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Optimization of Multiple Response Using Taguchi-WPCA In ST 60 Tool Steel Turning Process With Minimum Quantity Cooling Lubrication(MQCL) Method

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Abstract - A research was conducted for the optimization of the turning process ST 60 tool steel with multiple performance characteristics based on the orthogonal array with Taguchi-WPCA method. Minimum Quantity Cooling Lubrication (MQCL) method was applied as a coolant. The experimental studies were conducted by varying the cutting speed, feeding rate, depth of cut and type of coolant. The optimized multiple performance characteristics were surface roughnessand material removal rate. An orthogonal array, signal-to-noise ratio, grey relational analysis, weighted principal component analysis and analysis of variance were employed to study the multiple performance characteristics. Experimental results showed hat cutting speed gives the highest contribution inminimizing the surface roughness and maximizing the material removal rate, followed by feeding speed, type of coolant and depth of cut. The minimum surface roughness and maximum of material removal rate could be obtained by using the values of cutting speed, feeding speed, depth of cut and coolant of 172.95 m/minute, 0.053 mm/rev, 0.25 mm, and vegetable oil respectively.

Keywords: MQCL, optimization, surface roughness, st 60, Taguchi, WPCA.

Introduction

The machining process is one of the most important production process technologies in the manufacturing industry. Production processes that take place in the manufacturing industry can not be separated from the machining process. The machining process most often found in the manufacturing industry is the turning process. The turning process is a machining process using a turning machine, which produces cylindrical machining components. To cut the workpiece, the turning process requires a single cutting tool with a rotating workpiece on its chuck (Rochim, 1993).

In order to obtain machine components of the machining process according to the specification, the selection of the cutting parameters must be properly considered. Feeding, spindle rotation and depth of cut are the main parameters in machining process especially turning which can be set directly on the machine. While other parameters such as cutting tool and coolant fluid is a parameter that can not be set directly on the machine.Choosing appropriate type of cutting tool, coolant and setting parameters of the cutting process, will affect the machinability of a material or workpiece. If a product of a machining process has a low surface roughness, the cutting force used during the machining process is low and the flank wear is low, the material may be considered to have good machinability (Kalpakjian and Schmid, 2009).

Surface roughness is a quality characteristic often required on a product. The surface is defined as the boundary that separates solids from the surrounding environment (Munadi, 1980). Characteristics of a surface plays an important role in the design of machine components/equipment. One of the deviations from a surface caused by the cutting condition of the machining process is called surface roughness (Munadi, 1980). Surface roughness is also commonly referred to as arithmetic surface roughness (Ra) and defined as the average arithmetic deviation from the average profile line (Sato and Sugiarto, 1994). The Ra parameter is suitable for checking the quality of the endproduct of the work piece in large quantities, since

Ra is more sensitive to deviations occurring at the end surface of the machining work piece (Rochim, 2001). However, the Ra parameter does not actually have a solid basis for identifying such deviations because surface identification is only used to explain the irregularity of the respective surface configuration. Variable of machining process, cutting tool geometry, that is, corner radius and angle of chip, properties of work piece material and cutting tool, type and quality of machine used, vibration between cutting tool, work piece and machine, auxiliary tool and coolant used are factors affecting surface roughness (Rochim, 1993).

Coolant fluid in the machining process serves to reduce the coefficient of friction between the tool and the workpiece, the heat that occurs due to the friction between the tool with the workpiece and cleanse the fury of the workpiece surface. Conventional coolant liquids are classified into two, namely oil-based fluid and chemical fluid (Yue, 1998). Oil-based fluid consists of pure oil and soluble-oil with added ingredients, while the chemical fluid consists of synthetic and semi-synthetic oils. The use of conventional cooling fluids in industry, causing many health and environmental problems (Yildiz, 2008). Since the composition of the coolant is very complex, the additional components are more toxic and may cause irritation than the underlying material (Bienkowski, 1993).

One method of using coolant that is often used in the machining process is by discharging or flooding. The use of flooding method with conventional fluid gives bad impact for operator and environment. Exposure to excessive cooling fluids over a long period of time can cause health problems for operators such as skin irritation, respiratory problems and microbial infections. In addition to causing health problems, the use of cooling fluids by flooding methods can increase the cost of production.

