Optimization of Cutting Parameters of CNC Machine using Taguchi Method

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Abstract— This study present a new method to determine optimum turning parameters based on the Taguchi method to minimize cycle time and surface roughness (Ra). Experiments have been conducted using the L27 orthogonal array in a CNC turning machine. Dry turning tests are carried out on hardened EN353 with Insert TNMGR0.8. Each test is carried out in batch of three and every time uses a new cutting insert in order to get accurate readings of the surface roughness. The statistical methods of signal to noise ratio (SNR) are applied to investigate effects of cutting speed, feed rate and depth of cut on cycle time and surface roughness (Ra). The results shows that the feed rate is the dominant factor affecting surface roughness. In addition, the effects of two factor interactions of the feed rate-cutting speed and depth of cut-cutting speed appear to be important. The developed model can be applied in the metal machining industries in order to calculate the optimum cutting parameters for minimum cycle time and surface roughness.
Key words: CNC Machine, Taguchi Method

I. Introduction

In modern industry the goal is to manufacture low cost, high quality products in short time. Automated and flexible manufacturing systems are employed for that purpose along with computerized numerical control (CNC) machines that are capable of achieving high accuracy and very low processing time. Turning is the first most common method for cutting and especially for the finishing machined parts. In a turning operation, it is important task to select cutting parameters for achieving high cutting performance. Generally, the desired cutting parameters are determined based on experience or by use of a Design data book.

Cutting parameters are reflected on surface roughness, surface texture and dimensional deviations of the product. Surface roughness is most important factor used to determine and to evaluate the quality of a product, is one of the major quality attributes of a turning product. Surface roughness is a measure of the technological quality of a product and a factor that greatly influences manufacturing cost. It indicates the geometry of the machined surfaces and combined with the surface texture. The mechanism behind the formation of surface roughness is very complicated and process dependent. To select the cutting parameters properly, several mathematical models based on statistical regression or neural network techniques have been constructed to establish the relationship between the cutting performance and cutting parameters. Then, an objective function with constraints is formulated to solve the optimal cutting parameters using optimization techniques. Therefore, considerable knowledge and experience are required for this approach. In this experiment, an alternative approach based on the Taguchi method is used to determine the optimum cutting parameters more efficiency. There were two purposes of this research. The first was to demonstrate a systematic procedure of using Taguchi parameter design in process control of turning machines. The another was to express a use of the Taguchi parameter design in order to make out the optimum cycle time and surface roughness performance with a exacting combination of cutting parameters in a turning operation. The paper is organized in the following manner. An overview of the parameter design based on the Taguchi method is given first. Then, the parameter design with the multiple performance characteristics is introduced. The experimental detail of using the parameter design to determine and analyze the optimal cutting parameters in turning operations is described next. Finally, the paper concludes with a summary of this study.

II. Literature Review

1) Niyom Suwandej describes that in order to stimulate a quality development of the Thai governmental operations for public services, the Office of the Public Sector Development Commission (OPDC) has exercised to monitor and evaluate governmental offices. The practice is to ensure a reduced number of steps and time spent in the operation. Rewarding program has also been activated by the OPDC in order to appraise governmental offices with quality public service provision. This helps encourage staff and organizations to continue improving their services. Furthermore, this reformation contributes to increasing the capabilities of governmental servants as well as raising the public faith towards governmental bureaucracies. In this regard, essential guidelines based on the Planning Strategies of Thai Public Sector Development (2003-2007) were established to be utilized in improving public service quality, reforming the process and operations of governmental offices for enhancing operational capacity and standards to meet the international level, on a good governance basis. The prominent characteristics of the public administration and management quality criteria encompass the following three items: 1) goal- oriented; 2) flexible and adjustable for all governmental organizations' missions; and 3) linking and corresponding to other items within the criteria. Implementing these criteria can lead to an integrated outcome, which will ultimately become beneficial as the communication tool of the organization, whereas it endorses flexibility innovation and decentralization or empowerment of organizations.
2) Cemal Zehir, Öznur Gülen Ertosun, Songül Zehir, Büşra Müceldilli describes that the links between TQM and performance have been investigated by numerous scholars. While examining the relationship between TQM and performance scholars have used different

performance types such as financial, innovative, operational and quality performance. Although the effects of TQM on various performance types are inconsistent, quality performance generally indicated strong and positive relations. Supporters of TQM suggest that implement it well generate higher quality products. According to Deming, quality is the principal determinant of success in competitive environments. Quality management is increasingly high-profile activities for all kinds of firms and is associated with gaining a competitive advantage

