TELKOMNIKA Indonesian Journal of Electrical Engineering
Vol. 12, No. 12, December 2014, pp. 8200 ~ 8204
DOI: 10.11591/telkomnika.v12i12.4959

CNC Parametric Optimization for Exercise Equipment Parts Surface Roughness Using TRIZ

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Abstract

Product quality is the most important issue in the Computer Numerical Control (CNC) process. Hence, with exercise equipment parts Surface Roughness as the target, this study selected Spindle speed, Cutting depth, Feeding, and Tool runoff, as control parameters in CNC parametric optimization of target quality. By using the Theory of Inventive Problem Solving (TRIZ) to define the Cause and Effect relationship and conflicting points, this study quickly identified an optimal solution, according to TRIZ, and determined factor relevance by cutting control parameters. By the 40 Inventive Principles of TRIZ corresponding to Contradiction Matrix, we obtained the Surface Roughness optimization strategy. The empirical research results suggest that Surface Roughness can actually be improved under the optimal parameter combination. The effectiveness and practicality of the proposed method are verified.

***Keywords**: TRIZ, surface roughness, computer numerical control*

1. Introduction

The turning process is a widely used cutting processing method. In turning processing, in addition to the dimensions and shape of the work piece, the surface roughness of the work piece should also be considered [1]. Since turning is cutting by a single-point cutting tool, it can easily result in tool marks on the surface [2], and surface smoothness level can affect the appearance of the work piece [3], coordination functionality, and fatigue service life. The size and number of tool marks can cause Surface Roughness, which further affects subsequent processing and the mechanical properties of the work piece [4]. Major factors affecting Surface Roughness include tool shape, tool life, cutting drive, vibrations, feeding speed, material properties, spindle rotation error, and cutting chatter [5]. In the process, 4 cutting factors (Spindle speed, Cutting depth, Feeding, and Tool runoff) are often used as the control factors of Surface Roughness.

Ghassan et al. [6] used two different methods to measure Surface Roughness. Two light reflection models, namely, the Intensity-Topography Compatible (ITC) model and Light-Diffuse model were adopted and applied to interpret acquired vision data and enable suitable computation of roughness parameters. Roque et al. [7] found the weak points of CNC from the perspective of CAD/CAM, namely, the lack of an advanced mathematical algorithm. The addition of advanced algorithms can significantly reduce the computation of the machine algorithm. This study applied TRIZ [8] to develop CNC cutting technology. TRIZ is put forward by G.S. Altshuler and other researchers of Russia, and based on analysis of 2,500,000 world-wide patents. G.S. Altshuller has drawn three axioms, which constitute the scientific background for the Classic TRIZ [8].

At present, there are many industries applying TRIZ. For example, Samsung and LG of South Korea use the TRIZ method to improve their products and reduce costs. With Surface Roughness as the research subject, this study introduced TRIZ in the CNC process to design Turning Parameters. By using the Contradiction Matrix [9], this study determined the cutting factors (Spindle speed, Cutting depth, and Feeding and Tool runoff) and Surface Roughness relationship, and established quality characteristic analysis of Surface Roughness. Using the Fuzzy Linguistic method, without experimental equipment or materials, this study fuzzified the target setting rules to save experimental time and costs to compute and implement numerical processing of the relationships between turning parameters and targets. The research findings

Received May 23, 2014; Revised October 15, 2014; Accepted November 7, 2014

can be a reference for the subsequent surface roughness design.

2. Quality Discussion
2.1. CNC Turning Quality
In the measurement of CNC Computer Numerical Control turning quality, Surface Roughness is one of the most important items. This study selected “Spindle speed, Cutting depth, Feeding, and Tool runoff” as the control factors [10] to analyze the effects of various cutting factors on Surface Roughness quality [11].

Surface Roughness can be represented by many methods, and the most common representation methods include the Center line average roughness (Ra), Maximum height roughness (Rmax), and Ten point height of irregularities (Rz); this study applied Ra as the method to represent Surface Roughness. Ra is defined by cutting a section of the rough curve of the processing surface for the measurement length of L. By using the central line of the average heights of the length as the X axis and the lines vertical to the central line as the Y axis, the roughness curve can be represented by y= f(x).