One of alternative methods of giving coolant that can be used to replace the flooding method is to use Minimum Quantity Cooling Lubrication (MQCL). MQCL is a giving coolant method in the machining process by minimizing the amount of cooled coolant during the machining process. The flow rate of coolant in the MQCL method is the same as the flow rate in the Minimum Quantity Lubrication (MQL) method of 6 - 100 ml / h (Su Yu, 2010). In the MQCL method, the coolant is cooled through a heat exchanger so that the heat reduction process due to friction between the tool and the workpiece is better than the MQL method.

In addition to the use of methods and safe, environmentally friendly coolant for the operator, determining the right combination of process variables in the machining process to achieve the optimum response is essential to do effectively. It aims to reduce the experimental process, so that the time and machining process cost can be minimized. One of the optimization methods that can be used in research is Taguchi method. This method is one of the effective methods to control the quality of products off-line, that is business control or quality improvement starting from design to product processing.

Based on consideration of the significant negative effects associated with the use of cooling fluids in machining processes on the environment, the health and safety of operator, and the importance of determining the right combination of process variables in the machining process to achieve the optimum response, it is necessary to do a research on the influence of cooling fluids by the MQCL method and the determination of a combination of ST-60 tool steel turning process variables to optimize the surface roughness (SR) and material removal rate (MRR) response. The results of this study are expected to be used as a reference by the manufacturing industry to reduce the level of surface roughness and increase the material removal rate. Process variables in this study are cutting speed, feeding, depth of cut and type of coolant. The optimization method to be used is Taguchi couple with weighted principal component analysismethod.Simultaneous optimization of multiple responses can be performed by using the combination of Taguchi method and weight principal component analysis (WPCA).

Material and Methods
Tools and materials

The work piece used in this study is ST 60 tool steel with a diameter of 50 mm and a length of 100 mm. The tool used is a CNMG insert tool with a 0.4 mm corner radius. The turning used is a conventional turning machine with maximum spindle speed of 2000 rpm.

Research variable

The independent variable or process variable is a variable whose value can be controlled and determined based on certain considerations in research that lead to the objectives of the study. The turning process variables varied in this study were cutting speed (Vc), feeding rate (f), depth of cut (a) and coolant (C). The response variable is a variable whose value can not be determined at the beginning and will be affected by the given treatment. The value of this variable can be determined after doing an experiment.

Surface roughness (SR) and material removal rate (MRR) is the response variable obtained as data. The sequence of data retrieval steps of the cutting process result is as follows:

a. workpiece cutting time

The cutting time of the workpiece is measured using a stopwatch during the cutting process for each combination of experiments.

b. Surface roughness measurement (SR)

The surface roughness of the workpiece was measured in the metrology laboratory Mechanical Engineering Department of Brawijaya University using the Mitutoyo surftest SJ-210. Measurements were made twice on two different sides. The surface roughness value obtained is an arithmetic roughness value (Ra) for each combination. The results of the overall surface roughness measurement can be seen in Table 4.

c. Calculation of the material removal rate (MRR)

During the cutting process, the volume of wasted material is kept constant at 3885.75 mm³. At a depth of cut 0.5 mm, cutting process can be done onceto get the volume of 3885.75 mm³, at a depth of cut 0.25, cutting process can be done twice and at a depth of cut0.125 mm, cutting process can be done four times to get the volume of 3885.75 mm³. Thematerial removal rate can be defined as the volume of material wasted per unit time (mm³ / min). The material removal rate is calculated by dividing the volume of wasted material by cutting time as expressed by equation 1 (Moshat, 2010).

$$MRR = \frac{Volume\ of\ work\ piece\ remove}{Machining\ time}\ (mm^3/min) \tag{1}$$

Characteristics of Optimal Response

Each response variable that includes surface roughness (µm) and material removal rate (mm³/ min) has an optimal response characteristic. Optimal response characteristics used are the smaller the better (smaller is better) and the greater the better (largers better). The smaller is better characteristic applies to surface roughness, which means that the surface roughness value is the most desirable. In response to the material removal rate with the characteristics of largers is better indicate the highest rate of material removal rate is the most desirable.

Design Experiment

Based on the number of process variables and the number of levels shown in Table 1, the calculations of degrees of freedom were done to determine the orthogonal matrix used

Table 1. Turning process parameter

Turning Parameter	1	2	3
Cutting speed(V_c) (m/minute)	172.95	143.73	132.67
Feeding rate(f) (mm/rev)	0.053	0.103	0.161
Depth of cut (a) (mm)	0.125	0.25	0.5
Coolant (C)	soluble oil	air+vegetable oil	vegetable oil

The results are presented in Table 2.

