	Medium	High
Speed (S)	rpm	280	400	630
Feed (F)	mm/rev	0.1	0.2	0.3
Depth of cut (D)	mm	0.15	0.20	0.25

Fig 1: Experimental Setup

Table 3.2: Chemical composition of AISI 1018 Carbon steel

Element	C	Fe	Mn	P	S
Content %	0.14 - 0.20	98.81 - 99.26	0.60 - 0.90	≤ 0.040	≤ 0.050

In this experiment, in order to investigate the material removal rate of the machined work piece, during cutting, a tungsten carbide tool was used. A view of the cutting zone and Experimental setup is shown in Fig. 1. The initial and final diameters was measured with the help of Digital vernier, material removal rate are calculated as below type.

The working ranges of the parameters for subsequent design of experiment, based on Taguchi's L9 Orthogonal Array (OA) design have been selected. In the present experimental study, spindle speed, feed rate and depth of cut have been considered as Process variables. The process variables with their units (and notations) are listed in Table 1.

3.1 Experimental Procedure

Turning is a popularly used machining process. The lathe machines play a major role in modern machining industry to enhance product quality as well as productivity. In the present work, three levels, three factors and nine experiments are identified. Appropriate selection of orthogonal array is the first step of Taguchi approach. According to Taguchi approach L9 orthogonal array has been selected. Cutting tests were carried out on lathe machine under dry conditions. A pre-cut with a 1 mm depth of cut was performed on work piece of actual turning. This was done in order to remove the rust layer or hardened top layer from the outside surface and to minimize any effect of in homogeneity on the experimental results. Then, using different levels of the process parameters have been turned in lathe accordingly. Machining time, initial and final diameters for each sample has been calculated. The results of the experiments have been shown in table 3.a, 3.b & 3.c.

3.2 Calculation of the Material Removal Rate

Material removal rate (MRR) has been calculated from the difference of weight of work piece before and after experiment by using the following formula.

$$MRR = \frac{3.14}{4} [\text{Initial dia}^2 - \text{Final dia}^2] \times \text{Feed} \times \text{Rpm} \quad (mm3 / min).$$

IV. Data Collection & Data Analyses

The results of the experiments have been shown in Table 3 (a) to (c). Analysis has been made based on those experimental data in the following session. Optimization of material removal rate of the cutting tool has been made by Taguchi method and couple with Regression analysis, Confirmatory test also been conducted finally to validate optimal results.

Table 4.1: Experimental Results L9 Orthogonal array

Run	Speed	Feed	DOC	Initial dia	Final dia	Material removal
1	1	1	1	45	44.83	0.17
2	1	2	2	44.83	44.64	0.19
3	1	3	3	44.64	44.39	0.25
4	2	1	2	44.39	44.24	0.15
5	2	2	3	44.24	44.05	0.19
6	2	3	1	44.01	43.80	0.25
7	3	1	3	43.80	43.64	0.16
8	3	2	1	43.64	43.44	0.2
9	3	3	2	43.44	43.19	0.25

Table 4.2: Measurement of Output Data

Run	Material removal rate (mm^3/min)	Chip thickness ratio (r)	Shear angle (φ), degrees	Ranges in MR
1	335.829	0.937	45.45	0.02
2	747.66	0.952	45.95	0.02
3	1468.404	0.961	46.24	0.04
4	417.656	0.949	45.85	0.02
5	1054.01	0.970	46.53	0.04
6	2069.916	0.980	46.85	0.04
7	692.246	0.961	46.24	0.02
8	1723.49	0.952	45.95	0.02
9	3214.844	0.915	44.71	0.04

Data Analyses

Experiment was conducted to assess the effect of Spindle speed, feed rate and depth of cut on material removal rate (MRR).

4.1 Taguchi Method

Taguchi Method is developed by Dr.Genichi Taguchi, a Japanese quality management Consultant, He has developed both the philosophy and methodology for the application of factorial design experiments that has taken the design of experiments from the exclusive world of the statistician and brought it more fully into the world of manufacturing. His contributions have also made the practitioner's work simpler by advocating the use of fewer experimental designs, and providing a clearer understanding of the nature of variation and the economic consequences of quality engineering in the world of manufacturing and uses a statistical measure of performance called Signal-to-Noise (S/N) ratio. Taguchi methods seek to remove the effect of noises, he pointed out that the key element for achieving high quality and low cost is parameter design. The S/N ratio takes both the mean and the variability into account. The ratio depends on the quality Characteristics of the product/process to be optimized. The optimal setting is the parameter combination, which has the highest S/N ratio. The standard S/N ratios generally used are as follows: - Nominal is Best (NB), Lower the Better (LB) and Higher the Better (HB). Taguchi approach has potential for savings in experimental time and cost on product or process development and quality improvement. Quality is measured by the deviation of a functional characteristic from its target value. Through parameter design, levels of product and process factors are determined, such that the product's functional characteristics are optimized and the effect of noise factors is minimized.