3) Aysel Cetindere, Cengiz Duran, Makbule Seda Yetisen describes that under the developing and changing world conditions, businesses in the race which is excessively competitive and to be able to grab rapidly increasing market share with the developing technology have to revise their understanding of quality and decrease the margin of error in the product or service they produce in order to be able to survive, compete and reach the level they want and maintain this level. In this context, companies began a "quality race" and Total Quality Management approach gained importance. TQM can be described as "a combination of participatory management and team work, produce defect-free products or customer satisfaction". TQM including the human and the quality-productivity relationship; compromises the process in which requires improving performance at all levels and activities of everyone in the organization.
4) Moslem Alimohammadlou, Farzaneh Eslamloo describes that the research found that strategic planning and human resource management had a positive and significant relationship with KM elements. Furthermore, process management was found to have a significant effect on knowledge acquisition/distribution. Considering the importance of TQM and Knowledge transfer in the academic environments, the present study seeks to create a ground for understanding TQM and its facilitating role in knowledge transfer, explaining how TQM can enhance the transfer and distribution of knowledge in academic settings.
5) Mateus C. Gerolamo, Camila F. Poltronieria, Tuane T. Yamadaa, Ana L. B. Cintraa describes that, successful implementation cases of QM programs have been conducted in several organizations worldwide. Despite recognizing QM, there are still many unsuccessful cases. Beer reviewed some studies on QM programs and concluded that 60% to 70% of firms fail in their effort to implement TQM practices or improve the quality of products and services not boosting their capacity to compete.

III. OBJECTIVES

1) Literature reviews of turning process parameters.
2) Identify the performance characteristics and select process parameters to be evaluated
3) Determine the number of levels for the process parameters and possible interactions between the process parameters.
4) Select the appropriate orthogonal array and assignment of process parameters to the orthogonal array.
5) Conduct the experiments based on the arrangement of the orthogonal array.
6) Optimization of process parameters using Design of Experiments (DOE).
7) Analyze the experimental results using the S/N ratio and ANOVA.
8) Verify the optimal process parameters through the confirmation experiment.

IV. TAGUCHI METHOD

Taguchi has developed a methodology for the application of designed experiments, including a practitioner's handbook. This methodology 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 through the practitioner work simpler by advocating the use of less experimental designs, and providing a clearer understanding of the variation nature and the economic consequences of quality engineering in the world of manufacturing. Taguchi introduces his approach, using experimental design for.

– Designing products so as to be robust to ecological condition;
– Designing and developing products/processes so as to be robust to component variation;
– Minimizing variation around a target value.

