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Reducing Cutting Forces and Surface Roughness in Turning Operations by Multi-Objective Optimization of Cutting and Geometric Characteristics

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Abstract*:* *One of the most crucial machining operations that must be performed in a variety of sectors in order to manufacture a wide range of products is turning. Optimizing the several elements impacting turning operation is crucial for the best operating conditions because it is a fundamental operation for many industries. Both geometrical and cutting characteristics have an impact on turning operations. Cutting velocity, depth of cut, feed rate, and cutting tool geometry such as nose radius, rake angle, and principal cutting edge angle are the parameters that have the biggest effects. Since the product with the intended qualities depends on these characteristics, it is imperative to manage surface roughness and cutting force acting on material during turning operations. Finding the ideal values for various cutting parameters, such as cutting speed, depth of cut, feed rate, and principle cutting edge angle, in order to minimize cutting force and surface roughness, is the project's goal. WC inserts are used as a tool in the project to turn 304 SS as the work component. The following cutting settings are chosen: depth of cut (0.5, 0.6, 0.7 mm), feed rate (0.105, 0.166, 0.25 mm/rev), cutting speed (13.18, 20.724, 33.912 m/min), and principle cutting edge angle (78, 66, 62 degrees). Taguchi's L9 orthogonal array architecture serves as the basis for the design and execution of various experimental combinations. After normalizing the output response values for the lower-the-better condition, grey relational coefficients are calculated, and a grey relation grade is then obtained. The best amounts of the input parameters are determined by plotting the S/N ratio in MINTAB 16 after grey relation grade values are converted to S/N ratio for larger-the-better conditions. To validate the experimental outcome, a confirmation test is performed for the ideal level of input parameters.*

Keywords: turning

I. INTRODUCTION

Nowadays, the majority of economically developed nations have a sizable metal cutting sector. Machining has the most diverse operating conditions of any process used to shape metals[8]. The most popular method for creating various shapes in the engineering field is machining.

One of the most common machining operations in industries is turning. In order to cut away the layer of metal from the work piece and create a cylinder or other complex profile, the turning process involves holding the work material in the chuck and rotating it while holding the tool solidly in a tool post and moving it at a steady pace along the work material's axis. Cutting and geometry parameters govern the turning action. Among the cutting parameters are feed rate and cutting speed[9].

The rate at which the uncut surface of the work material goes through the cutting tool is known as the cutting speed, and it is often stated in feet per minute or meters per minute. The distance that the tool moves in the axial direction with each work material revolution is known as the feed rate. The thickness of material removed from the work material in a radial direction is known as the depth of cut. The two most important cutting factors during tuning are feed rate and cutting speed, which the operator should regulate to attain the best cutting conditions[6].

Traditionally, machine operators are in charge of choosing the cutting parameters for turning, but even for highly experienced operators, finding the ideal values of the parameter can be quite challenging. We employ the optimization technique to forecast the ideal value of certain parameters. We can determine the ideal settings for various cutting and geometry parameters that yield the operation's best economic performance by employing an optimization technique. In order to attain the desired value of the answers, we undertake multi-objective turning operations to establish tradeoffs between different input parameters[7]. Various responses, including tool life, material removal rate, surface roughness, and cutting force, are used to measure the machining performances in turning operations. These performance metrics, like production cost and profit rate, have a big impact on how economically successful machining is. Any product's manufacture involves a variety of procedures, and in the modern world, these procedures must balance the increasing demands for quality, high production costs, high process safety, and quick production schedules[5]. The optimal selection of manufacturing process control parameters is necessary to satisfy the necessary demand. Choosing the best process parameter is crucial for ensuring product quality, cutting manufacturing costs, and boosting productivity. One of the most challenging tasks is modeling and optimizing the input process parameters, which calls for the following skills: understanding of the manufacturing process, empirical formulas to create realistic constraints, machine capability specification, creation of an efficient optimization criterion, and familiarity with mathematical and numerical optimization techniques. Two of the most crucial technological factors in the machining process are cutting force and surface roughness. Cutting pressure, power consumption, heat production, tool wear, work piece deformation, dimensional accuracy, chip formation, and machining system stability are all directly impacted by cutting force[4]. It is essential for assessing power machining (electric motor selection). Numerous machine element characteristics, including wear resistance, friction, and heat transport, are correlated with surface roughness[10].

