Innovative Systems Design and Engineering www.iiste.org
ISSN 2222-1727 (Paper) ISSN 2222-2871 (Online)
Vol.4, No.7, 2013 - National Conference on Emerging Trends in Electrical, Instrumentation & Communication Engineering

Investigations of Machining Parameters on Surface Roughness in CNC Milling using Taguchi Technique

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Abstract
With the more precise demands of modern engineering products, the control of surface texture has become more important. This investigation outlines the Taguchi optimization methodology, which is applied to optimize cutting parameters in end milling operation. The study was conducted in machining operation for hardened die steel H-13. The processing of the job was done by solid carbide four flute end-mill tool under finishing conditions. The input machining parameters like spindle speed, depth of cut, and feed rate were evaluated to study their effect on SR (surface roughness) using L-9 standard orthogonal array. Signal-to-Noise (S/N) ratio, Analysis of Variance (ANOVA) and various plots were generated using MINITAB software. Finally the effect of machining input parameters on SR is studied and reported in this paper.
Key Words: CNC Milling, H-13, SR, L-9, ANOVA

1. INTRODUCTION & LITERATURE REVIEW

This experiment gives the effect of different machining parameters (spindle speed, feed, and depth of cut) on Surface Roughness in end milling. The demand for high quality and fully automated production focus attention on the surface condition of the product, surface finish of the machined surface is most important due to its effect on product appearance, function, and reliability. For these reasons it is important to maintain consistent tolerances and surface finish.

Among several CNC industrial machining processes, milling is a fundamental machining operation. End milling is the most common metal removal operation encountered. It is widely used in a variety of manufacturing in industries. The quality of the surface plays a very important role in the performance of milling as a good-quality milled surface significantly improves fatigue strength, corrosion resistance, or creep life. The surface generated during milling is affected by different factors such as vibration, spindle run–out, temperature, tool geometry, feed, cross-feed, tool path and other parameters. During finish milling, the depth of cut is small. [1]. Technological parameter range plays a very important role on surface roughness [2]. In end milling, use of high cutting speed, low feed rate and low depth of cut are recommended to obtained better surface finish for the specific test range in a specified material [3].

With the more precise demands of modern engineering products, the control of surface texture together with dimensional accuracy has become more important. This experimental investigation outlines the Taguchi optimization methodology, which is applied to optimize machining parameters in end milling operation. The experiment is conducted on hot die steel H 13 and mild steel. The processing of the job is done by solid carbide four flute end-mill tools under finishing conditions. The machining parameters evaluated are cutting speed, feed rate and depth of cut. The experiments are conducted by using L-9 (3^4) orthogonal array as suggested by Taguchi. Signal-to-Noise (S/N) ratio and Analysis of Variance (ANOVA) is employed to analyze the effect of milling parameters on surface roughness

Milling is a process of producing flat and complex shapes with the use of multi-tooth cutting tool, which is called a milling cutter and the cutting edges are called teeth. The axis of rotation of the cutting tool is perpendicular to the direction of feed, either parallel or perpendicular to the machined surface. The machine tool that traditionally performs this operation is a milling machine.

D. Mahto et al (2008) [2], investigated that optimization of process parameters in vertical CNC mill machines using taguchi design of experiments. Founded that in end milling,use of high cutting speed, low feed rate and low depth of cut are recommended to obtained better surface finish for the specific test range in a specified material. Similar experiments can be conducted to choose the best combination of speed, feed and depth of cut in order to improve product quality and productivity. And use of high cutting speed, low feed rate and low depth of cut leads to better surface finish (or low surface roughness),

C.H.Xiong et al (2008) [3], investigated the Geometric parameter optimization in multi-axis machining. The source of accuracy-related factor which has considerable on machining efficiency in the planning stage. They maximized the similarity between the desired surface and the actual surface..

2. EXPERIMENTAL METHODOLOGY

2.1 Taguchi Method Philosophy

Dr. Genichi Taguchi gives three philosophies to improve the product quality .

