Optimization of Process Parameters for Tool Wear in Turning Process Using Al Alloy

[1]Farhat Kowser, [2]Dr. Sorabh Gupta, [3]Er. Didar Singh

[1]PG Scholar, Department of Mechanical Engineering, Galaxy Global Educational Trust Group of Institutions Dinarpur (Ambala), India

[2]Professor & Director, Galaxy Global Educational Trust Group of Institutions Dinarpur (Ambala), India

[3]Assistant Professor, Department of Mechanical Engineering, Galaxy Global Educational Trust Group of Institutions Dinarpur (Ambala), India

Abstract - **This study was more focused upon the determination of most influencing input parameter for desirable or undesirable output, apart from it the main aim was selection of optimal parameters for improved surface finish and high productivity. The approach used for the optimization of the process capabilities for oil & Gas components machining will be described. These components are machined by turning of stainless steel castings work pieces. For this purpose, a proper Design of Experiments (DOE) plan has been designed and executed: as output of the experimentation, data about tool wear have been collected. The DOE has been designed starting from the cutting speed and feed values recommended by the tools manufacturer; the depth of cut parameter has been maintained as a constant. Wear data has been obtained by means the observation of the tool flank wear under an optical microscope: the data acquisition has been carried out at regular intervals of working times. The optimization approach used is a multi-objective optimization, which minimizes the production time and the number of cutting tools used, under the constraint on a defined flank wear level.**

Keywords: Optimization, Turning, Tool wear, Al alloy.

I. INTRODUCTION

The most fundamental machining for working with metal and finds widespread use in the metalworking industry [1]. An essential step in reaching peak performance [2] in a turning process is the selection of machining parameters. Good machinability, superior surface smoothness, reduced tool wear, increased material removal rate, quicker production speed, etc. all fall under the umbrella term "high performance." Surface roughness is a common metric for gauging a product's level of polish. As such, it is used as a quality indicator [3]. Strength qualities including corrosion, temperature, and fatigue life of the machined surface may all be enhanced by a greater degree of surface polish [4, 5]. Machine functionality components, such as friction, light reflectivity, heat transfer, capacity to distribute and retain lubricant, etc. [6, 7], may be affected by surface quality in addition to strength attributes. The cost of manufacturing is also affected by the surface finish [3]. For these reasons, it is crucial to reduce the surface roughness to an acceptable level, which may be accomplished by adjusting the settings of the cutting machine. Traditional cutting operations always include some degree tools. Tool wear affects product quality and manufacturing costs, researchers work to eradicate or significantly reduce it wherever possible. Extensive research on tool wear characteristics is required to extend tool life [8]. Machining parameters Tool wear and surface roughness are affected by cutting speed, feed, and depth of cut, tool material, work material, and tool geometry. Changes in the above listed elements, even if little may have a profound effect on product quality and tool life [3]. The goal of optimization is to get the best possible outcomes while meeting a number of competing demands on available resources. To keep up with the increasing demand for higher product quality, lower production costs, and quicker production rates, businesses and academic institutions must optimize their processes [9]. Optimization procedures often include statistical experimentation design. Statistical design of experiments is the procedure of arranging experiments such that relevant data may be analyzed by statistical techniques in a way that yields reliable and objective results [10].

The traditional, one-factor-at-a-time experimental methodology is being phased out in favour of more efficient and cost-effective design methods as the RSM, Taguchi's approach, factorial designs, etc. [11]. Based on their application of the RSM technique to the input variables Nose radius, approach angle, and rake angle, Neseli et al. [4] determined that the nose radius affects surface roughness more than the others. Nanavati and Makadia [3] discovered that feed, cutting speed, and tool nose radius were the most important predictors of surface roughness in the RSM approach. Using the Taguchi approach, Yang and Tarng [2] determined the best values for the cutting parameters. According to research by Bouacha [5], feed rate is more

important than cutting speed in influencing the final surface quality of a product. While considering the components that contribute to tool wear, Halim [14] found that cut depth mattered most. This study optimizes cutting speed, feed rate, and depth of cut to reduce surface roughness and tool wear.