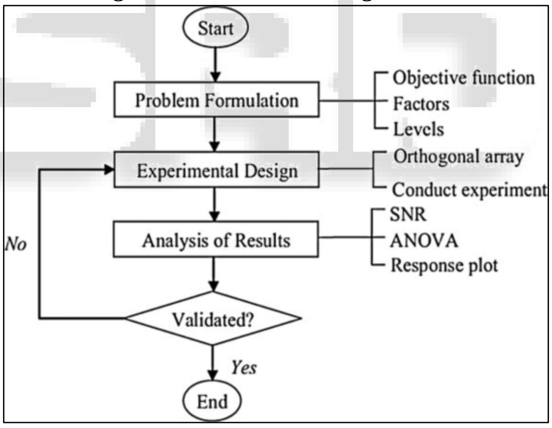

Fig. 1: Taguchi Method Flow chart

The philosophy of Taguchi is broadly applicable. He proposed that engineering optimization of a process or product should be carried out in a three-step approach, i.e., system design, parameter design, and tolerance design. In system design, the engineer applies scientific and engineering knowledge to produce a basic functional prototype design, this design including the product design stage and the process design stage. In the product design stage, the selection of materials, components, tentative product parameter values, etc., are involved. As to the process design stage, the analysis of processing sequences, the selections of production equipment, tentative process parameter values, etc., are involved. Since system design is an initial functional design, it may be far from optimum in terms of quality and cost. The purpose of the parameter design is to optimize the settings of the process parameter values for optimizing performance characteristics and to discover the product parameter values under the optimal process parameter values. In addition, it is expected that the optimal process parameter values obtained from the parameter design are insensitive to the variation of environmental conditions and other noise factors. Hence, the parameter design is the main step in the Taguchi method to achieving high quality without increasing cost.

V. MATERIAL AND METHOD

A. Work piece

Fig. 2: Work piece

In this study, a work piece made of Alloy steel grade (EN353) was used. Its sizes were Ø25×130mm. As thermal treatment, the steel was tempered at 6700C for an hour and oil quenched at 8100C for 2 hour to eliminate stresses and to reduce hardness. As a result, hardness of the material was decreased from 64 HRC to 60-62 HRC.

B. CNC Machine

The experimental studies were carried out on a MAZATROL 640T CNC Lathe. The experiments were conducted using coolant Quicker of PH 7(3755BIO with 5%).

Fig. 3: MAZATROL 640T CNC Lathe

C. Cutting tool

Fig. 4: Selected insert for experimentation

TNMGR0.8 of six edges inserts were used as the cutting tool material.

D. Surface Roughness Tester

Fig. 5: Surface roughness Tester

The surface roughness was measured using Mitutoyo SJ-301P portable device within the sampling length of 2.5 cm.

E. Method

The level of cutting parameter ranges and the initial parameter values were chosen from the manufacturer's handbook recommended for the tested material. These cutting parameters are shown in Table I.

Level	Cutting speed(V) rpm	Feed(f) mm/rev.	Depth of cut(a) mm
1	315	0.1	0.5
2	345	0.15	0.8
3	354	0.2	1.0

Table 1: Cutting Parameters and their levels,

The Taguchi method and L9 Orthogonal Array were used to reduce number of the experiments. The design of experiments (DOE) and measured Ra values are shown in Table I. The experiments were conducted with three replicates.

VI. THE EXPERIMENTAL DESIGN USING TAGUCHI METHOD

The traditional experimental design methods are too complex and difficult to use. Additionally, large numbers of experiments have to be carried out when the number of machining parameters increase. Therefore, the factors causing variations should be determined and checked under laboratory conditions. These studies are considered under the scope of off-line quality improvement.

The Taguchi method is an experimental design technique, which is useful in reducing the number of experiments dramatically by using orthogonal arrays and also tries to minimize effects of the factors out of control. The basic philosophy of the Taguchi method is to ensure quality in the design phase. The greatest advantages of the Taguchi method are to decrease the experimental time, to reduce the cost and to find out significant factors in a shorter time period.

Fig. 6: Samples

The most reliable of Taguchi's techniques is the use of parameter design, which is an engineering method for product or process design that focuses on determining the parameter (factor) settings producing the best levels of a quality characteristic (performance measure) with minimum variation. The overall aim of quality engineering is to make products that are robust with respect to all noise factors. The most important stage in the design of an experiment lies in the selection of control factors. As many factors as possible should be included in order to it would be possible to identify non-significant variables at the earliest opportunity. Taguchi creates a standard orthogonal array to accommodate this requirement. Taguchi used the signal-to-noise (S/N) ratio as the quality characteristic of choice. S/N ratio is used as a measurable value instead of standard deviation because as the mean decreases. The standard deviation also decreases and vice versa. In less technical terms, signal-to-noise ratio compares the level of a desired signal (such as music) to the level of background noise. The higher the ratio, the less obtrusive the background noise is. ''Signal-to-noise ratio'' is sometimes used informally to refer to the ratio of useful information to false or irrelevant data in a conversation or exchange. In other words, the standard deviation cannot be minimized first and the mean brought to the target [4,24,25]. Taguchi has empirically found that the two stage optimization procedure involving S/N ratios indeed gives the parameter level combination, where the standard deviation is minimum while keeping the mean on target [26].This implies that engineering systems behave in such a way that the manipulated production factors can be divided into three categories:

1) Control factors, which affect process variability as measured by the S/N ratio.
2) Signal factors, which do not influence the S/N ratio or process mean.
3) Factors, which do not affect the S/N ratio or process mean.