1. Quality should be designed into a product, not inspected into it. Quality is designed into a process through system design, parameter design, and tolerance design. Parameter design, which will be the focus of this article, is performed by determining what process parameters most affect the product and then designing them to give a specified target quality of product. Quality "inspected into" a product means that the product is produced at random quality levels and those too far from the mean are simply thrown out.

2.Quality is best achieved by minimizing the deviation from a target. The product should be designed so that it is immune to uncontrollable environmental factors. In other words, the signal (product quality) to noise (uncontrollable factors) ratio should be high.

3.The cost of quality should be measured as a function of deviation from the standard and the losses should be measured system wide. This is the concept of the loss function, or the overall loss incurred upon the customer and society from a product of poor quality. Because the producer is also a member of society and because customer dissatisfaction will discourage future patronage, this cost to customer and society will come back to the producer**.**

3. EXPERIMENTAL SETUP AND PROCESS PARAMETERS SELECTED

Work piece material

Hot die steel H13 in the plate form of size 280x178x25 mm^3 have been used to carry out experiments. H13 die steel have been chosen because of high hardness, excellent wear resistance, hot toughness and good thermal shock resistance properties. The chemical composition of the material is given below. The chemical composition of H13 die steel is given in table-1.

Table No. 1 Chemical composition

Element	Weight percent	Element	Weight percent
Carbon	0.4	Chromium	5.25
Manganese	0.4	Molybdenum	1.35
Silicon	1.0	Vanadium	!.0

Selection of Tool for experiment

A four flute solid carbide type flat end mill tool of 12.7 mm diameter is used in this experiment with dry cutting condition.

Experimental design

Experimental design with a L9 orthogonal Array as suggested by Taguchi have been used to carryout experiments with three input parameters and for three level of individual parameters. The input parameters used are spindle speed, depth of cut , and feed rate. The details of experiments with parameters and levels are given in table-2.

4. EXPERIMENTAL SET UP

Starway's Vertical Machining Center VMC-850 with Maho controller (Figure-1) a three axis machine with a capability to control all three axes simultaneously have been used to carryout experiments with utmost accuracy. The VMC-850 Machining Center can perform multiplicity of operations in one setup e.g. face milling, profile mill contours, drill bore, counter bore, etc.

Table No. 2 Orthogonal array, L9 for experiment

Parameters Experiment no.	1 (A) Spindle speed (RPM)	2 (B) Feed Rate (mm/tooth)	3 (C) Depth of cut (mm)
1	214.8	0.08	0.1
2	214.8	0.12	0.2
3	214.8	0.15	0.3
4	286.8	0.08	0.2
5	286.8	0.12	0.3
6	286.8	0.15	0.1
7	358.8	0.08	0.3
8	358.8	0.12	0.1
9	358.8	0.15	0.2

Fig.1 Starway's Vertical Machining Center VMC-850

5. RESULT & DISCUSSION

Conducting the experiments

Figure 2 illustrates the experimental settings in this experiment for measuring sr of work piece in end-milling operations. The tool used in this experiment is a four-flute, solid carbide end mill of diameter 12.7 mm. The set of 9 experiments with parameters and their levels as given in table 2 are conducted using the CNC vertical milling machine (VMC 850).

Surface Roughness

Three measured surface roughness (SR) data values were collected using the Mitutoyo Surftest SJ-201P instrument to measure the surface roughness of workpieces after end milling was completed.

Surface Roughness basically depend upon the feed rate, spindle speed, tool diameter and depth of cut. It is important output characteristic in milling or every machining process because SR has direct relation with the quality. And quick and high production is the need of modern production system. In end milling, the cutter generally rotates on an axis vertical to the work piece.