1.1 Machining Process

When it comes to producing a wide range of component geometries and geometric characteristics, machining stands head and shoulders above all other production methods. Closer dimensional tolerances, surface roughness, or surface-finish characteristics may be required for casting, forming, powder metallurgy, and other shaping processes; and also part geometries may be too complex or expensive to manufacture by other processes, which is where machining processes like cutting, abrasive Process, and various advanced machining processes come in. Nevertheless, machining methods always produce unwanted byproducts called "chips," production rates may be poor, and improper machining may have a negative impact on the surface characteristics and performance of components. Conventional machining includes turning, boring, drilling, reaming, threading, milling, shaping, broaching, grinding, ultrasonic machining, lapping, and honing. Water, abrasive, laser, and electron beams are only some of the cutting-edge tools used in modern machining, along with more traditional electrical and chemical techniques.

Cutting power affects tool life, turning temperature, and work piece finish. Tools wear due to cutting force. Depending on its severity, this force might cause attrition or fracture. During turning, the work piece's functionality and surface quality are affected by the machining force. Another reason to measure torque per turn High-quality turning surfaces improve fatigue strength, roundness, corrosion resistance, wear rate, assembly tolerance, low coefficient of friction, heat resistance, clean ability, aesthetics, and more. For mass manufacturing without compromising quality, industries demand larger MRRs. Optimizing cutting speed, feed rate, and depth of cut may increase MRR. Nevertheless, fast cutting speeds create more power than the machine tool can provide. Adjusting process parameters may raise the cutting temperature. Thermal deformation causes dimensional errors, dulls the tool, and degrades machined surfaces due to thermal effects and built-up edges. The tool and output suffer. Machining is effective, efficient, and cost-effective, improving MRR and product quality. Turning parameters effect surface smoothness, roundness, machining force, cutting power, and material removal rate (MRR). Turning requires adjustments to cutting speed, feed rate, depth of cut, tool form, etc. It's hard to choose the turning settings.

1.2 Cutting Parameters

Cutting speed, feed, and depth of cut are the three cutting parameters in turning, and they all have an impact on the quality attributes of the turned pieces.

a) Cutting Speed

The rate at which a tool's cutting edge moves through a material is measured in meters per minute and is known as the cutting speed.

b) Feed

A cutting tool's feed is the distance it moves into or along the work piece whenever the tool tip reaches a predetermined location. The feed in lathe turning refers to the distance the tool travels during one complete circle of the work piece. One millimeter per revolution, one millimeter per stroke, etc., is a common feed rate specification for single-point instruments. For milling cutters and broaches, it may alternatively be written as millimeters per tooth.

c) Depth of Cut

The machined surface's perpendicular distance to the work piece's uncut surface is the depth of cut.

II. RESEARCH METHODOLOGY

One of the most pressing concerns is how heat treatment, processing, and environmental responses influence the characteristics and performance of engineered materials. It is possible to classify stainless steels into a few major categories. The first two classes include austenitic, ferrite, and martensitic metals, while the third class includes carbon and molybdenum, among others.

Stainless steel is a generic phrase that may refer to various different steel varieties. Like other steels, stainless steel is made using a two-step process that predominantly utilizes iron and carbon. For the production of stainless steel, the base metal is alloyed with metals like chromium (Cr) and nickel (Ni). Because of this, stainless steel is the best metal available. Several different uses exist for duplex precipitation hardened iron. The predominant phase within the metal, which is set by the primary alloying elements, is the primary means by which different varieties of stainless steel may be distinguished from one another. Both chromium and nickel play crucial roles in the stainless steel alloying process. The primary benefits of chromium are its resistance to corrosion and its overall strength. Nickel is a strong metal that also has considerable corrosion resistance. Manganese, which causes steel to corrode, never occurs alone in nature. To manufacture steel, iron must be artificially processed to get a pure form, but

this makes the iron unstable, and it soon recombines with oxygen. When chromium is added to steel, chromium oxide is produced. This oxide acts as a covering, shielding the steel from the corrosive effects of air and moisture. To tailor its properties to its environment, the amount of chromium added to steel may range from 10.5% to 30%. While there are more than a hundred distinct varieties of stainless steel, they may all be classified into one of five basic categories:

Austenitic stainless steel is the most popular kind. It is resistant to corrosion and high temperatures and maintains its mechanical qualities over a broad temperature range. Whether it's for the house, the building industry, or the outside of a structure, austenitic steel has a wide range of applications. The qualities of ferrite stainless steel are similar to those of mild steel, the most prevalent kind of steel, but with improved resistance to corrosion, heat, and cracking. The production of washing machines, boilers, and the construction of enclosed structures are only some of the many common uses for ferrite steel. The high hardness and strength of martensitic stainless steel make up for its lower corrosion resistance when compared to austenitic or ferritic grades. Blades for turbines and knives made from this material have a chromium content of around 13%.

The combination of austenitic and ferrite steels gives duplex stainless steel its incredible strength while retaining part of the material's pliability. The paper and pulp industry, the marine industry, the shipbuilding industry, and the petrochemical industry are just a few of the many that rely on duplex steels. Manufacturing many duplex varieties allows manufacturers to provide a wider variety of uses.

2.1 Experimental Procedure

Material: High speed steel (HSS) cutters are the least expensive alternative, but they also wear out the quickest. Since it can be processed at higher speeds, cobalt steel is preferable to HSS. Carbide tools are more expensive than steel ones in the outset, but they last far longer and can be used at greater speeds, which reduces the overall cost of ownership. HSS instruments are adequate for many purposes. From high-speed steel (HSS) through cobalt steel (cobalt) to carbide (carbide), the progression may be ranked as good, better, and best, respectively.

Diameter: The largest cutter that can be employed for a particular job is often chosen due to the fact that it can make quicker work of the task at hand. The radius of the cutter must be less than or equal to the radius of the smallest arc. In order to determine how long it will take to produce a certain quantity of components, you must factor in both the setup time and the cycle time for each individual component. The overall

setup time includes the time it takes to mount the fixture device into the CNC turning lathe, set up the turning machine, and organise the tool movements (either manually or mechanically).

Figure 1: Workpiece on cnc machine

The experimental procedure is carried out in the following steps:

STEP 1: The raw material (metal rods) is fed into the CNC Turning lathe Machine.
STEP 2: The Metal rods are magnetically clamped in the machine.
STEP 3: The program is written in the computer console according to the required cutting parameters i.e. Cutting Speed, Depth of Cut and Feed Rate.

2.2 Design of Experiments

The design of experiments is the area of applied statistics concerned with planning, conducting, examining, and interpreting controlled tests to assess the variables that determine the value of a parameter.

2.2.1 Taguchi Experiments

Each of the nine experiments in Table 1 is designed around a different combination of level values, as seen in the L9 orthogonal array.

Table 1: Layout of L9 Orthogonal Array

L9(3x 3)Orthogonal Array			
Experim ent No.	Independent Variables		Performance
1	1	1	1	P1
2	1	2	2	P2
3	1	3	3	P3
4	2	1	2	P4
5	2	2	3	P5
6	2	3	1	P6
7	3	1	3	P7
8	3	2	1	P8
9	3	3	2	P9

2.2.2 Grey Relational Analysis Method

A new approach to optimization is shown by fusing the Taguchi method with GRA (Grey Relational Analysis). This theory relies on the random uncertainty of very small samples. The concept matures into an evaluation technique that resolves internal problems despite the system's well-documented complexity and incomplete data. All the information is available on white computers, but not on black ones. Between the two extremes, data quality drops to its lowest point across all systems. As a normalisation evaluation tool, GRA is excellent for solving complex problems that include several performance metrics.

2.2.3 Grey Relational Analysis

Normalization of the experimental data (in the range between 0 and1 according to the type of performance response is the foremost step of the GRA. If the goal value of the original sequence is infinite, it has the-larger-the-better characteristic and the original sequence shall be normalized as Equation (1).

$$X_i^*(k) = \frac{max\, x_i(k) - x_i(k)}{max\, x_i(k) - min\, x_i(k)} \qquad 1$$

To calculate the grey relation coefficient $\xi_i(k)$ from the normalized values by the following equations

$$\xi(k) = \frac{\Delta_{min} + \xi\Delta_{max}}{\Delta_{oi}(k) + \xi\Delta_{max}} \qquad 2$$

Where Δ_{oi} is the deviation sequence of the reference sequence and the comparability sequence

$$\Delta_{oi} = \| x_o(k) - x_i(k) \| \qquad 3$$

$x_o(k)$Is the reference sequence

$x_i(k)$Is the comparability sequence

Δ_{min} & Δ_{max} are the minimum and maximum values of the absolute differences Δ_{oi}

§ is the distinguishing or identification coefficient and its range is taken as 0.5.