Taguchi's ideas can be distilled into two fundamental concepts:

(a) Quality losses must be defined as deviations from targets, not conformance to specifications

(b) Quality is designed, not manufactured, into the product.

Main effect plot

The analysis is made with the help of a software package MINITAB 16. The main effect plot and SNR plots are shown inFig.1 and 2.These show the variation of individual response with the three parameters i.e. Speed, feed, and depth of cut separately. In the plots, the x-axis indicates the value of each process parameter at three level and y-axis the response value. Horizontal line indicates the mean value of the response. The signal-to-noise ratio plots are used to determine the optimal design conditions to obtain the optimum MRR. Fig.2 shows the SNR plot for maximum material removal rate.

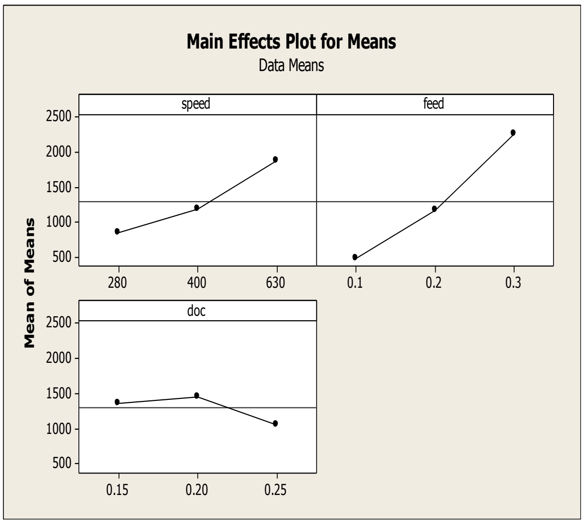

Fig.1 Main effect plot for MRR

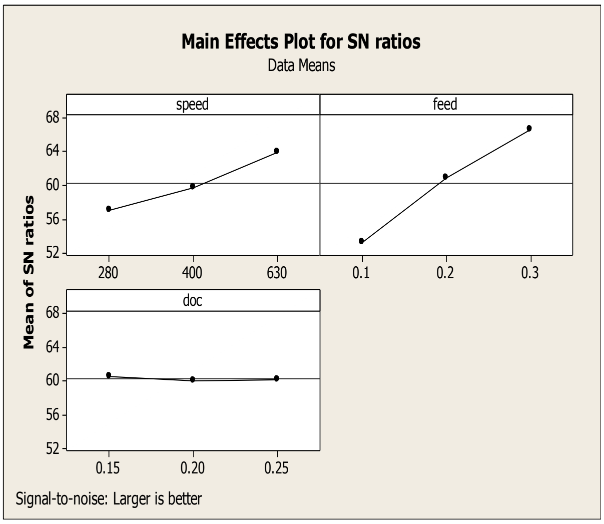

Fig.2 SNR plot for MRR

Table 4.3: Optimal turning conditions

Response	Best-Levels
MRR	3-3-1

4.2 Statistical Quality Control

Statistical quality control (SQC) is a branch of quality control, which involves collection, analysis and interpretation of data to solve a particular problem.
Statics: means data, sufficient enough to obtain reliable results.
Quality: is a relative term, and can be defined as fitness for the purpose.
Control: is a system for measuring and checking. This also incorporates a feedback mechanism to explore the cause of poor quality and takes corrective steps.
Commonly used techniques of Statistical Quality control are: (1) Frequency distribution charts, (2) Control charts, (3) Theory of Sampling and (4) Special methods (Correlation and Regression analysis).

Control Chart Analysis

A control chart is a simple graphical device for knowing, at a given instance of time, whether or not a process is under control. The statistical data can be divided into: (1) variables data , a dimension of a part measured such as diameter and length, temperature in degree centigrade, weight in Kgs. and (2) Discrete data, No. of defective pieces found in a sample, tubes having cracks, etc.

Control Charts for Variables

These charts are used for the quality characteristics which are specified as variables, i.e., on the basis of actual readings taken. The mainly used variable charts are X -chart and R –chart. The present work is enough to analyze by using Range chart [15].