In practice, the target mean value may change during the process development. Two of the applications in which the concepts of S/N ratio are useful are the improvement of quality through variability reduction and the improvement of measurement. The S/N ratio characteristics can be divided into three categories given by Eqs. (1)–(3), when the characteristic is continuous Nominal is the best characteristic,

– Nominal is the best characteristic,

$$\frac{S}{N} = 10log\,\frac{y}{S_y^2} \quad\text{..........................(1)}$$

– Smaller is the better characteristic,

$$\frac{S}{N} = -10\,log\,\frac{1}{n}\left(\sum y^2\right) \quad\text{....................(2)}$$

– Larger is the better characteristic,

$$\frac{S}{N} = -log\,\frac{1}{n}\sum\frac{1}{y^2} \quad\text{........................(3)}$$

VII. Results and Discussion

A. Test performance

The experimentally obtained values of Surface roughness (Ra), and Cycle TIME (t) are also presented in Table. In this section, the use of the OA with the GRA for determining the optimal process parameters is reported step by step. The optimal process parameters with consideration of the multiple performance characteristics are obtained and verified.

Exp. No	Control factor levels			Outputs		
	Cutting speed(V) rpm	Feed(f) mm/rev.	Depth of cut(a) mm	Cycle time	Ra	S/N Ratio For Ra
1	315	0.1	0.5	2.57	2.83	-9.035
2	315	0.1	0.8	2.01	2.60	-8.299
3	315	0.1	1.0	1.41	2.74	-8.755
4	315	0.15	0.5	2.07	1.89	-5.529
5	315	0.15	0.8	1.29	2.65	-8.464
6	315	0.15	1.0	1.16	1.86	-5.390
7	315	0.2	0.5	1.42	2.10	-6.444
8	315	0.2	0.8	1.14	2.02	-6.107
9	315	0.2	1.0	1.03	1.83	-5.249
10	334	0.1	0.5	2.56	2.25	-7.043
11	334	0.1	0.8	2.01	2.92	-9.307
12	334	0.1	1.0	1.40	2.86	-9.127
13	334	0.15	0.5	2.07	1.86	-5.390
14	334	0.15	0.8	1.29	2.96	-9.425
15	334	0.15	1.0	1.15	1.84	-5.296
16	334	0.2	0.5	1.41	2.03	-6.149
17	334	0.2	0.8	1.10	1.76	-4.910

18	334	0.2	1.0	1.02	1.82	-5.201
19	354	0.1	0.5	2.56	2.85	-9.096
20	354	0.1	0.8	2.01	2.93	-9.337
21	354	0.1	1.0	1.40	2.87	-9.157
22	354	0.15	0.5	2.06	1.06	-0.506
23	354	0.15	0.8	1.29	2.78	-8.880
24	354	0.15	1.0	1.15	1.93	-5.711
25	354	0.2	0.5	1.41	1.66	-4.402
26	354	0.2	0.8	1.13	2.09	-6.40
27	354	0.2	1.0	1.03	3.81	-11.618

Table 2: Experimental Layout using an L27 Orthogonal Array and Performance Results