Table 2. Total degrees of freedom of independent variables and levels

No	Independent variable	Number of level (k)	υ_{fl} (k-1)
1	Cutting speed (V_c, m/min)	3	2
2	Feeding rate (V_f, mm/rev)	3	2
3	Depth of cut (A_a, mm)	3	2
4	Coolant (C)	3	2
Total degrees of freedom			8

Table 2 shows that the total degree of freedom for the design of this experiment that is eight with three levels, the orthogonal matrix to be used should be greater than or equal to eight. Therefore, in accordance with the available options, the L27 orthogonal matrix qualifies to serve as the experimental design. The experimental design for this study can be seen in Table 3. The experimental data were collected randomly with reference to the experimental design in Table 3. This randomization was performed using the help of statistical software. To overcome the noise factor that occurs during the cutting process, each combination of process variables will be replicated once.

Table 3.Orthogonal array L_{27}

Vc	f (mm/rev)	a (mm)	Coolant
1	1	1	1
1	1	2	2
1	1	3	3
1	2	1	2
1	2	2	3
1	2	3	1
1	3	1	3
1	3	2	1
1	3	3	2
2	1	1	1
2	1	2	2
2	1	3	3
2	2	1	2
2	2	2	3
2	2	3	1
2	3	1	3
2	3	2	1
2	3	3	2
3	1	1	1
3	1	2	2
3	1	3	3
3	2	1	2
3	2	2	3
3	2	3	1
3	3	1	3
3	3	2	1
3	3	3	2

Taguchi Method - Weighted Principal Component Analysis (WPCA)

In Taguchi method, optimization can only be done for one response only.To optimizemultiple response such as surface roughness and material removal rate simultaneously can be used the combination of Taguchi method and weighted principal component analysis (WPCA). The method is used to eliminate correlations between responses and to change the correlated response to an uncorrelated response index called the principal component (Das, 2013). The steps for the optimization process with Taguchi - weighted principal component analysis (WPCA) method can be seen in Figure 1.
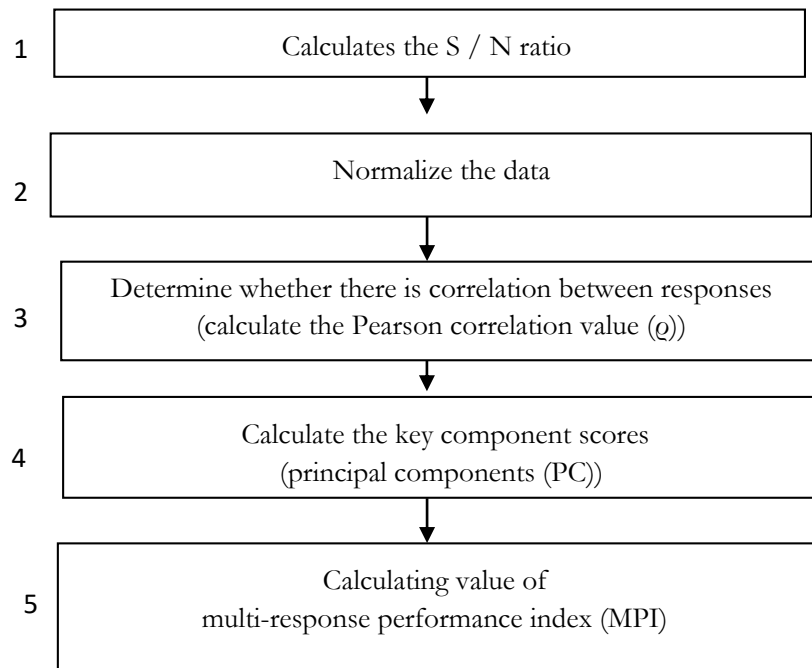
1	Calculates the S / N ratio

2	Normalize the data

3	Determine whether there is correlation between responses (calculate the Pearson correlation value (ϱ))

4	Calculate the key component scores (principal components (PC))

5	Calculating value of multi-response performance index (MPI)

Figure 1. Taguchi-Weighted Principal Component Analysis (WPCA) optimization steps

Results and Discussion

The result of the research is surface roughness value (Ra) and material removal rate (MRR) is shown in Table 4.