Table 4.4: Upper control limit & lower control limit

UCL	0.05096
LCL	0.00504

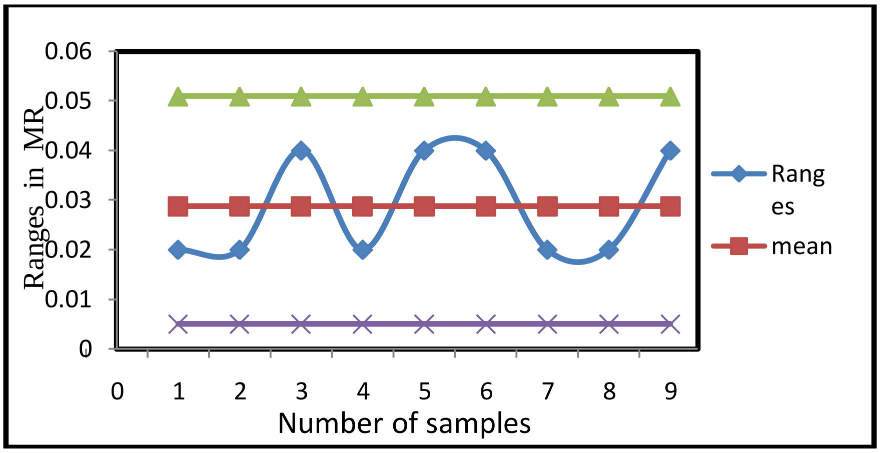

Fig.3 Range plot for material removal

Draw the centre horizontal line of the graph with value equal to average of ranges (R), Draw the UCL and LCL horizontal lines above and below average (R). Plot the points R of all the samples in the graph and join all the successive points to obtain the chart (refer table 3).Ranges of MR is within the control limit (LCL<MR<UCL) then the process is in control.

Regression Analysis

The linear polynomial models are developed using commercially available Minitab 16 software for various turning parameters. The predictors are speed, feed and depth of cut. Linear regression equations are used to develop a statistical model with an objective to establish a correlation between the selected turning parameters with the quality characteristics of the machined work piece. The regression equation for Material removal rate.

(Eq. 1) $\ln (MRR) = R + a * \ln (S) + b * \ln (F) + c * \ln (D)$

(Eq. 2) $\ln (MRR) = 3.34 + 0.967 \ln(S) + 1.39 \ln (F) - 0.079 \ln (D)$.

Where, D the depth of cut (mm), S the spindle speed (rpm), F the feed (mm/rev), R the coefficient of regression.

Table 4.5: Comparison of Experimental Vs Predicted Data

Experimental Data	Predicted Data
335.83	310.48
747.66	795.42
1468.40	1413.15
417.66	428.50
1054.01	1103.39
2069.92	2018.47
692.25	653.24
1723.49	1782.49
3214.85	3161.42

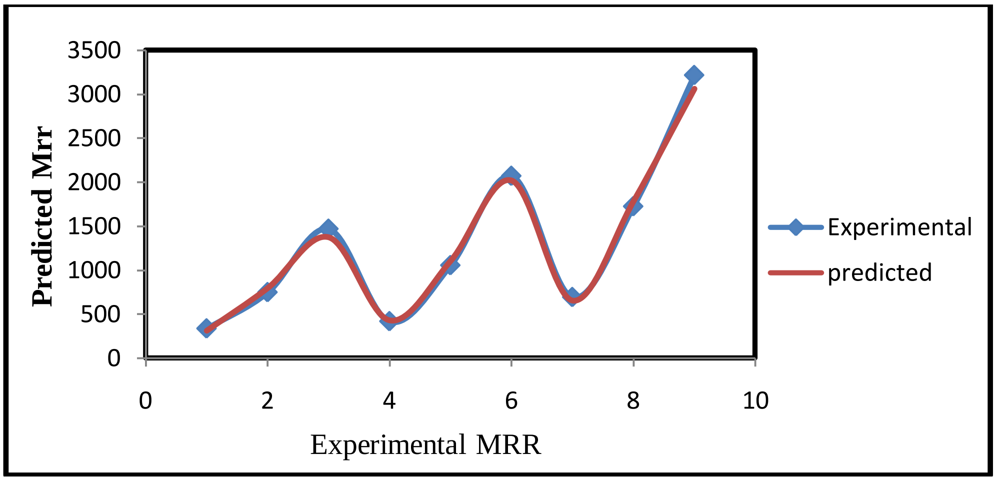

Fig.4 Comparison plot for material removal

Confirmation Experiment

Table 4.6 shows the turning conditions, the pin point optimal values of controlling factors, results obtained from the confirmation test, calculated from the developed model [Eq. 2], and identify in between the results. Therefore, Eq. (2) correlates the material removal rate with the turning conditions (depth of cut, speed, and feed) with a realistic degree of approximation.

Table 4.6: Optimal Turning Conditions & Pin Point Optimal Value

Response	S	F	D	Optimal value
MRR(mm3/min)	630	0.3	0.15	2898.981

V. Conclusion

The machining of AISI Carbon steels is relatively easy and high if there is no built-up edge or material adhesion problem. However, some problems may arise with the chip form and particle emissions. It is shown that long, continuous and spiral chips can indeed be prevented by selecting appropriate Machining feeds and speeds.

The optimal cutting conditions are 630 rpm, 0.3 mm/rev and 0.15 mm gives maximum material removal rate of 2898.981(mm3/min) from Taguchi confirmation test.

A method, which satisfies every static aspect with respective quality, is appreciable. Taguchi is such a method is flexible enough to accommodate different approach to quality improvement. Statistics are used as a catalyst to engineering creation; they need to learn statistical methods that can tap into the knowledge. Which always result in the fastest and most economical progress.

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