II. WORK MATERIAL

WORK PIECE

The most widely used stainless steel is SS 304, which comes in a large range of items, shapes, and finishes[3]. It has outstanding forming and welding capabilities[11]. Without the need for intermediate annealing, grade 304's balanced austenitic structure can be deep drawn. For use in the transportation, architectural, and industrial domains, stainless steel 304 can be easily rolled or braked into a variety of components. It comes in two varieties:Heavy gauge components frequently employ 304L, the low carbon version that doesn't require post-weld annealing. Because of its high carbon content, 304H is used at high temperatures. It is very rough[2].

CHEMICAL COMPOSITION OF SS 304

GRADE	C	Mn	Si	P	S	Cr	Mo	Ni	N
304	0.08	2.0	0.75	0.045	0.030	20.0	-	10.5	0.10

MECHANICAL PROPERTIES OF SS 304

GRADE	Tensile strength(Mpa)	Yield strength0.2% proof(MPa)	Elongation (% in 50 mm)	Rockwellhardness (HR B)	Brinell hardness (HB)
304	515	205	40	92	201

The material stainless steel 304 is widely used and has applications in a variety of sectors, including:

- Equipment Used In Food Processing, Such As In The Production Of Milk.
- Trim And Paneling For Architecture.
- Heat Exchangers And Containers For Chemicals.
- Springs And Fasteners With Threads[12].

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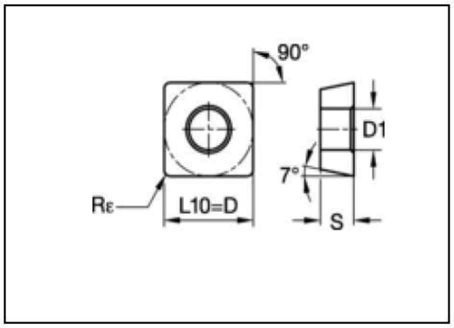
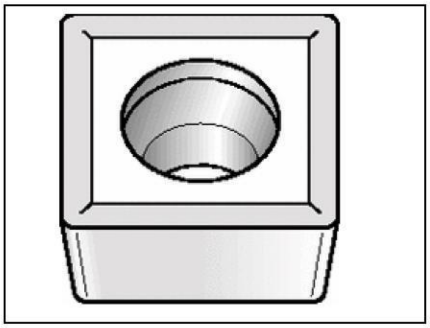
TOOL SPECIFICATION

Tool used for turning of the 304 SS was carbide inserts.





ISO Catalog Number	Tip	Dimension				
		D	L10	S	R_e	D1
SCMT 09T308TN5120	**Carbide**	**9.53**	**9.53**	**3.97**	**0.8**	**4.40**

III. METHODOLOGY

The Taguchi approach was used for the experiment's design, while the gray relational analysis method was used for multi-objective optimization.

TAGUCHI METHOD

A Japanese engineer named Genichi Taguchi developed an experimental design theory that is used to quality engineering. "Quality is the loss imparted to society from the time a product is shipped," according to Taguchi[1]. The Taguchi method's idea is to create levels for each parameter in order to lessen the characteristic's departure from its intended value. In a limited number of studies, he examined numerous combinations of variables using the idea of an orthogonal array. The idea of experimental design lies at the heart of both process and product design. Our experiment design process provides guidance for choosing combinations of the different factor levels that allow us to identify the output characteristic and, in turn, compute the performance statistic. A matrix of numbers is represented as an orthogonal array. Each column denotes a particular component whose impact on the response variable is of interest, and each row reflects the levels or states of the selected factors. Every factor setting occurs the same number of times for every test setting of every other factor in an orthogonal array. This enables us to compare factors at a level that is balanced under a range of circumstances.To find the process response deviation from the desired value, Taguchi suggests using loss functions. The signal-to-noise (S/N) ratio is further calculated from the loss function value, and the parameter levels that optimize this ratio are sought after.