Calculating S / N Ratio Value

Based on Table 4, theS/N ratio for the surface roughness response and the material removal rate are thus calculated. The calculation of the S / N ratio depends on the type of quality characteristics of the response. The surface roughness response has smaller the better quality characteristics. This quality characteristic has a 0 and non-negative boundary, so the smaller value or near zero is the desired value, calculated by using equation 2 and the material removal rate has greater the better characteristics. This quality characteristic has an infinite range of values and is non-negative, so an increasing value is the desired value calculated using equation 3 (Soejanto, 2009):

$$S/N = -10 \log\left[\sum_{i=1}^{n} \frac{y_i^2}{n}\right] \tag{2}$$

$$S/N = -10 \log\left[\sum_{i=1}^{n} \frac{(1/y_i^2)}{n}\right] \tag{3}$$

The calculation of the S / N ratio for each response can be seen in Table 5.

Table 4. Experiment result

No.	Vc (m/min)	f (mm/rev)	a (mm)	C	Average		MRR (mm³/min)	
					R1	R2	R1	R2
1	172.946	0.053	0.125	Soluble oil	0.828	0.963	1,192.31	1,184.68
2	172.946	0.053	0.25	Air + Vegetable Oil	0.657	0.782	2,358.81	2,428.59
3	172.946	0.053	0.5	Vegetable Oil	0.608	0.700	4,754.18	4,571.47
4	172.946	0.103	0.125	Air + Vegetable Oil	0.914	0.903	2,388.05	2,383.90
5	172.946	0.103	0.25	Vegetable Oil	0.537	0.630	4,846.08	4,857.19
6	172.946	0.103	0.5	Soluble Oil	0.906	0.981	9,259.13	8,635.00
7	172.946	0.161	0.125	Vegetable Oil	1.001	0.998	3,634.94	3,772.57
8	172.946	0.161	0.25	Soluble Oil	1.009	1.037	6,938.84	6,699.57
9	172.946	0.161	0.5	Air + Vegetable Oil	1.032	1.099	13,869.42	13,877.68
10	143.727	0.053	0.125	Soluble Oil	1.140	1.131	967.69	966.60
11	143.727	0.053	0.25	Air + Vegetable Oil	1.201	1.185	1,996.96	2,100.41
12	143.727	0.053	0.5	Vegetable Oil	1.110	1.167	3,809.56	3,885.75
13	143.727	0.103	0.125	Air + Vegetable Oil	1.261	1.228	1,988.95	2,002.96
14	143.727	0.103	0.25	Vegetable Oil	1.136	1.189	2,340.81	2,340.81
15	143.727	0.103	0.5	Soluble Oil	1.206	1.332	7,609.17	7,619.12
16	143.727	0.161	0.125	Vegetable Oil	1.341	1.354	2,860.67	3,035.74
17	143.727	0.161	0.25	Soluble Oil	1.413	1.339	5,595.03	5,978.08
18	143.727	0.161	0.5	Air + Vegetable Oil	1.332	1.417	11,587.72	9,714.38
19	132.671	0.053	0.125	Soluble Oil	1.561	1.400	922.98	922.98
20	132.671	0.053	0.25	Air + Vegetable Oil	1.641	1.515	1,886.29	1,886.29
21	132.671	0.053	0.5	Vegetable Oil	1.323	1.336	2,989.04	2,878.33
22	132.671	0.103	0.125	Air + Vegetable Oil	1.636	1.617	1,885.37	1,933.21
23	132.671	0.103	0.25	Vegetable Oil	1.421	1.594	3,751.33	3,809.56
24	132.671	0.103	0.5	Soluble Oil	1.630	2.003	7,336.22	7,771.50
25	132.671	0.161	0.125	Vegetable Oil	1.402	1.719	2,869.12	2,878.33
26	132.671	0.161	0.25	Soluble Oil	1.896	1.955	5,642.42	5,551.07
27	132.671	0.161	0.5	Air + Vegetable Oil	2.357	2.274	11,044.29	11,102.14

