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Optimization Of Surface Roughness of CNC Step Turning Components Using Taguchi Method

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Abstract- Turning process is one of the important processes useful in the manufacturing industries. The turning operations can be effected by many factors like velocity of cutting, force of cutting, feed rate, depth of cutting, tool geometry, etc. In these operations, it is difficult to achieve surface of the parts and very challenging task. So the quality of the parts is depending on the selected parameters. However, different responses are affected by various parameters in a material removal process.

In this project the machining parameters such as velocity of cutting, force of cutting, feed rate, depth of cutting on the roughness of surface in a turning operations are investigated by using the Taguchi optimization method. The step turn model is created in Pro-Engineer software and turning operations are performed using SPINNER15 CLASSIK CNC Lathe machine. First Taguchi Orthogonal Array is selected in Minitab18 software to evaluate S/N ratio and Mean. The good surface smoothness is obtained at optimal parameters of spindle speed 2500rpm, feed rate 120mm/min and depth of cutting 1.5 mm for EN 31 steel.

Keywords: CNC Turning, Cutting Parameters, Roughness of surface, Signal to noise Ratio, Taguchi Technique.

I. INTRODUCTION

A. Turning

Turning is a process to remove materials at the outer periphery of a cylindrical work part. Diameter of the work pieces can be reduced by turning process for getting good surface finish. Often the work part can turned so that the nearby sections have different diameters. Here the work part material used is EN31 steel.

B. EN 31 Steel [2]

Density of EN31 steel is 7.81 g/cc. The mechanical properties, thermal properties and Component Elements compositions are given in table.1, table.2 and Table.3 respectively.

Table 1. Mechanical Properties of EN31

	Mechanical Properties	Metric
1	Hardness, Brinell	290 - 341
2	Tensile Strength, Ultimate	1010 MPa
3	Tensile Strength, Yield	800 MPa
4	Modulus of Elasticity	205GPa
5	Compressive Yield Strength	850 - 1000 MPa
6	Charpy Impact	5.02 - 10.0 J

Table 2. Thermal Properties

	Thermal Properties	Metric
1	CTE, linear	12.6 µm/m-°C
2	Specific Heat Capacity	0.460 J/g-°C
3	Thermal Conductivity	29.0 W/m-K

Table 3. Component Elements Properties

	Component Elements Properties	Metric
1	Carbon, C	0.370 %
2	Chromium, Cr	2.0 %
3	Manganese, Mn	1.40 %
4	Molybdenum, Mo	0.20 %
5	Nickel, Ni	1.0 %
6	Silicon, Si	0.30 %
7	Sulfur, S Remaining IRON	< = 0.010 %
8	Chromium, Cr	2.0 %

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C. Cemented Carbide Tool

Cemented carbide [5] is a hard material, having 14.95 g/cc density, used extensively as good cutting tool material, and for other industrialized applications. It contains finer particles of carbide cemented into a composite by a binder medium. Cemented carbides generally use tungsten carbide (WC), titanium carbide (TiC), or tantalum carbide (TaC). These are considered as cemented composites in industries.

Most carbide tools will give better surface finish on parts, and allow faster machining than high-speed steel or other tool steels cutters. Carbide tools can be withstands at higher temperatures at the cutter-work piece interfacing than standard high-speed steel [6] tools (which are the main reason for the fastest machining). Carbides are usually have superior properties shown in table.4, for the cutting of hard materials such as carbon steel or stainless steel.

The cemented carbide tool of 94 % developed first, was tungsten carbide (introduced in 1927's) which used tungsten carbide fine particles held together by a 6% cobalt binder. Since then other cemented carbide tools have been developed, such as titanium carbide, which is best suited for cutting steel, and tantalum carbide, which is harder than tungsten carbide.

Table 4. Mechanical Properties

	Mechanical Properties	Metric
1	Hardness, Rockwell A	91.9
2	Hardness, Vickers	1575
3	Rupture Strength	2200 MPa
4	Compressive Strength	6200 MPa

D. PRO/Engineer

Pro/ENGINEER, integrated 3D CAD/CAM/CAE solver , is used by discrete manufacturers for design and manufacturing, It was created by Dr. Samuel P. Geisberg in the mid-1980s. Pro/ENGINEER was the industry's first successful parametric 3D CAD model making system.

