Implementation of Particle Swarm Optimization (PSO) Method in Minimum Quantity Lubrication (MQL) Optimization to Obtain Optimal Machining in CNC Milling Machine

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Keywords: Minimum Quantity Lubricant, Particle Swarm Optimization, CNC Milling Machine, ISO 14001, Regression.

Abstract: One of the machining processes used is the milling process with CNC milling machines equipped with cutting fluid to reduce the impact of the cutting process. One of the techniques of cutting fluid is to use MQL (Minimum Quantity Lubricant) as an application of ISO 140001 in reducing coolant waste in the environment which has the advantage of being more economical in reducing friction between the tool and the workpiece, thereby reducing the temperature rate in the cutting tool. The CNC tool machine of Politeknik Manufaktur Bandung is equipped with MQL (Minimum Quantity Lubricant) with Arduino control which has no parameters for optimum coolant discharge during the machining process.

In this study, the Particle Swarm Optimization (PSO) method was used, which is one of the optimization methods for making decisions used in the manufacturing process by looking for a minimum value. There sulting from the milling process becomes a response in the process on CNC milling machines to obtain the characteristics of an effective discharged lubricant discharge. Some parameters such as cutting depth and feeding speed for aluminum and steel materials St37 were identified as experimental data for response. The data was searched for equations with regression, so in this study a polynomial regression model was chosen that could describe the data value better than linear regression.

Polynomial equations are calculated with the Particle Swarm Optimization (PSO) algorithm to find the optimum flowrate. So that the minimum discharge obtained on aluminum material for a feeding depth of less than 0.85 mm is 25ml/h, and more than 0.85mm is 85ml/h. while for St.37 material the feeding depth of less than 0.35 mm is 25ml/h, and more than 0.35mm is 85ml/h.

1 INTRODUCTION

One of the machine tools that uses automation systems that are commonly used by industry today is CNC (Computer Numerical Control) machines. In the machining process, it cannot be separated from the use of coolant or coolant to clean and cool the workpiece and cutting tools. Related to environmental issues regulated in ISO 140001 on recommendations for reducing coolant waste in the machining process. Therefore, a method is needed by using a coolant that is as minimal as possible with more environmentally friendly materials. One of the methods used is minimum quantity lubricant (MQL). Related to environmental issues regulated in ISO 140001 on recommendations for reducing coolant waste in the machining process. Therefore, a method is needed by using a coolant that is as minimal as possible with more environmentally friendly materials. One of the methods used is minimum quantity lubricant (MQL).

Be advised The development of POLMAN CNC machine tools already has a cooling system by installing a minimum quantity lubricant (MQL) method cooling system with Arduino control on a MINI CNC Milling machine made by POLMAN. However, the Minimum Quantity Lubricant (MQL) does not yet have an optimum discharge. The Particle Swarm Optimization (PSO) method is used as one of the optimization algorithms that can solve complex optimization problems if solved in an exact manner.

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2 THEORY AND RESEARCH METHODS

The machining process is the process of removing material parts (removal of material) with the help of cutting tools on the machine. The machining process aims to achieve the desired. geometry, size, surface smoothness, and function of the workpiece in the process.

The principle of the machining process is that the part of the workpiece that is not needed will be removed by means of a cutting process using a cutting tool with a rotating or shifting motion. Here are the five elements of the machining process, namely (Rochim, 1993):

1) cutting speed: v (m/min);
2) feeding speed: vf (mm/min);
3) depth of cut: a (mm);
4) cutting time: tc (min);
5) rate of metal removal: z (cm3 /min);

2.1 Wet Machining

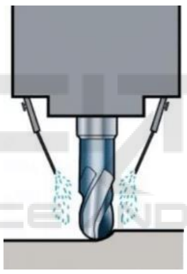

Figure 1: Wet machining.

Wet machining method is the use of coolant in the machining process aimed at cooling the cutting tool used. According to how coolant is given to the Wet Machining method, it can be divided into three types of cooling processes, namely: flooded to the workpiece (Flood application), sprayed (Jet application fluid) and atomized (Mist application fluid).