Table 5. Calculation of S / N ratio

No.	Vc (m/min)	f (mm/Rev)	a (mm)	C	S/N	
					SR	MRR
1	172.946	0.053	0.125	Soluble oil	0.937	79.5618
2	172.946	0.053	0.25	Air + Vegetable Oil	2.829	85.6441
3	172.946	0.053	0.5	Vegetable Oil	3.671	91.4364
4	172.946	0.103	0.125	Air + Vegetable Oil	0.836	85.6151
5	172.946	0.103	0.25	Vegetable Oil	4.652	91.7796
6	172.946	0.103	0.5	Soluble Oil	0.501	97.1007
7	172.946	0.161	0.125	Vegetable Oil	0.007	89.4361
8	172.946	0.161	0.25	Soluble Oil	-0.194	94.7378
9	172.946	0.161	0.5	Air + Vegetable Oil	-0.553	100.9056
10	143.727	0.053	0.125	Soluble Oil	-1.102	77.7716
11	143.727	0.053	0.25	Air + Vegetable Oil	-1.531	84.2941
12	143.727	0.053	0.5	Vegetable Oil	-1.126	89.7661
13	143.727	0.103	0.125	Air + Vegetable Oil	-1.897	84.0649
14	143.727	0.103	0.25	Vegetable Oil	-1.306	85.4491
15	143.727	0.103	0.5	Soluble Oil	-2.080	95.6942
16	143.727	0.161	0.125	Vegetable Oil	-2.587	87.4568
17	143.727	0.161	0.25	Soluble Oil	-2.774	93.3150
18	143.727	0.161	0.5	Air + Vegetable Oil	-2.764	98.6431
19	132.671	0.053	0.125	Soluble Oil	-3.420	77.3657
20	132.671	0.053	0.25	Air + Vegetable Oil	-3.966	83.5740
21	132.671	0.053	0.5	Vegetable Oil	-2.472	87.4116
22	132.671	0.103	0.125	Air + Vegetable Oil	-4.223	83.6799
23	132.671	0.103	0.25	Vegetable Oil	-3.577	89.6129
24	132.671	0.103	0.5	Soluble Oil	-5.228	95.6288
25	132.671	0.161	0.125	Vegetable Oil	-3.907	87.2307
26	132.671	0.161	0.25	Soluble Oil	-5.691	93.0208
27	132.671	0.161	0.5	Air + Vegetable Oil	-7.294	98.9473

Data Normalization

Based on Table 5, then normalize the data for the surface roughness response and the material removal rate. The process of normalizing the response data is the process of changing the response value which is between 0 and 1.The process of normalization is also done based on the quality characteristics of the response. The quality characteristics of the surface roughness are the smaller the better while the quality characteristics of the material removal rate are larger the better. The equations used to normalize the response or quality characteristics are equations 3 and 4:

Smaller the better

$$X_i^*(k) = \frac{X_i(k) - minX_i\ (k)}{maxX_i\ (k) - minX_i\ (k)} \tag{4}$$

Larger the better

$$X_i^*(k) = \frac{maxX_i\ (k) - X_i\ (k)}{maxX_i\ (k) - minX_i\ (k)} \tag{5}$$

The calculation results of normalization of each response for each combination of factors can be seen in Table 6 below.

Table 6. Normalization of each response

No.	Vc (m/min)	f (mm/Rev)	a (mm)	C	Xi*1	Xi*2
1	172.946	0.053	0.125	Soluble oil	0.689	0.907
2	172.946	0.053	0.25	Air + Vegetable Oil	0.847	0.648
3	172.946	0.053	0.5	Vegetable Oil	0.918	0.402
4	172.946	0.103	0.125	Air + Vegetable Oil	0.681	0.650
5	172.946	0.103	0.25	Vegetable Oil	1.000	0.388
6	172.946	0.103	0.5	Soluble Oil	0.653	0.162
7	172.946	0.161	0.125	Vegetable Oil	0.611	0.487
8	172.946	0.161	0.25	Soluble Oil	0.594	0.262
9	172.946	0.161	0.5	Air + Vegetable Oil	0.564	0.000
10	143.727	0.053	0.125	Soluble Oil	0.518	0.983
11	143.727	0.053	0.25	Air + Vegetable Oil	0.482	0.706
12	143.727	0.053	0.5	Vegetable Oil	0.516	0.473
13	143.727	0.103	0.125	Air + Vegetable Oil	0.452	0.715
14	143.727	0.103	0.25	Vegetable Oil	0.501	0.657
15	143.727	0.103	0.5	Soluble Oil	0.436	0.221
16	143.727	0.161	0.125	Vegetable Oil	0.394	0.571
17	143.727	0.161	0.25	Soluble Oil	0.378	0.322
18	143.727	0.161	0.5	Air + Vegetable Oil	0.379	0.096
19	132.671	0.053	0.125	Soluble Oil	0.324	1.000
20	132.671	0.053	0.25	Air + Vegetable Oil	0.279	0.736
21	132.671	0.053	0.5	Vegetable Oil	0.404	0.573
22	132.671	0.103	0.125	Air + Vegetable Oil	0.257	0.732
23	132.671	0.103	0.25	Vegetable Oil	0.311	0.480
24	132.671	0.103	0.5	Soluble Oil	0.173	0.224
25	132.671	0.161	0.125	Vegetable Oil	0.284	0.581
26	132.671	0.161	0.25	Soluble Oil	0.134	0.335
27	132.671	0.161	0.5	Air + Vegetable Oil	0.000	0.083