This powerful and robust design approach was used by companies whose product strategy is family-based or platform-driven, where a prescriptive design model strategy is critical to the success of the design process by embedding engineering constraints and relationships to quickly optimized the design, or where the resulting geometry may be complex or based upon equations. Pro/ENGINEER provides a complete set of design, analysis and manufacturing capabilities, integral, scalable platform. These capabilities include Solid Modeling, Surfacing, Data Interoperability, Routed Systems Design, Simulation, Tolerance Analysis, and NC and Tooling Design. Companies use Pro/ENGINEER to create a complete 3D digital model of their products. The models consist of 2D and 3D solid model data which can also be used downstream in finite element analysis, rapid prototyping, tooling design, and CNC manufacturing. All the data is associative and interchangeable between the CAD, CAE and CAM softwares without conversion. A product and its entire bill of materials can be modeled accurately with associative engineering drawings, and revision control information. The associability in Pro/ENGINEER enables users to make changes in the design model at any time during the product development processes. This capability enables concurrent engineering model design, analysis of model and manufacturing engineers working in this parallel and streamlines product development processes.

Pro/ENGINEER is an integral part of edge product development system developed by the PTC. It generally connects to the PTC's other solutions such as Wind-chill, Product Views, MathCAD and Arbor text. Different modules in PRO/E are part design, assembly, drawing, sheet metal, and manufacturing. The 3D models of the work part with diameters 25mm, 35mm, 45mm of each 50mm length used in this project is shown in figure.1

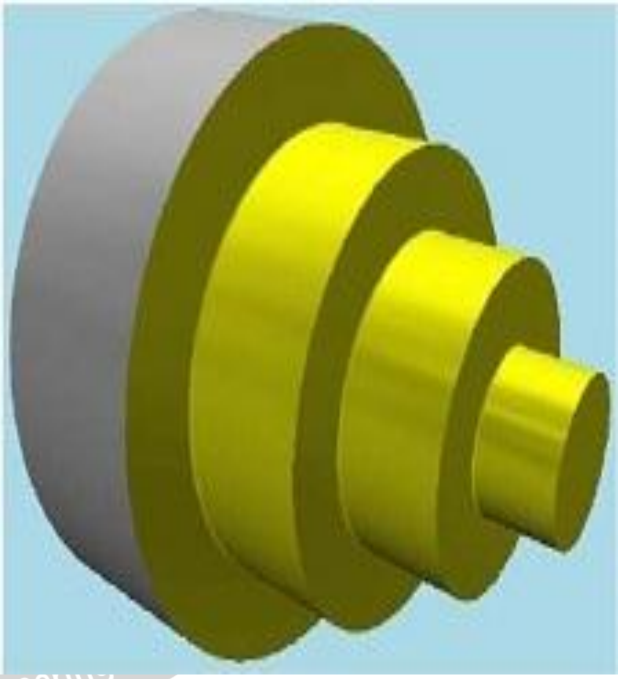

Figure 1. 3D Pro/E model of stepped bar

II. EXPERIMENTATION

A. Spinner CLASSIK CNC Lathe machine

The turning experiments are done based on parameters specified in table.5 using CNC turning machine shown in figure.2 and figure.3 with the following parameters.

Table 5. Selected parameters

Parameters	1	2	3
Feed (mm/min)	120	250	380
Cutting speed(rpm)	1200	2000	2500
Depth of cut(mm)	0.5	1	1.5

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Figure.2 Spinner CLASSIK CNC Lathe machine

Figure 3. Step turning work piece

B. *Taguchi Technique* [7], [8]

Taguchi defines Quality of a product as the total loss incurred by the society due to failure of a product. This includes costs associated with poor performance, operating costs (which changes as a product ages) and any added expenses due to harmful side effects of the product in use. It is used for help companies to perform the fixed quality, Quality problems are due to noises in the product or process system, Noise is any undesirable effect that increases variability, Conduct extensive problem analyses, Employ inter-disciplinary teams, Perform Designed Experimental Analyses [8], [9], Evaluate Experiments using ANNOVA and Signal-to noise techniques, this process is shown in figure 4.As selected factors and levels is indicated in table.6 with L9 orthogonal array. Noise factors give functional variations. They are three classes, i. Outer Noise-Environmental Conditions, ii. Inner noise-life time deterioration, iii. Between product noise - part to part variation. The point is that to produce processes or products with robust against noises. Don't spend the money to eliminate all noise, build designs (product and process) that can perform as desired- low variability-in the presence of noise.