The use of this many coolants in the machining process can accelerate the rate of cooling that occurs. With the material studied is the steel type AISI 422 states that, for wet engine temperatures are in the range of 26-30 °C, which is the temperature spreading throughout the cutting surface with pressure from the engine pump, and absorbing the temperature from the tool, workpiece and furious (Glanis, 2008). In this study, synthetic fluids were used, synthetic fluids consisted of a mixture of organic and inorganic alkaline materials and added with additives to ward off corrosion. This liquid has the best cooling capacity when compared to other coolants.

2.1.1 Minimum Quantity Lubrication

Minimum quantity lubrication (MQL), using a very small amount of liquid for the machinery process in the form of an aerosol formed from a mixture of coolant and air using a venturi working insert. The pressure difference between the air pressure channel in and output through the nozzle is lower pressed so that the coolant enters the mist lubrication spray system.

MQL has two types of coolant supply, namely External MQL Supply and Internal MQL Supply. The application of MQL although the provision of a minimum coolant but is able to produce better tool life, better surface finish, better furious shape, reduced cutting power and on the workpiece, cutting tools and parts affected by the coolant will provide resistance to oxidation, providing environmental friendliness

Minimum quantity lubrication (MQL) is a total-loss lubrication method, which means using new and clean lubricants only one-time use. But as a general rule, 25-85 ml / hour on a cutting tool less than 40 mm in diameter,

2.2 Particle Swarm Optimization (PSO)

The PSO algorithm was invented by Kennedy and Eberhart in 1995, mimicking the behavior of a flock of seagulls that fly together to forage or nest. Pso algorithms can easily reach global and optimal points because of their ease of application to solve problems and have consistent performance, so that PSO algorithms are good and effective for solving optimization problems.

The PSO algorithm, birds are represented as "particles", where each particle represents a possible solution to an optimization problem. The word "particle" denotes an individual, where each individual is connected using their own intelligence (Intellegence) and influences the behavior of their group. Thus, if one of the particles finds the fastest

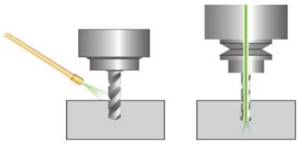

Figure 2: Minimum quantity lubrication type.

and right path to the food source then the rest of the other group can immediately follow the path even though the location of the member is far from the group.

2.2.1 PSO Algorithm Structure

There are several components in the PSO Algorithm including the following:

1. Swarm, which is the number of particles in a population in an algorithm. The size of the swarm depends on how complex the problem is. In general, the swarm size in PSO algorithms tends to be smaller
2. Particle, is an individual in a swarm that represents the solution of solving a problem. Each particle has a position and speed determined by the representation of the solution at that moment.
3. Personal best (pbest), is the best position that a particle has ever achieved by comparing fitness in the current particle position with before. Personal best is prepared to get the best solution.
4. Global Best (gbest), is the best position of particles obtained by comparing the best fitness values of all particles in the swarm.
5. Velocity (velocity), v is a vector that determines the direction of displacement of the particle's position. Velocity changes are made each iteration with the aim of correcting the original particle position.
6. Inertial weight (inertia weight), w is used to control the impact of the velocity change given by the particle.
7. Acceleration coefficient, is the controlling factor of the extent to which particles move in one iteration. In general, the values of the acceleration coefficients c1 and c2 are the same, namely in the range of 0 to 4. Nevertheless, the value can be determined by yourself for each different study

2.3 Mathematical Equations with Regression

The term regression according to statisticians applied to almost all areas of science, to estimate or foresee the value of one variable based on another variable whose value has been known, and both variables have a functional or causal relationship with one another.
Before creating a regression equation it is necessary to determine the form of the data distribution. So it is better to make it in a scatter diagram or scatter diagram and then look at the regression equation that is closest based on the number of data distribution so that the deviation that occurs can be as small as possible.

There are two types of regression sought in this study:
Multiple linear regression equation

$$\hat{Y} = b0 + b1\ X1 + b2\ X2 \quad (1)$$

Ý = function value (bound variable)
b0 = constant value
b1 = partial regression coefficient of X1 b2 = coefisen partial regression of X2
Polynomial regression equation

$$Y = a + bX + cX2 \quad (2)$$

Y = function value (bound variable) a = constant value
b = the value of the coefficient constant X c = coefficient constant value X2
X = free variable value

In this study the search for regression equations was carried out with the help of matlab software and IBM SPSS.