Fig.2 Mitutoyo Surftest Instrument SJ-201P

ISSN 2222-1727 (Paper) ISSN 2222-2871 (Online)
Vol.4, No.7, 2013 - National Conference on Emerging Trends in Electrical, Instrumentation & Communication Engineering

The SR value is calculated for each trial from the basic data collected and it is tabulated in Table 3. The signal-to-noise ratios of each experimental run are calculated based on the following equation, which are listed in corresponding tables with the data.

$$(S/N)_i \quad = \quad -10\ x\ \log\left(\frac{1}{n}\sum_{i=1}^{N} Y_i^2\right) \qquad (1)$$

Where
$(S/N)_i$ is the signal to noise ratio of i_{th} term,
n is thenumber of measurements in a trial/row, and
Yi is the i_{th} measured value in a run/row. The average response values are also calculated and recorded in Table 3

Table No. 3 Raw data of SR

Ex. No.	(A) Cutting Speed	(B) Feed rate	(C) Depth of cut	Surface roughness (Ra) at different location			Signal to noise ratio (dbi)	Mean response value
				Response 1	Response 2	Response 3		
1	214.8	0.08	0.1	0.79	0.61	0.87	-8.8144	0.75
2	214.8	0.12	0.2	0.23	0.34	1.20	-10.2569	0.59
3	214.8	0.15	0.3	0.99	0.86	1.93	-11.8813	1.26
4	286.8	0.08	0.2	1.77	1.87	1.90	-5.3317	1.84
5	286.8	0.12	0.3	1.45	0.46	1.58	-7.9496	1.61
6	286.8	0.15	0.1	0.72	0.67	0.68	-11.3407	0.70
7	358.8	0.08	0.3	0.51	1.64	0.73	-4.2393	0.96
8	358.8	0.12	0.1	0.75	0.92	0.64	-8.8571	0.77
9	358.8	.15	.2	1.00	0.90	1.22	-9.8077	1.04

Determination of the Optimum parameters

Figure 3 shows three graphs, which contain the curve between mean of signal to noise ratio data and input parameters (control factors). Figure 4 shows the curve between the mean of mean and the control factors. The objective of using the S/N ratio as a performance measurement is to develop products and processes insensitive to noise factors. The S/N ratio indicates the degree of the predictable performance of a product or process in the presence of noise factors. Process parameter settings with the highest S/N ratio always yield the optimum quality with minimum variance (Antony & Kaye, 1999). Consequently, the level that has a higher value determines the optimum level of each factor. For example, in graph 3, level three for spindle speed (A3= 358.8rpm) has the highest S/N ratio value, which indicated that the machining performance at such level produced minimum variation of the surface roughness. In addition, the lower surface roughness value has a better machining performance. Furthermore, level of spindle speed (A3 = 358.8rpm) has indicated the optimum situation in terms of mean value. Similarly, the level one of feed rate (B3=0.15mm/tooth) and the level three of depth of cut (C3=0.3mm) have also indicated the optimum situation in terms of S/N ratio and mean value.