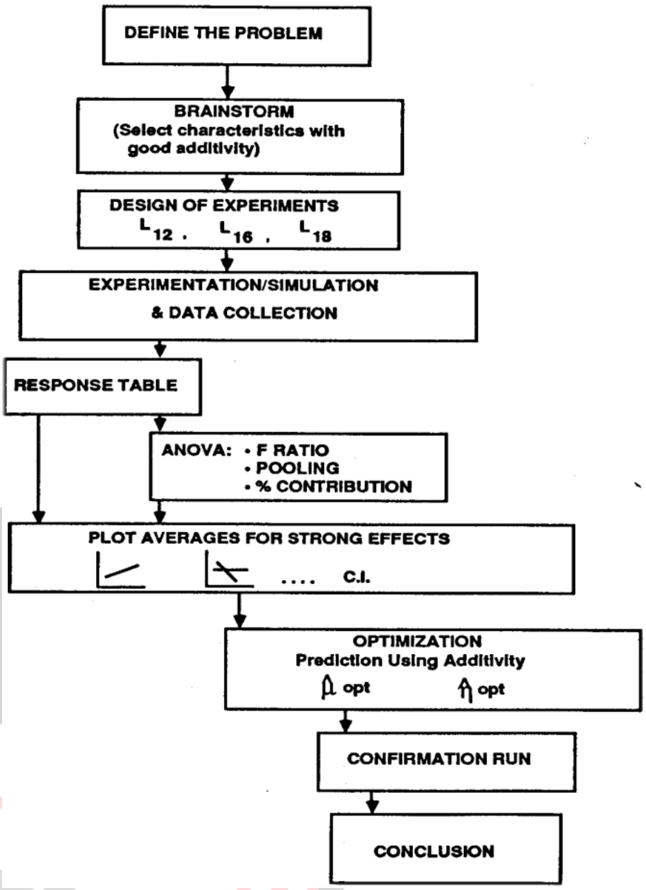

Figure 4. Taguchi flow chart

Table 6.Selected factors and levels

Factors	Process parameters	Level 1	Level 2	Level 3
A	Cutting Speed(rpm)	1200	2000	2500
B	Feed rate (mm/rev)	120	250	380
C	Depth of cut(mm)	0.5	1	1.5

II. RESULTS AND DESCUSSIONS

Surface roughness of the work pieces at one location are measured and shown in table.7 after conducting the experiments. These results are verified with Minitab18 software shown in table.8. The Signal- to- Noise ratio and mean are indicated in column C6 and C7 respectively.

Table 7.Matrix Experiments with results

Expt. No.	Spindle speed (rpm)	Feed rate (mm/min)	Depth of cut (mm)	Surface roughness (Ra) 1	Surface roughness (Ra) 2
1	1200	120	0.5	5.830	5.81
2	1200	250	1	6.290	6.28
3	1200	380	1.5	7.070	7.09
4	2000	120	1	5.300	5.33
5	2000	250	1.5	5.760	5.78
6	2000	380	0.5	7.380	7.37
7	2500	120	1.5	5.280	5.27
8	2500	250	0.5	5.810	5.83
9	2500	380	1	7.110	7.12

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Table.8 Surface roughness obtained by tester and Minitab18 with S/N ratios and mean

↓	C1	C2	C3	C4	C5	C6	C7
	SPEED	FEED	D O C	Surface Roughness	Surface roughness 1	SNRA1	MEAN1
1	1200	120	0.5	5.83	5.81	-15.2985	5.820
2	1200	250	1.0	6.29	6.28	-15.9661	6.285
3	1200	380	1.5	7.07	7.09	-17.0007	7.080
4	2000	120	1.0	5.30	5.33	-14.5101	5.315
5	2000	250	1.5	5.76	5.78	-15.2235	5.770
6	2000	380	0.5	7.38	7.37	-17.3552	7.375
7	2500	120	1.5	5.28	5.27	-14.4445	5.275
8	2500	250	0.5	5.81	5.83	-15.2985	5.820
9	2500	380	1.0	7.11	7.12	-17.0435	7.115

The average of the signal to noise ratios is shown in table 9. Similarly S/N ratios can be calculated for other factors.