2.2. TRIZ Theory
TRIZ (Theory of Inventive Problem Solving) is a term in Russian for the theory of inventive problem solving. The theory was proposed by a Russian named Altshuller and the research group led by him; they used 200 thousands patents of a technological nature to perform analysis and study, and found that common and basic problems, and problems solving techniques, exist in the innovation and invention problems of different fields. Hence, they proposed the same solution for use in problems of different fields and occurring in different times; thus, the model for solving a problem might already exist. Altshuller analyzed and summed 39 technical contradictory system characteristics that are frequently encountered [12], and arranged the corresponding solving rules into a matrix in order to provide designers with a fast method to find most fitting solutions. This matrix uses a 39x39 technical system to help find the rules to solve technical contradictions, for a total of 1263 elements, with numbers in the medium column meaning the numbers of the corresponding new rules. This is a widely known contradiction matrix table using technical contradictions [13], which determines the characteristics of five perspectives, and its own characteristic is determined through correspondence to 39 engineering parameters. In the contradiction matrix, first select and list all items that need to be improved. In the contradiction matrix, 39 characteristics in the vertical axis are the characteristics to be improved, while 39 characteristics in the horizontal axis are characteristics that are about to deteriorate; after orthogonal operation, the required inventive principle can be obtained.

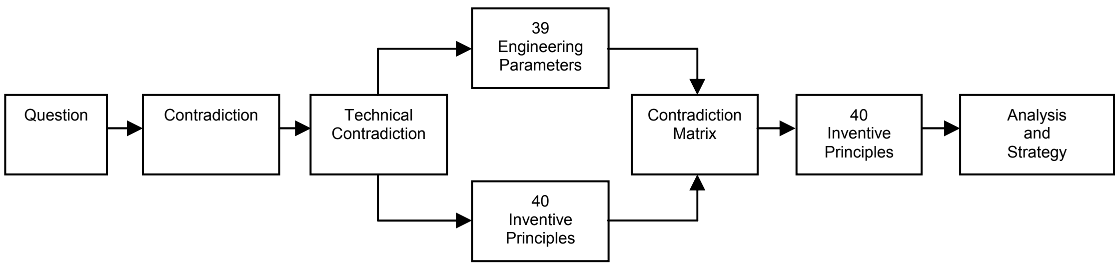

Figure 1. TRIZ research process

3. Research Methods
3.1. Quality Characteristics
In order to understand the focus of quality characteristics, the quality characteristics performed by two researchers [5, 14] on cutting noise is used first, then fuzzy semantics [5] and experimental data [14, 15] will be further used to define TRIZ issues; in this article, cutting noise will be studied first.

3.2. TRIZ Process Flow

By following the research suggestions of Weng [5] and Chan [15], this study used 4 cutting parameters (Spindle speed, Cutting depth, Feeding, and Tool runoff) to analyze the quality characteristics of Surface Roughness, and used TRIZ to determine the conflicts of Surface Roughness. Through the *39 Engineering Parameters,* 40 Inventive Principles, and the Contradiction Matrix, we can obtain a cutting strategy that can optimize surface roughness quality.

3.3. TRIZ of Innovation Strategy

First, we connected the relationships of the four cutting parameters and selected the *Engineering Parameters* by Surface Roughness in order to determine the improving Parameters and worsening parameters of Surface Roughness. The steps of TRIZ are, as follows:

a) Attempt to determine the attributes that cause conflicts from the textual description of the problem to be addressed, and convert the textual descriptions into an item of the 39 Engineering Parameters*;*
b) Determine the traditional method or rule of thumb to propose a possible problem-solving direction;
c) Improving: to determine "improving features" from the horizontal axis of the matrix;
d) worsening: to determine the "worsening parameters" from the vertical axis of the matrix;
e) Use the Interactive TRIZ Matrix to determine the grids of pairwise conflicting attributes;
f) Regarding the 40 Inventive Principles in the grid, determine and evaluate the concepts from the inventive principles.

3.3.1. TRIZ Definition

First, based on the four cutting parameters, this study implemented the TRIZ definition, according to the literature of Weng [5] and Chan [15]:

a) Spindle speed: excessively fast and slow feeding speed will result in better surface roughness,
b) Cutting depth: when cutting circular material, the addition of lathe center can stabilize the object and improve surface roughness.
c) Feeding: tool pressure affects surface roughness.
d) Tool runoff: according to the 81 groups of the Taguchi method proposed by Weng [5], the median values of the manufacturing process will result in the most stable cutting.

3.3.2. Engineering Parameters

By using the TRIZ *39 Engineering Parameters*, this study proposed the improving features and worsening parameters features, and listed the factors to be improved on the left of Table 1, and the worsening parameters in the upper part of Table 1. The improving features include: #9 speed, #13 object stability, #11 pressure or stress, and #29 manufacturing precision, while worsening parameters include: #10 force, #25 time waste, #39 productivity, and #31 hazardous factors.