2.3.1 Normality Test

Parametric statistical analysis is an analysis used to test population parameters through statisticalanalysis or test population size through sample data. In order for the data to be tested for parametric analysis, it is required that the data must be normally distributed (Widana,2020).

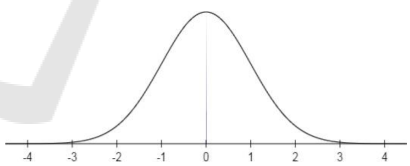

Figure 3: Normal distribution chart.

A data will form a normal distribution curve with the shape of the bottom open curve or resemble a bell with two parameters, namely average and standard deviation. The shape of the normal distribution curve can be seen in the figure below:

Normality tests can also be performed by plotting probability plots. Where a data in the regression model is said to be normal if the plotting data (dots) depicting the actual data follows a diagonal line (Widana,2020).

2.3.2 T Test (Partial)

Partial tests are used to show how much influence an independent variable or free variable has on a dependent variable or bound variable.

Step-by-step in performing partial testing on data (Nuryadi, 2017):

1. Determine the significance value of the α (the value used α = 0.05).
2. Looking for the calculated value of t
3. Comparing the calculated t value with t table (α/2 ;n-k-1)

If:

Sig value. > α significantly different (no relationship)
Sig value. < α does not differ significantly (there is a relationship)
t count < t the table differs significantly (there is no relationship)
t count > t the table does not differ significantly (thereis a relationship)

2.3.3 F Test (ANOVA)

The F test or Analysis Of Variance (ANOVA) is one of the tests in test statistics used to test the distribution or variance means in variables simultaneously or together (Nuryadi, 2017).
Steps in conducting the F Test used (Nuryadi, 2017):
1 Specifies the significance value of the α (the value used α = 0.05).
2 Looking for the calculated F value.
3 Comparing F count with F Table (k ; n-k) If:
Sig value. > α significantly different (no relationship)
Sig value. < α does not differ significantly (there is a relationship)
F count < F the table differs significantly (there is no relationship)
F count > F the table does not differ significantly (there is a relationship)

2.4 Research Methods

In this study, an experimental method was used, namely a method by testing the Minimum Quantity Lubricant (MQL) with quality controlled based on predetermined parameters. These parameters are Depth of Cut (DoC), the composition of the lubricant flowrate, RPM and feeding that have been determined.

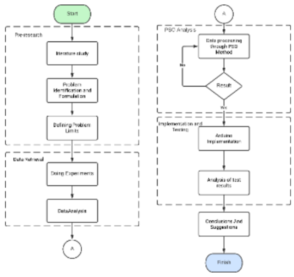

Figure 4: Research method flow chart.

2.4.1 Activity Flowchart

Flowchart planning activities optimization minimum quantity lubricant on CNC machines, consisting of pre-research activities, data retrieval, PSO analysis, and implementation and testing.

2.4.2 Experiment Strategy

Strategic planning in conducting minimum quantity lubricant (MQL) optimization experiments in accordance with the selected parameters. The activities on the experimental strategy can be seen in the flow chart below:

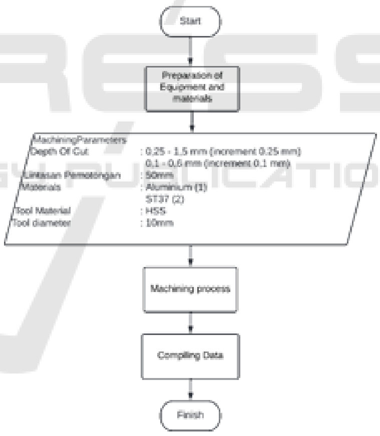

Figure 5: Experiment strategy flow chart.

2.4.3 Machining Parameters

Here is the determination of the parameters for aluminum and St.37 materials:

1. Aluminium
   Vc aluminium = 80 m/mnt
   Feed per teeth= 0.02
   $Rpm = \frac{1000 \; x \; 80}{\pi \; x \; 10} = 2546.47 \approx 2500$ rpm
   $feeding(s) = 2500 \times 0.02 \times 4 = 200 \; mm/min$
2. St.37
   Vc St.37= 20 m/mnt
   Feed per teeth = 0.02

$$Rpm = \frac{1000\ x\ 20}{\pi\ x\ 10} = 636.61 \approx 650 \text{ rpm}$$
$$feeding(s) = 650 \times 0.02 \times 4 = 52\ mm/min$$