Determining Whether or not There is Correlation of Each Response

To determine whether or not there is correlation of each response is done by calculating the correlation value of Pearson (ρ). The calculation is done by using equation 6. The result of Pearson correlation coefficient value (ρ) is 0.106

$$\rho_{jk} = \frac{Cov(Q_j, Q_k)}{\sigma_{Q_j} x \sigma_{Q_k}} \tag{6}$$

Table 7. Pearson correlation value (ρ)

It is known that the Pearson correlation coefficient is not equal to zero, ie $\rho = 0.106$. This indicates that there is a correlation between responses.

The Calculation of Principal Component Value

The calculation of Principal Component (PC) values can be seen in Table 7.

Table 7. The value of principal component

No.	Vc (m/min)	f (mm/Rev)	a (mm)	C	PC1	PC2
1	172.946	0.053	0.125	Soluble oil	-0.154	1.128
2	172.946	0.053	0.25	Air + Vegetable Oil	0.141	1.058
3	172.946	0.053	0.5	Vegetable Oil	0.365	0.933
4	172.946	0.103	0.125	Air + Vegetable Oil	0.022	0.940
5	172.946	0.103	0.25	Vegetable Oil	0.433	0.981
6	172.946	0.103	0.5	Soluble Oil	0.347	0.576
7	172.946	0.161	0.125	Vegetable Oil	0.088	0.777
8	172.946	0.161	0.25	Soluble Oil	0.235	0.605
9	172.946	0.161	0.5	Air + Vegetable Oil	0.399	0.399
10	143.727	0.053	0.125	Soluble Oil	-0.328	1.061
11	143.727	0.053	0.25	Air + Vegetable Oil	-0.158	0.840
12	143.727	0.053	0.5	Vegetable Oil	0.031	0.700
13	143.727	0.103	0.125	Air + Vegetable Oil	-0.186	0.825
14	143.727	0.103	0.25	Vegetable Oil	-0.110	0.819
15	143.727	0.103	0.5	Soluble Oil	0.152	0.465
16	143.727	0.161	0.125	Vegetable Oil	-0.125	0.682
17	143.727	0.161	0.25	Soluble Oil	0.040	0.496
18	143.727	0.161	0.5	Air + Vegetable Oil	0.200	0.336
19	132.671	0.053	0.125	Soluble Oil	-0.478	0.936
20	132.671	0.053	0.25	Air + Vegetable Oil	-0.324	0.717
21	132.671	0.053	0.5	Vegetable Oil	-0.120	0.691
22	132.671	0.103	0.125	Air + Vegetable Oil	-0.336	0.699
23	132.671	0.103	0.25	Vegetable Oil	-0.119	0.559
24	132.671	0.103	0.5	Soluble Oil	-0.036	0.281
25	132.671	0.161	0.125	Vegetable Oil	-0.210	0.611
26	132.671	0.161	0.25	Soluble Oil	-0.142	0.332
27	132.671	0.161	0.5	Air + Vegetable Oil	-0.059	0.059

The Calculation of Value of Multi-Response Performance Index (MPI)

The values of Table 8, the calculation of MPIs were obtained.

Table 8. The Value of Multi-Response Performance Index

No.	Vc (m/min)	f (mm/Rev)	a (mm)	C	MPI
1	172.946	0.053	0.125	Soluble oil	0.4230
2	172.946	0.053	0.25	Air + Vegetable Oil	0.5533
3	172.946	0.053	0.5	Vegetable Oil	0.6205
4	172.946	0.103	0.125	Air + Vegetable Oil	0.4352
5	172.946	0.103	0.25	Vegetable Oil	0.6796
6	172.946	0.103	0.5	Soluble Oil	0.4499
7	172.946	0.161	0.125	Vegetable Oil	0.3976
8	172.946	0.161	0.25	Soluble Oil	0.4017
9	172.946	0.161	0.5	Air + Vegetable Oil	0.3989
10	143.727	0.053	0.125	Soluble Oil	0.2970
11	143.727	0.053	0.25	Air + Vegetable Oil	0.2912
12	143.727	0.053	0.5	Vegetable Oil	0.3316
13	143.727	0.103	0.125	Air + Vegetable Oil	0.2688
14	143.727	0.103	0.25	Vegetable Oil	0.3080