In the step 2 for the calculation of Grey Relation Coefficient we need to calculate the deviation sequence.

Calculate the maximum values in the step 1. It will be 1 only because the values are normalized from in between 0 to 1.

Step 3: To find the grey relation grade at

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \xi(k) \qquad 4$$

γ_i is the required grey relation grade.

III. RESULTS AND DISCUSSIONS

Turning Nine operations and surface roughness measurements have been done on the work pieces to assess the impact of three variables (Depth of cut, Feed, and Spindle Speed) on the Surface Roughness and wear of the turned specimens of Aluminum in the present study. Machine components were converted using a Carbide cutting tool and a wet cutting approach. This task required the use of a coolant.

We display both relative and absolute SN ratios. Together with the criteria, the rank is presented. Using this ranking, we can see which of several potential contributors had the most impact. Each signal level and factor's average SNR is determined using the following formula: Smaller the better

N = -10 Log10 [mean of sum of squares of measured data]

This is usually the chosen S/N ratio for all undesirable characteristics like "defects" etc. for which the ideal value is zero. Also, when an ideal value is finite and is maximum or minimum value is defined, then the difference between measured data and ideal value is expected to be as small as possible the generic form of S/N ratio then become

N = - 10 Log 10 [mean of sum of squares of {measured − ideal}]

The process parameters are mentioned in tables using L9 orthogonal array.

Table 2: Experimental Factors

Code	Parameter	Level(-1)	Level(+1)
A	Cutting Speed(m/min)	60	120
B	Feed (mm/rev)	0.05	0.15
C	Depth of cut(mm)	0.4	0.8

Nine experiments were successfully conducted based on Taguchi method and machined samples are shown in Figure 3.

Table 3: Experimental values for L9 array

Cutting Speed (m/min)	Feed (mm/rev)	Depth of cut (mm)
60	0.05	0.4
60	0.1	0.6
60	0.15	0.8
90	0.05	0.6
90	0.1	0.8
90	0.15	0.4
120	0.05	0.8
120	0.1	0.4
120	0.15	0.6

Figure 2: Machined Work piece

Table 3: Experimental results for the Aluminum

Cutting Speed (m/min)	Feed (mm/rev)	Depth of cut (mm)	Ra(um)	Flank Wear(mm)
60	0.05	0.4	0.916	0.443
60	0.1	0.6	0.629	0.928
60	0.15	0.8	0.883	1.17
90	0.05	0.6	1	0.948
90	0.1	0.8	1.082	1.604
90	0.15	0.4	1.713	0.859
120	0.05	0.8	0.87	0.932
120	0.1	0.4	0.938	1.001
120	0.15	0.6	1.634	0.768

From the optimization it is clear that the minimum flank wear is 0.443 and surface roughness is 0.629. So the optimal experiments are as enlisted in table 4.

Table 4: Optimum values

S.No	Factors	Optimum setting	Level
1	Cutting speed	60	1
2	Depth of cut	0.05	1
3	Feed Rate	0.4	1

IV. CONCLUSION

The parameters that determine the ultimate surface roughness of a metal following CNC machining have been the subject of intensive experimental investigation by our team. Based on what I've read, I believe that Taugchi and Grey relation optimization may be used to get optimal values for cutting speed, feed rate, and depth of cut. Minimizing surface roughness may be achieved by optimising the cutting speed, feed rate, and depth of cut. Examination of the change in the S/N ratios reveals that the feed rate has the greatest impact on the surface roughness, followed by the cutting speed and the depth of cut. Taugchi- Grey Optimization shows that the parameters 0.443 and 0.629 produce the lowest flame wear and the smoothest surface, respectively.

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