Whereas noise is a measure of the characteristic's variability, signal is the square of the quality characteristic's mean.

When analyzing the S/N ratio, output characteristics fall into three categories: nominally the best, lower-the-better, and higher-the-better.

The technique is mainly applicable to single response optimization. Multi-objective optimization requires the resulting S/N ratio of the replies because a lower S/N ratio of one answer may be used to optimize the multi-response to a higher S/N ratio of another. To do this, we must combine the Taguchi method with another approach. Grey relational analysis has been utilized in this instance.

PROCEDURE FOLLOWED

The following procedures have been used for the multi-objective optimization of the turning operation utilizing Taguchi and Grey Relational Analysis in accordance with the description above.

1. The cutting parameters and geometric parameters for turning operation are selected.

Cutting parameters:

- Cutting speed
- Feed rate
- Depth of cut

level	Cutting speed (m/min)	Feed rate (mm/rpm)	Depth of cut(mm)	Principal cutting edgeangle (Degree)
1	13.18	0.105	0.5	78
2	20.724	0.166	0.6	66
3	33.912	0.25	0.7	62

Design Of Experiment L_9 Orthogonal array

Sl.no	Cutting speed	Feed rate	Depth of cut	Principal cutting edge angle
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

The work piece is now turned using a carbide tool on the lathe in accordance with the configuration of the orthogonal array table (5). The 304 SS work piece fits the headstock correctly and is centered. The work piece was first given a rough pass, and its diameter was set at 30 mm.

EXPERIMENTAL OBSERVATION AND RESULT

Using a dynamometer and Talysurf, cutting force and surface roughness are calculated for every set of input parameters based on an orthogonal array.

Sl. no	Cutting speed (mm/min)	Feed rate (mm/rpm)	Depth of cut(mm)	Principle cutting angle	Force (N)			Surface roughnessR_a (µm)
					Thrust	Feed	Radial	
1	13.18	0.105	0.5	78	235.2	107.8	98	2.6
2	13.18	0.166	0.6	66	196.0	117.6	88.2	1.5
3	13.18	0.250	0.7	62	480.2	294.0	235.2	1.3
4	20.724	0.105	0.6	62	284.2	235.2	176.4	0.8
5	20.724	0.166	0.7	78	284.2	176.4	147.0	0.7
6	20.724	0.250	0.5	66	323.4	196.0	147.0	0.8
7	33.912	0.105	0.7	66	303.8	245.0	176.4	0.9
8	33.912	0.166	0.5	62	196.0	137.2	137.2	1
9	33.912	0.250	0.6	78	486.2	196.0	235.6	1.2