3.3.3. Contradiction Matrix or Interactive TRIZ Matrix

According to the conditional equations of the TRIZ definition, this study arranged a contradiction matrix and applied 40 Inventive Principles in the table in order to form the Interactive TRIZ Matrix, as shown in Table 1.

Table 1. Interactive TRIZ Matrix

		Worsening features			
		#10	#25	#39	#31
Improving features	#9	13.28.15.19	-	-	2.24.35.21
	#13	10.35.21.16	35.27	23.35.40.3	35.40.27.39
	#11	36.35.21	37.36.4	10.14.35.37	2.33.27.18
	#29	28.19.34.36	32.26.28.18	10.18.32.39	4.17.34.26

4. Results and Discussions
4.1. Experiment Tool

In this study, the experimental equipment adopted the ECOCA PC-3807 model PC-Based CNC Lathe, as manufactured by the ECOCA Industrial Co., Ltd. Where S45C medium carbon steel is adopted as the experimental processing material, which is a processing material commonly adopted by the industry; the lathing material spec is a holding length of 100mm S45C medium carbon steel. The cutter adopted is a ready-to-use disposable cutter, with the handle of model No. TJNR2020K16 manufactured by Toshiba; the cutter used is of model No. NX2525 manufactured by Mitsubishi. The MITSUTOYO SURFTEST SV400 surface analyzer is used in this study to analyze the surface roughness of the cutting results, and the measured surface roughness value is selected as Ra.

4.2. Cutting Parameters

Regarding the four cutting parameters of CNC, including Spindle speed, Cutting depth, Feeding, and Tool runoff, this study listed the three levels, as shown in Table 2. In the process of cutting by CNC, the median values of the cutting parameters are generally used (Table 3):

Table 2. Levels of cutting parameters

	Level 1	Level 2	Level 3
A: Spindle speed v(m/min)	150	200	250
B: Cutting depth d(mm)	0.5	1	1.5
C: Feeding f(mm/rev)	0.02	0.06	0.1
D: Tool runoff runoff(mm)	-0.1	±0.03	0.1

Table 3. Median values of cutting parameters

A2	B2	C2	D2
Spindle speed (m/min)	Cutting depth (mm)	Feeding (mm/rev)	Tool runoff (mm)
200	1	0.06	±0.03

4.3. TRIZ Analysis Verification

The TRIZ cutting parameters of the on-site cutting are, as shown in Table 4. As compared with the research findings of Weng [5] (Table 5), the proposed optimization strategy to improve surface roughness through TRIZ has surprising effect. The Surface Roughness is 0.783μm, which is improved by 0.1403μm, as compared with the findings of Weng [5] (Figure 2).

Table 4. TRIZ parameters

A3	B1	C3	D1
Spindle speed (m/min)	Cutting depth (mm)	Feeding (mm/rev)	Tool runoff (mm)
250	0.5	0.1	-0.1

Table 5. TRIZ solution results

	Spindle speed (m/min)	Cutting depth (mm)	Feeding (mm/rev)	Tool runoff (mm)
Weng[5]	200	1	0.06	±0.03
The proposed method	250	0.5	0.1	-0.1

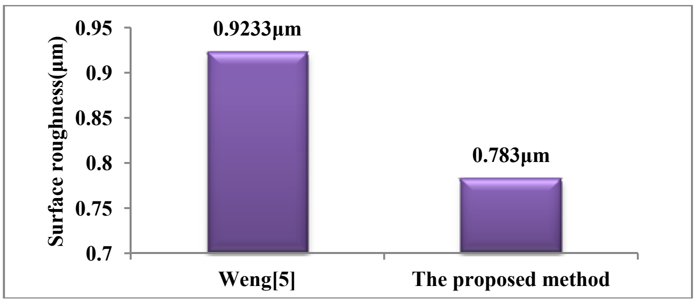

Figure 2. Research result

5. Conclusion

The bottleneck of CNC turning makes it extremely difficult to set cutting parameter conditions, which should be very rigorous and rigid in order to prevent reduced quality due to parameters. Therefore, most cutting personnel of the industry use the median values as the standard. Since processing practitioners cannot definitely select the numerical conditions to optimize turning quality, this study used TRIZ in setting parametric conditions for surface roughness in CNC turning. The method can rapidly determine a solution and the best strategy. As the results suggest, Surface Roughness can significantly improve the effect to achieve satisfying quality characteristics, thus, helping to lower costs, enhance profits, and improve product quality.

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