15	143.727	0.103	0.5	Soluble Oil	0.2930
16	143.727	0.161	0.125	Vegetable Oil	0.2382
17	143.727	0.161	0.25	Soluble Oil	0.2447
18	143.727	0.161	0.5	Air + Vegetable Oil	0.2613
19	132.671	0.053	0.125	Soluble Oil	0.1586
20	132.671	0.053	0.25	Air + Vegetable Oil	0.1449
21	132.671	0.053	0.5	Vegetable Oil	0.2449
22	132.671	0.103	0.125	Air + Vegetable Oil	0.1301
23	132.671	0.103	0.25	Vegetable Oil	0.1861
24	132.671	0.103	0.5	Soluble Oil	0.1064
25	132.671	0.161	0.125	Vegetable Oil	0.1594
26	132.671	0.161	0.25	Soluble Oil	0.0712
27	132.671	0.161	0.5	Air + Vegetable Oil	-

Table 8, the average MPI value can be calculated. MPI value at each level of process variable as shown in Table 9.

Table 9. Average MPI values at each level

	Level 1	Level 2	Level 3
Vc	0.484	0.282	0.133
f	0.341	0.317	0.241
a	0.279	0.320	0.300
C	0.272	0.275	0.352
The Average		0.300	

The Selection of Process Parameters Optimal Level

Base on Table 10, plots were carried out for the mean values of MPI at each level of the process variable of cutting speed (Vc), feeding rate (f), depth of cut (a) and the type of coolant (C) as shown in Figure 2.
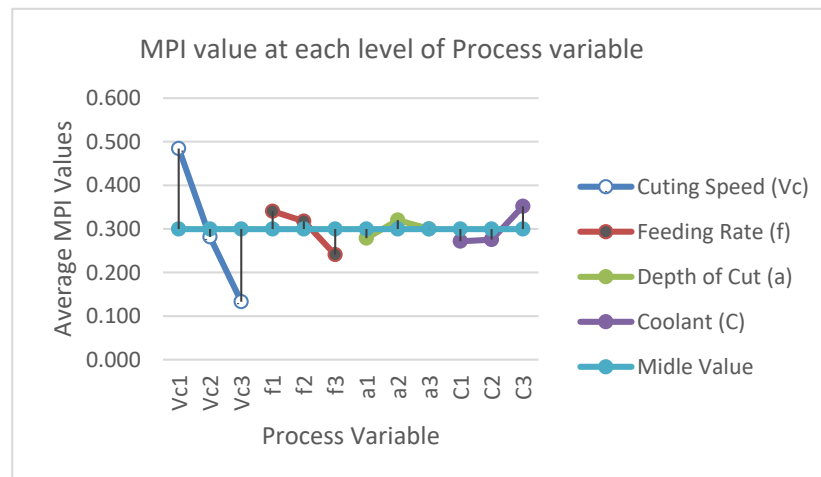

Figure 2 shows a combination of process variable levels that produce the optimum response can be determined by the highest average value of MPI as shown in Table 10.

Table 10 The Combination of Optimum response process variable

Process variables	Level	Value
Vc	1	172.946 m/min
f	1	0.053 mm/Rev
a	2	0.125 mm
C	3	Vegetable oil

Analysis of Variance and Percent Contribution Process variables that have a significant influence and the magnitude of the contribution of process variables to the response under study can be determined through analysis of variance (ANOVA). In this study ANOVA is performed against the value of Multi-Response Performance Index (MPI) which represents all responses simultaneously. ANOVA MPI calculation results as shown in Table 12.

The Analysis of Variance and Percent of Contribution.

The process variables that have a significant influence and the amount of the contribution of process variables to the response under study can be determined through analysis of variance(ANOVA). In this study, ANOVA is performed against the value of Multi-Response Performance Index (MPI) which represents all responses simultaneously. ANOVA MPI calculation results can be seen in Table 11.

Table 11. The analysis of variance and percent of contribution.

Source	DF	SS	MS	F	F-table	SS'FL	%
Vc	2	0.5606117	0.28030585	112.2361877	3.37	0.555617	79.4706134
f	2	0.0490818	0.02454088	9.826318684		0.044087	6.30579827
a	2	0.007721	0.0038605	1.545766874		0.002726	0.38991293
C	2	0.0367787	0.01838933	7.363199118		0.031784	4.54606857
Error	18	0.0449544	0.00249746				9.28760681
Total	26	0.6991475					

The F table for the process variables of cutting speed (Vc), feeding (f) and coolant (C) is greater than F count (Table 11). Thus, the process variable of cutting speed (Vc), feeding (f) and coolant (C) have a significant influence on the variable of surface roughness response (SR) and material removal rate (MRR) simultaneously observed. While the depth of cut(a) has an F value less than F table, so the depth of cut(a) does not have a significant effect on the surface roughness response (SR) and material removal rate (MRR) simultaneously observed.. The largest contribution in reducing total variance was given by the cutting speed process variable of 75.65%, feeding of 10.36%, coolant type of 4.75% and cutting depth of 0.26%.