Table 9. Average S/N Ratios for each factor

Level	Speed		Feed		Depth of Cut	
	Sum (S_{sj})	Avg S/N ratio	Sum (S_{sj})	Avg S/N ratio	Sum (S_{sj})	Avg S/N ratio
1	-47.26	-16.08	-44.25	-14.75	-47.95	-15.98
2	-47.08	-15.69	-46.48	-15.49	-47.51	-15.83
3	-46.78	-15.59	-51.39	-17.13	-46.66	-15.55

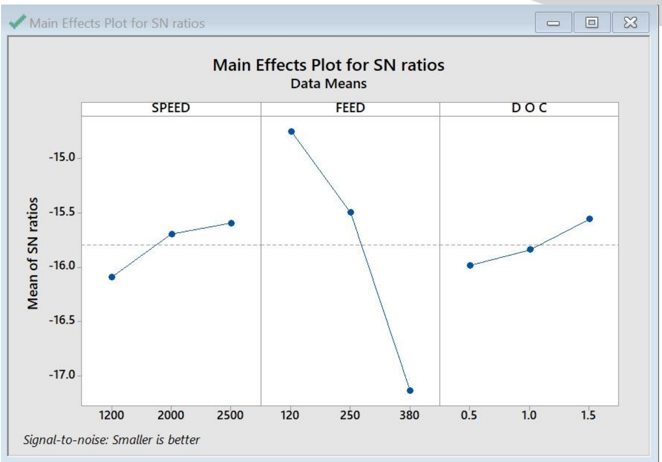

Figure 5. Turning parameters level Vs S/N ratio

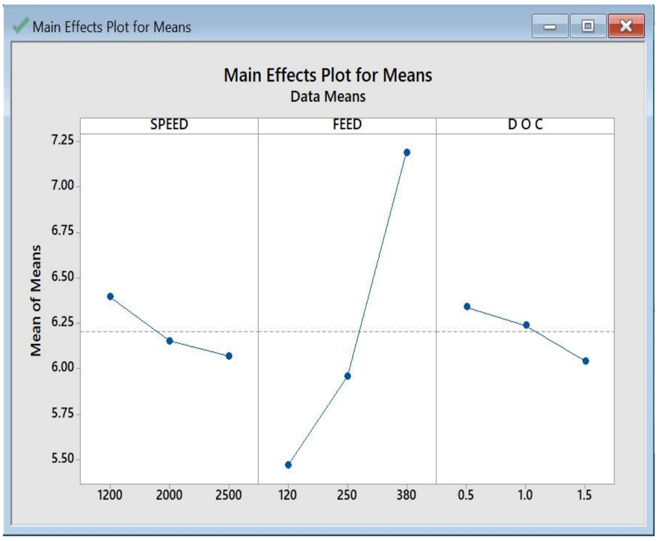

Figure 6. Turning parameters level Vs Means

Taguchi method focused on the importance of studying the response variation [1], [3] using the signal-to-noise (S/N) ratio, resulting in minimization of quality characteristic variation due to uncontrollable parameter. The cutting force is considered as the quality characteristic with the concept of "the smaller-the-better". The S/N ratio for the smaller-the-better is:

$$S/N = -10 *\log (\Sigma(Y^2)/n)) \quad \text{Eqn.1}$$

Where n is the number of measurements in a trial/row, in this case, n=1 and y is the measured value in a run/row. The S/N ratio values are calculated by taking into consideration of above Eqn.1 with the help of software Minitab 18. It is clear from the figure.5 and figure.6, for obtaining optimal values. From the analysis of variance (ANOVA) the percentage of contribution of each factor involved in this operation is given in table 10. Here the contribution of feed rate (91.75%) is more significant than cutting speed (3.4696%) and depth of cut (2.773%) on surface finish. The effect of noise factor (2.008%) is very less on the required response.

Table 10.Sum of all squares of deviations

Parameter	DOF	SS	SS%
Speed, s	2	0.1778	3.469
Feed, f	2	4.7017	91.75
Depth of cut, t	2	0.1421	2.773
Noise, e	2	0.1029	2.008
Total	8	5.1244	100

III. CONCLUSIONS

In this project an attempt is made to make use of Taguchi technique, to optimize cutting process parameters turning of EN 31 steel using cemented carbide tool. In this work, the parameters of cutting speeds are 1200pm, 2000rpm and 2500 rpm; feed rates are 120mm/min, 250mm/min, 380 mm/min; depth of cuts are 0.5mm, 1.0mm, 1.5mm taken for the machining operations. Experimentation is done by considering the above mention parameters. Surface roughness values are validated experimentally.

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By observing Taguchi results the following conclusions are made. First one, the good surface finish is obtained for optimal parameter set of 2500rpm spindle speed, 120mm/min feed rate and 1.5mm depth of cutting for EN 31 steel. Second, Taguchi Design of Experimentations can provides a small, simple and most effective methodology for optimizing the process parameters. Last one, the percentage of contribution of feed rate is more on this operation.

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