To obtain the data is carried out machining process with predetermined parameters. The following is a flow chart of the process of machiningactivities for data collection:

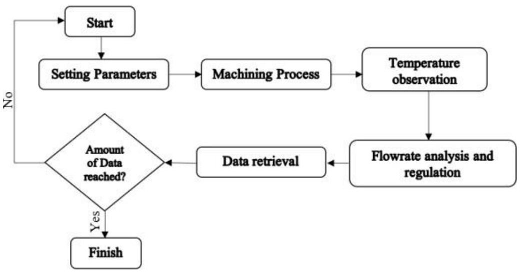

Figure 6: Machining experiment flow chart.

The optimization process is carried out with the model of mathematical equations obtained so thatthe optimum value of the flow rate of the corresponding machining process is obtained. The Optimization process is carried out according to the flow chart of the algorithm starting from the initialization of the position, the initial speed, the maximum iteration. then, calculate the value of each particle through the value of the function to determine the initial Pbest and Gbest. after that, do an update ofposition and speed. recalculates the fusion value based on the new position up to the specified iteration limit, and then sorted to find the minimum solution.

3 RESULT

3.1 Research Methods

The data taken is the influence into the feeding and flowrate on the temperature response that occurs during the machining process. So that data for aluminum and St.37 were obtained as follows:

Table 1: Alumunium experiment result, n=2500 rpm, feeding=200 mm/min.

No	DoC [mm]	Flow Rate [ml/h]	Temperature [ºC]
1	0.25	25	24.9
2		40	24.9
3		55	24.3
4		70	24.5
5		85	26.4
6	0.5	25	26.9
7		40	27
8		55	27.2
9		70	27.4
10		85	27.4
11	0.75	25	28.4
12		40	28.8
13		55	28.4
14		70	28.5
15		85	28.1
16	1	25	29.2
17		40	28.8
18		55	30
19		70	29.8
20		85	28.9
21	1.25	25	31.1
22		40	31.6
23		55	32.4
24		70	32.4
25		85	31.8
26	1.5	25	33.3
27		40	33.1
28		55	32.9
29		70	32.1
30		85	30.1

Table 2: ST37 experiment result, n = 650 rpm, feeding = 32 mm/min.

No	DoC [mm]	Flow Rate [ml/h]	Temperature [ºC]
1	0.1	25	25.8
2		40	26.5
3		55	26.2
4		70	26.1
5		85	26.4
6	0.2	25	27.1
7		40	27.1
8		55	27.7
9		70	27.7
10		85	27.4
11	0.3	25	28.1
12		40	28.3
13		55	28.1
14		70	27.9
15		85	27.8
16	0.4	25	28.3
17		40	28.2
18		55	28.3
19		70	28.2
20		85	28.2
21	0.5	25	29
22		40	29.1
23		55	29.2
24		70	28.5
25		85	28.6
26	0.6	25	28.9
27		40	29
28		55	28.8
29		70	29.1
30		85	28.9

3.2 Regression Equation Results from Experiments

The linear regression equations from the experiment obtained using IBS SPSS is:
$Y1 = 23{,}98 - 0{,}002\ X1 + 5{,}879\ X2$
$Y2 = 26{,}147 - 0{,}001\ X1 + 5{,}240\ X2$
The polynomial regression equations from the experiment obtained using Matlab is:
$Y1 = 21{,}42 + (0{,}06564 \times x1) + (7{,}819 \times x2)$
$- (0{,}0003333 \times x12)$
$- (0{,}03528 \times x1 \times x2)$
$Y2 = 24{,}81 + (0{,}006444 \times x1) + (13{,}47 \times x2)$
$- (0{,}02 \times x1 \times x2) - (10.18 \times x22)$
Information:
Y1 = Suhu Aluminium Y2 = Suhu St.37
x1 = Flowrate
x2 = Depth of Cut

3.3 Comparison of Linear Regression Equations and Polynomials

To see the regression equation that is suitable for processing with PSO, the role of regression equation is carried out

Table 3: Comparison of the coefficient of determination of aluminum regression.

Multiple Linear Regression	Polynomial Regression
0,916	0,9327

Table 4: Comparison of aluminum regression errors.

Multiple Linear Regression	Polynomial Regression
0,577942	0,501499

Table 5: Comparison of regression coefficients of determination St.37.