NORMALIZED VALUE OF CUTTING FORCE AND SURFACE ROUGHNESS

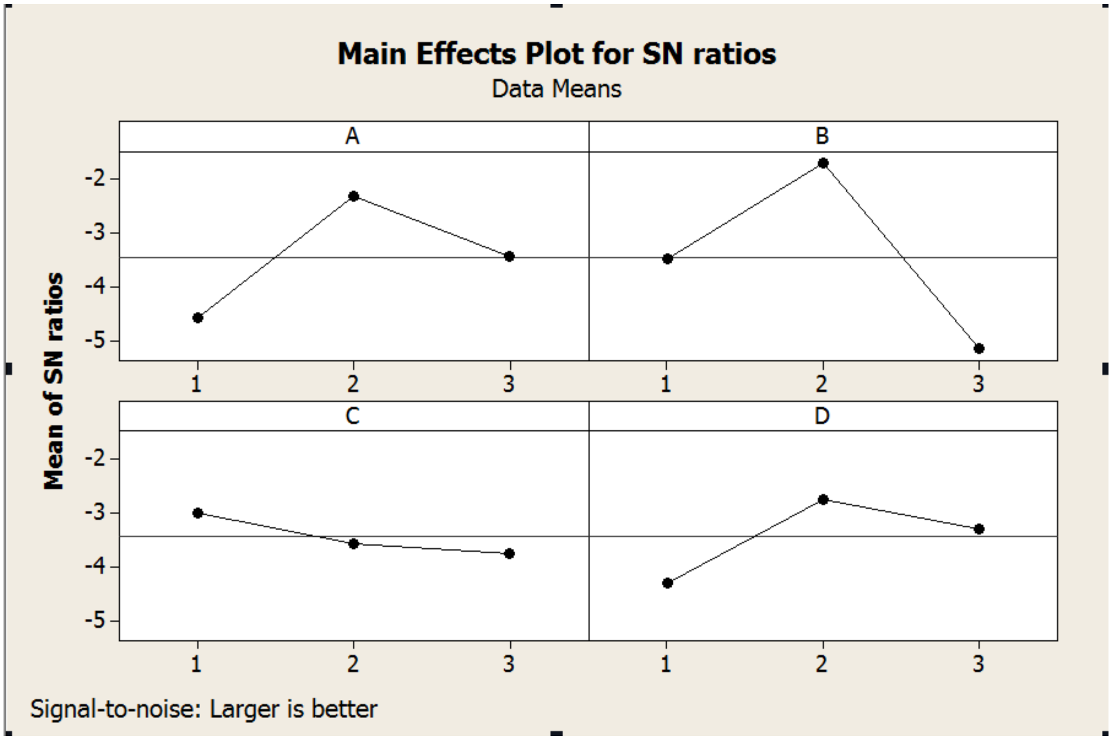
Sl.no	Cutting force	Surface roughness
1	0.8649	0.0000
2	1.0000	0.5789
3	0.0206	0.6842
4	0.6960	0.9473
5	0.6960	1.0000
6	0.5600	0.9473
7	0.6285	0.8947
8	1.0000	0.8421
9	0.0000	0.7326

CUTTING FORCE AND SURFACE ROUGHNESS VALUE FOR OPTIMAL SETTING

Sl .no	Cutting speed (m/min)	Feed rate (mm/rpm)	Depth of cut(mm)	Force(N)			Surface roughness R_a (µm)
				Thrust	Feed	Radial	
1	20.724	0.166	0.5	186.2	127.4	137.2	2.4

LOSS QUALITY ESTIMATE

Sl. no	Cutting force	Surface roughness
1	0.1351	1.0000
2	0.0000	0.4211
3	0.9794	0.3158
4	0.3040	0.0527
5	0.3040	0.0000
6	0.4400	0.0527
7	0.3715	0.1053
8	0.0000	0.1579
9	1.0000	0.2674



CONFIRMATORY TEST

	Optimal cutting factors	
	Prediction (MINITAB)	experiment
level	A2 B2 C1 D2	A2 B2 C1 D2
CUTTING FORCE (N)		186.2
SURFACE ROUGHNESS(µm)		2.4
S/N RATIO (larger-the-better)	-0.975681	-1.1069

It can be concluded that the optimal setting A2 B2 C1 D2 is correct and that turning for 304 SS should be done at this setting for the least amount of cutting force and surface roughness because the S/N ratio value predicted by MINITAB 16 and the S/N ratio calculated for the experimental optimal both equal each other.

IV. CONCLUSION

The following conclusion may be drawn from the experiment and analysis of the turning operation of 304 SS using a carbide insert tool.

1. The Taguchi and grey relational analysis approach can be used to optimize multi-objective solutions in an effective and straightforward manner.
2. The analysis indicates that the primary input parameters that have the greatest impact on cutting force and surface roughness are feed rate and cutting speed.
3. This method may jointly improve cutting force and surface roughness, two performance characteristics of turning operations.

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