The portion of each process variable to the total response variance observed is shown in Table 12. If a percent of the error contribution is less than 15%, then no process variable is negligible. If a percent of error contributes more than 15%, then indicates there is a variable process that influences neglected so that the error is too big.

The Confirmation Test

Validation of the results obtained was done by conducting a confirmation experiment with a combination of levels that produce the optimum response. The validation process was done by comparing the results of the initial combined experimental response with the optimum combination response (Ross, 2008). The optimum combination used in the confirmation experiments is shown in Table 11. While the initial combinations were set at the middle level, ie at level two as shown in Table 13. Comparison of initial combination experiments with optimum combination experiments can be seen in Table 13. Table 13 shows that the value of surface roughness (SR) decreased by 67.6% and the material removal rate (MRR) increased by 14.9%. This shows that the smaller the quality characteristics the better the surface roughness response and larger the better the response material removal rate has been fulfilled.

Table 12. The Setting of the initial combination level

Prosess Variable	Level	Value
Vc	2	172.946 m/min
f	2	0.103 mm/Rev
a	2	0.125 mm
C	2	Air+Vegetable oil

Table 13. Comparison of preliminary combinations and optimum combinations

	Initial combinations	Optimum combinations	Description	
SR	1.667	0.540	67.6%	decrease
MRR	2,305.673	2,311.672	14.9%	increase

Conclusion

Based on the experiment, the optimization process and the analysis, it can be concluded that the arrangement of the combination of the turning process variables significantly can minimize surface roughness and maximize the material removal rate simultaneously with the values as follows: Cutting speed of 172,946 m / min, Feeding 0.053 mm / Rev, Depth of cut 0.125 mm, and type of vegetable oil coolant

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References

Bienkowski, K., "Coolant & Lubricant The Truth," *Manufacturing Engineering,* 1993, Pp. 90-96.

Das, M.K., Kumar, K, Barman, T.K., dan Saho, P."*Optimization of Surface Roughness and MRR in EDM Using WPCA, International Conference On DESIGN AND MANUFACTURING,* Procedia Engineering 64 (2013) 446 – 455.

Kalpakjian, S. andSchmid, S.R.,*Manufacturing Engineering and Technology*, 6rdedition, Prentice Hall, New Jersey, 2009.

Moshat, S. dkk., "Parametric Optimization of CNC End Milling using Entropy Measurement Technique Combined with Grey-Taguchi Methode," *International Journal of Engineering, Science and Technology*, 2010, vol. 2, No. 2, hal.1-12.

Munadi, S., *Dasar-dasar Metrologi Industri*, Proyek Pengembangan Lembaga Pendidikan Tenaga Kependidikan, Jakarta, 1980.

Rochim, T., *Spesifikasi, Metrologi, dan Kontrol Kualitas Geometrik*, Bandung, Institut Teknologi Bandung, 2001.

Rochim, T., *Teori dan Teknologi Proses Pemesinan*, Bandung, Institut Teknologi Bandung, 1993.

Ross, P. J. (1996), *Taguchi Techniques for Quality Engineering*, 2rd edition, McGraw-Hill International Edition.

Sato, G. T. dan Sugiarto, N. H., *Menggambar Mesin Menurut Standar ISO,*Jakarta, PT Pradnya Paramita, 1994.

Soejanto, I. (2009), *Desain Eksperimen dengan Method Taguchi*, Graha Ilmu, Yogyakarta.

Su Yu, He Ning dan Li Liang,"Effect of Cryogenic Minimum Quantity Lubrication (CMQL) on Cutting Temperature and Tool Wear in High-Speed End Milling of Titanium Alloys," *Applied Mechanics and Materials*, 2010, Vol. 34-35.

Yildiz, Y. dan Nalbant, M.,"A Review of Cryogenic Cooling in Machining Processes," *International Journal of Machine Tools & Tools Manufacture,* Vol. 48, 2008, Hal. 947-964.

Yue, Y., Zheng, Y., Basu, S. dan Sutherland, W.J., "Cutting Fluids: Performance Measure and Health-Related Characteristics," Otsu Jepang, 1998.