Multiple Linear Regression	Polynomial Regression
0,865	0.9404

Table 6: Comparison of St.37 regression errors.

Multiple Linear Regression	Polynomial Regression
0,288933	0,202568

3.4 PSO Algorithm Calculation Results

Here are the results of the pso algorithm optimization calculation through Matlab *software*:

Table 7: Alumunium PSO algorithm results.

No	DoC [mm]	PSO Flow Rate Results [ml/h]	Best Fitness PSO Results [ºC]
1	0.05	25	23.1995
2	0.1	25	23.5464
3	0.15	25	23.8932
4	0.2	25	24.2401
5	0.25	25	24.5869
6	0.3	25	24.9338
7	0.35	25	25.2806
8	0.4	25	25.6275
9	0.45	25	25.9743
10	0.5	25	26.3212
11	0.55	25	26.668
12	0.6	25	27.0149
13	0.65	25	27.3617
14	07	25	27.7086
15	0.75	25	28.0554
16	0.8	25	28.4023
17	0.85	85	28.6885
18	0.9	85	28.9295
19	0.95	85	29.1705
20	1	85	29.4115
21	1.05	85	29.6525
22	1.1	85	29.8935
23	1.15	85	30.1345
24	1.2	85	30.3755
25	1.25	85	30.6166
26	1.3	85	30.8576
27	1.35	85	31.0986
28	1.4	85	31.3396
29	1.45	85	31.5806
30	1.5	85	31.8216

Table 8: Alumunium PSO algorithm results.

No	DoC [mm]	PSO Flow Rate Results [ml/h]	Best Fitness PSO Results [ºC]
1	0.05	25	25.5942
2	0.1	25	26.1663
3	0.15	25	26.6875
4	0.2	25	27.1579
5	0.25	25	27.5773
6	0.3	25	27.9459
7	0.35	85	28.2302
8	0.4	85	28.4369
9	0.45	85	28.5928
10	0.5	85	28.6977
11	0.55	85	28.7518
12	0.6	85	28.7549
13	0.65	85	28.7072
14	07	85	28.6085
15	0.75	85	28.4590

Table 8: Alumunium PSO algorithm results (cont.).

No	DoC [mm]	PSO Flow Rate Results [ml/h]	Best Fitness PSO Results [°C]
16	0.8	85	28.2585
17	0.85	85	28.0072
18	0.9	85	27.7049
19	0.95	85	27.2728
20	1	85	26.9477

3.5 Implementation on Arduino

Implementation of optimization results in the form of a data base on the Arduino from the optimum flowrate results for feeding recommendations. The add-on program to MQL is a new menu for recommendations of MQL optimum values. Flowrate recommendation menu display:

Table 9: Arduino menu display.

Menu Aluminium   Menu St.37

3.6 Results Test and Validation Results

The test results are carried out to validate the results of the optimization data calculated using the PSO method, by testing the feeding in accordance with the optimum flowrate obtained. here are the results of MQL testing with optimization results with Particle Swarm Optimization.

Table 10: Validation of optimum flowrate comparison (Alumunium).

DoC	Temp with MQL	Temp without MQL	PSO Measure. Temp.
0.15	24.8	25.8	23.89
0.25	25.9	26.4	24.58
0.35	26.3	26.8	25.28
0.5	27.2	28.1	26.32
0.85	28.8	30.8	28.68

Table 11: Validation of optimum flowrate comparison (ST37).

DoC	Temp with MQL	Temp without MQL	PSO Measure. Temp.
0.2	27.8	30.9	27.17
0.25	28.5	31.5	27.57
0.3	28.9	31.9	27.94
0.35	29.3	32.7	28.23
0.4	29.8	33.2	28.43

4 CONCLUSIONS

To obtain the optimal lubricant discharge in MQL, data collection is carried out with depth of cut and flowrate parameters. so that the results of the data will be processed to obtain the regression equation. The Regression Equation will be calculated through the PSO algorithm and the results will be obtained:

In aluminum materials the discharge of lubricant for a depth of less than 0.85mm is 25 ml/h. Meanwhile, more than 0.85 ml/h is 85 ml/h.

In St.37 materials the discharge of lubricant for depths of less than 0.35mm is 25 ml/h. Meanwhile, more than 0.35 ml/h is 85 ml/h.

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