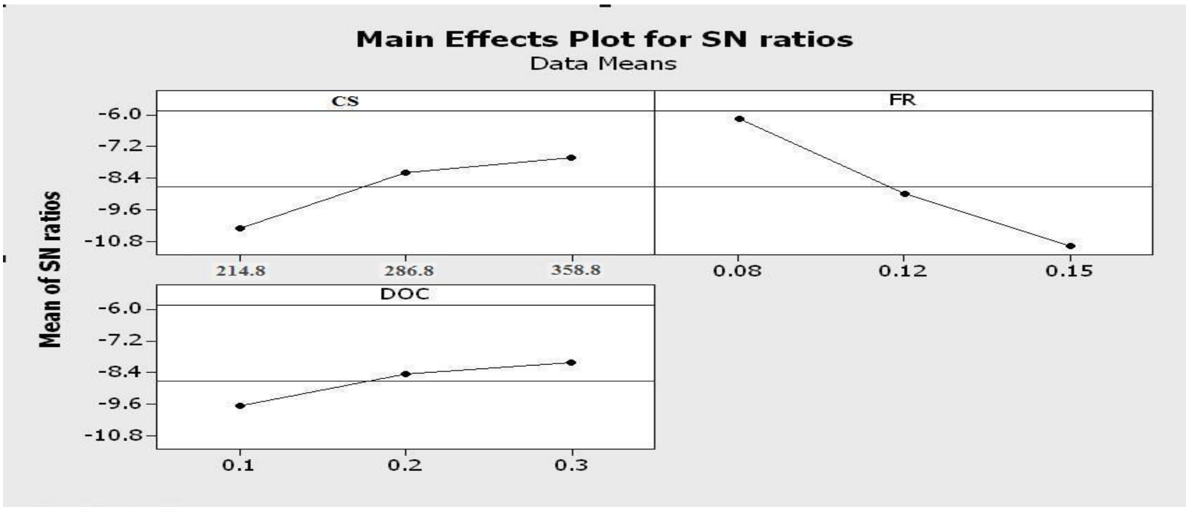

Fig.3, Main effect plots for SN ratio (SR)

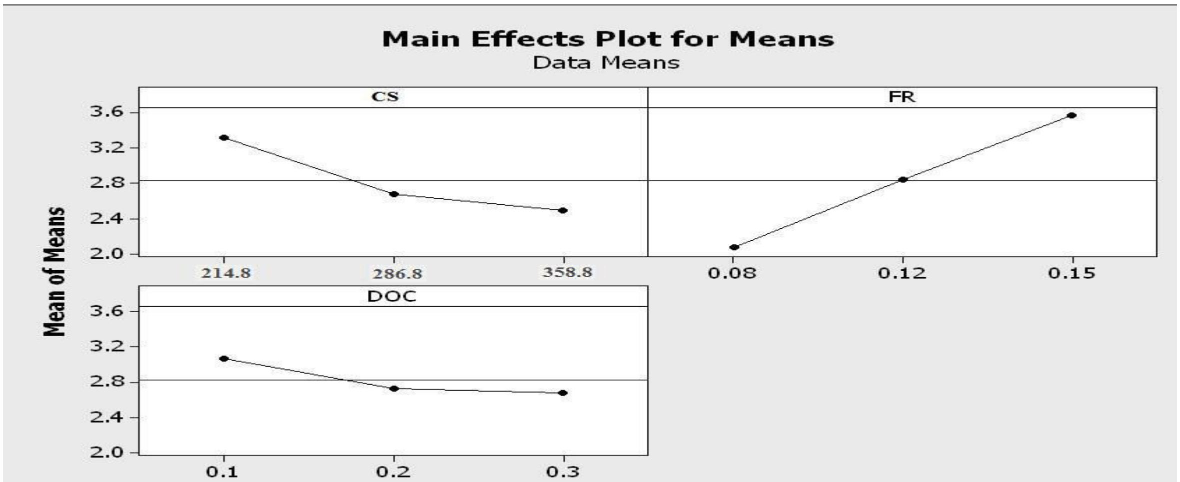

Fig.4, Main effect plots for mean data (SR)

Effect of spindle speed on SR

It is seen that the SR is less at the third level of spindle speed (358.8rpm). As the spindle speed increases the surface roughness decreases.

Effect of feed rate on SR:

With the increase in the feed rate, the SR increases. It is seen that the highest SR is obtained at the third level (0.15m/tooth). Higher the feed rate lower the processing time thus increases the SR.

Effect of depth of cut SR:

It is seen that the SR is minimum at the third level of depth of cut (0.3mm).

6. CONCLUSION

1. Taguchi's robust design method is suitable to analyze the metal cutting problem as described in the present work.
2. In end milling, increase in spindle speed, decrease in feed rate and increase in depth of cut will decrease the SR within specified test range.
3. Low feed rate (0.08mm/tooth), high depth of cut (0.3mm) and high spindle speed (2500RPM) are optimized parameters for surface roughness for the specific test range.
4. The feef rate is by far the most dominant factor for surface roughness.

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