Ex no.	Cycle Time (t)	Surface Roughness(Ra)	Normalize (t)	Normalize (Ra)	GREY coeff. (t)	GREY coeff. (Ra)
1	2.57	2.83	0	0.3563	0.3333	0.4372
2	2.01	2.6	0.3636	0.44	0.44	0.4716
3	1.41	2.74	0.7532	0.389	0.6695	0.45
4	2.07	1.89	0.3246	0.6981	0.4254	0.6235
5	1.29	2.65	0.8311	0.4218	0.7475	0.4637
6	1.16	1.86	0.9155	0.709	0.8555	0.6321
7	1.42	2.1	0.7467	0.6218	0.6637	0.5693
8	1.14	2.02	0.9285	0.6509	0.875	0.5888
9	1.03	1.83	1	0.72	1	0.641
10	2.56	2.25	0.0064	0.5672	0.3347	0.536
11	2.01	2.92	0.3636	0.3236	0.44	0.425
12	1.4	2.86	0.7597	0.3454	0.6754	0.433
13	2.07	1.86	0.3246	0.709	0.4254	0.6321
14	1.29	2.96	0.8311	0.309	0.7475	0.4198
15	1.15	1.84	0.9220	0.7163	0.8651	0.638
16	1.41	2.03	0.7532	0.6472	0.6695	0.5863
17	1.1	1.76	0.9545	0.7454	0.9166	0.6626
18	1.02	1.82	1.0064	0.7236	0.9871	0.644
19	2.56	2.85	0.0064	0.349	0.3347	0.4344
20	2.01	2.93	0.3636	0.32	0.44	0.4237
21	1.4	2.87	0.7597	0.3418	0.6754	0.4317
22	2.06	1.06	0.3311	1	0.4277	1
23	1.29	2.78	0.8311	0.3745	0.7475	0.4442
24	1.15	1.93	0.9220	0.6836	0.8651	0.6124
25	1.41	1.66	0.7532	0.7818	0.6695	0.6962
26	1.13	2.09	0.9350	0.6254	0.885	0.5717
27	1.03	3.81	1	0	1	0.3333

Table 3: Normalized Value and Grey Relation Coefficient

Grey relation grade is find out and give ranking for obtaining the optimal condition and shown in table

Ex No	Grey relation grade	Order
1	0.385268	26
2	0.455849	22
3	0.559824	17
4	0.524499	21
5	0.605658	14
6	0.74387	5
7	0.616576	13
8	0.731933	7
9	0.820513	1
10	0.435422	23
11	0.432519	24
12	0.554255	18
13	0.528799	20
14	0.58371	16
15	0.75161	4
16	0.62796	12
17	0.789659	3
18	0.815604	2
19	0.384611	27
20	0.431864	25
21	0.553575	19
22	0.713889	9
27	0.595919	15
24	0.73882	6
25	0.682884	10
26	0.728392	8

Table 4: Grey Relation Grade and Their Order

The mean response for each factor and the ranks are determined from the loss function as shown in Table.

Level	VC	F	a
1	0.604888	0.534213	0.612738
2	0.613282	0.642975	0.595056
3	0.610736	0.717138	0.686532
Delta	0.008394	0.182925	0.091476
Rank	3	1	2

Table 5: Grey Relation Grade Response

The effect from response table is plotted in Figure

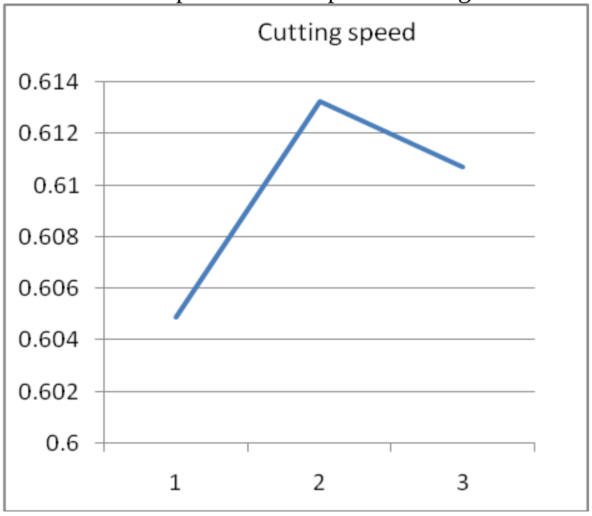

Fig. 7: Cutting Speed

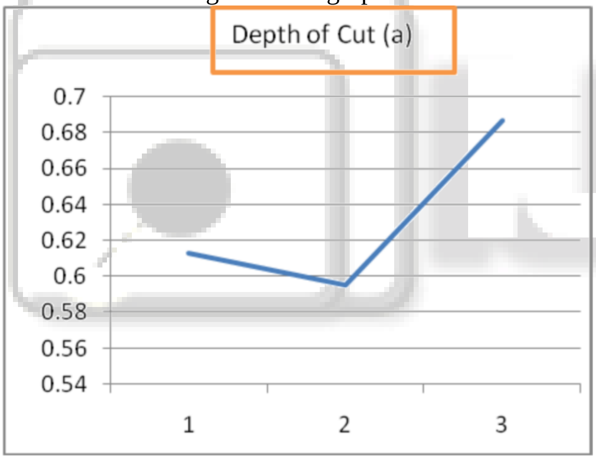

Fig. 8: Depth of Cut

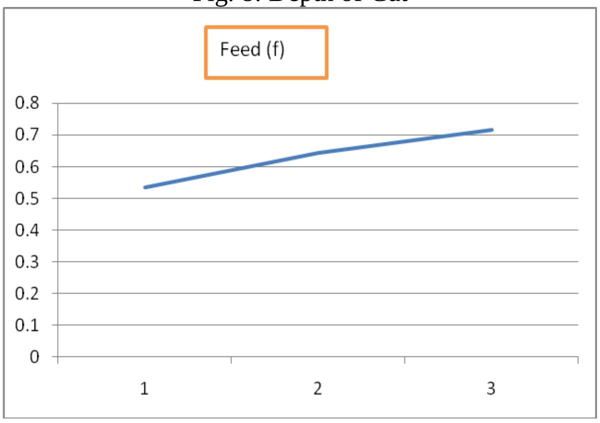

Fig. 9: Feed

In order to understand contribution of the cutting parameters depth of cut, cutting speed, feed, and corner radius on the experimental result of variance were carried out. The result of ANOVA for grey relation grade are shown in Table

Parameters	DOF	Sum of square	Mean square	F value	% contribution
Vc	2	0.000333	0.000167	0.001327	0.071803
f	2	0.165211	0.082606	0.657644	35.57563
a	2	0.055218	0.027609	0.219803	11.89039
error	16	0.243632	0.015227		52.46218
total	22	0.464395	0.125609		100

Table 6: Anova for Grey Relational Grade

Here, Table 9 gives the results of the analysis of variance (ANOVA) for the Cycle Time(t) and the Surface roughness (Ra) using the calculated values from the Grey relational grade of Table 7 and the response table of Table 8. According to Table 9, the feed with 35.57 %of contribution, is the most significant controlled parameters for the turning operation; the Depth of cut is with 11.89039% contribution, the Cutting speed with0.071803 %, and the corner radius with 6% of contribution if the minimizing surface roughness and flank wear are simultaneously considered.

B. *Confirmation test*

After identifying the most influential parameters, the final phase is to verify the t and Ra by conducting the confirmation experiments. The Vc1F1Dc2 is an optimal parameter combination of the turning process via the Grey relational analysis. Therefore, the condition Vc1F1Dc2 of the optimal parameter combination of the turning process was treated as a confirmation test. If the optimal setting with a cutting speed 315 m/min, a feed of 0.1 mm/rev, a depth of cut of 0.8 mm is used, the final work piece gives the Cycle Time (i.e., t) of 2.01min., the Surface roughness(i.e., Ra) of 2.60 µm.

VIII. CONCLUSION

The following conclusions can be drawn based on the results of experimental study:

- The machining parameters namely cutting speed, feed rate, depth of cut is optimized to meet the objectives. The results reveal that the primary factor affecting the surface roughness and cycle time is speed subsequently followed by depth of cut, feed.
- The feed is most significant factor which minimizing surface roughness and improving cycle time is 35.57% subsequently followed by depth of cut which contributes 11.89%, cutting speed 0.071803%.
- The optimized factor for great surface finish and low flank wear is cutting speed Vc1=315m/min, feed F1= 0.1 mm/rev, depth of cut Dc2=0.8 mm.
- It is shown that performance characteristics of the

CNC turning process such as t and Ra are improved together by using grey taguchi method. The research demonstrates how to use Grey Taguchi parameter design for optimizing machining performance with minimum cost and time to industrial readers. The research can be extended by considering more factors (e.g., lubricants, materials, etc.) to see how the factors would affect surface roughness and cycle time.

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