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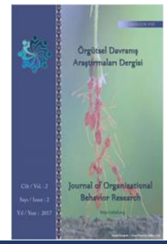

# Optimization of Machining Parameters in Milling of AISI4140 Steel to Obtain the Best Surface Quality using Evolutionary Optimization Algorithms

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## ABSTRACT

*Today, end milling technique is one of the most common methods available for the production of industrial parts. Basically, in this method, the rotation of a high-speed cylindrical steel with sharp edges on its floor and around leads to the removal of material from the work piece. Adjustable parameters in this process include tool rotation speed, the linear speed of work piece, tool load depth, chipping direction (agree, disagree), and tool diameter. The main objective of this technique is to obtain the highest material removal rate and the best surface quality. The main objective of optimization methods in this field is to provide suitable conditions for optimizing both outputs. Over the past few years, the variety of evolutionary algorithms has increased their application in various researches. AISI 4140 steel is one of the most widely used alloy steels in the industry. This study investigates the optimal conditions for end milling of AISI 4140 steel by different evolutionary algorithms. Surface quality and cutting rate are the optimal outputs of a machining process, and reducing the cutting rate leads to increased surface quality. Improving the surface quality and increasing the chipping rate simultaneously is the focal result of this study.*

***Keywords:*** *Milling, optimization, surface quality, Taguchi method*

## INTRODUCTION

Milling is considered to be one of the most common processing and machining operations on manufactured parts. A milling machine is used to create complex shapes in metal pieces or other solids. The moveable work piece is placed on a table, and the rotation of the cutting tool leads to the removal of the load from the piece. Milling machines can create a wide range of chipping geometries such as flat surfaces, angled surfaces, cogwheels, and grooves. This process requires a variety of equipment such as milling machines, work pieces, fixtures, and cutting tools. At the same time, the work piece is connected to a fixture embedded into the machine. In the milling process, each edge of the milling cutter periodically chips during its rotation and rotates freely for cooling until the next turn. As a result, the edges are not under constant pressure like turning grates. Chipping is also done faster by the cutter. Milling machines are divided into two classes include horizontal and vertical, depending on whether the main axis of the milling cutter is horizontal or vertical.
The rotational motion of the end mill is called the main motion or cutting. To make the chip thicker, the work piece has a straight-line movement called load motion. Both the main motion and the load motion are done by the milling machine. In rotary milling, as a rule, the load motion cutter is adjusted against the direction of the milling cutter. Of course, it is possible to adjust the

direction of load motion with the direction of cutter motion. In the first method, when the direction of cutter motion and the work piece is not the same, the chip is removed from the thinner point. Also, before the milling cutter edges penetrate into the work piece, the cutter slides on the work surface and leads to the production of a lot of friction. In this position, the cutting force tries to pull the work piece upwards.

The massive application of AISI 4140 steel in the industry, as well as the widespread use of end milling in the final stages of parts manufacturing, motivate us to focus on them. The number of parameters involved in this process is very large and access to the desired results depends on accurate knowledge of their impact as well as the creation of accurate models. As a result, after conducting sufficient studies and reviewing the principles of end milling, we identified the effective parameters for performing practical tests and collected the required data.

End milling is one of the final manufacturing processes of parts and affects the quality of the surface obtained, which in turn affects the important characteristics of the product such as fatigue resistance, light reflection, heat transfer, and so on. For this reason, to achieve the desired surface quality, we must minimize the surface roughness of the part. As a result, the surface roughness obtained from the end milling process was selected as the output of the process. In light of the above, the objective of the present study is to optimize the machining parameters in the milling of AISI4140 steel to obtain the best surface quality based on evolutionary optimization algorithms.

## Materials and methods

The work piece is a cubic block with the dimensions reflected in Figure (1). The material selected for the work piece is Mo40 or 1.7225 or AISI 4140 or 42CrMo4 steel, which are known as the most important and widely used steels in the class of heat-treatment operational steels in the industry.

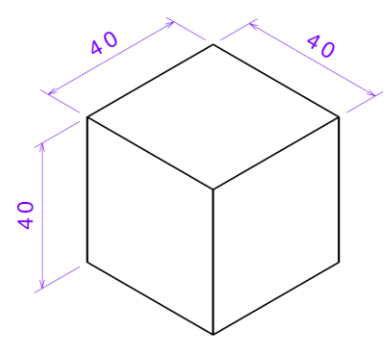


Figure (1): An example of a work piece and its dimensions

A hand-held milling machine equipped with a digital ruler is used to prepare the work piece. Three types of movement strategies namely spiral, zigzag and one-way have been extracted from Katia software.

Taylor Habson's roughness meter is used to measure surface roughness. Also, for milling test parts, the end mill of high-speed steel of TEKNIK Company has been used. Complete characteristics and view of the milling cutter are presented in Table (1) and Figure (2), respectively.

Table (1): Characteristics of the milling cutter

| Number of edges | Tool length | Tool diameter | Tool material | Manufacturer | Tool type |
|---|---|---|---|---|---|
| 4 | 60 mm | 10 mm | HSS high speed Steel | TEKNIK | end mill |

Figure (1): End mill cutter

**Input variables and preliminary tests**

The input parameters in surface roughness detection tests along with their level of variation are listed in Table (2).

Table (2): Input values range of milling parameters

| | Parameters | Variation range | | | Unit of measurement |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | |
| Cutting Speed | V | 110 | 130 | 150 | m/min |
| feed rate | F | 500 | 700 | 900 | mm/min |
| Depth of load | $a_p$ | 0.1 | 0.2 | 0.3 | mm |
| Tool path distance | Step over | 4 | 5 | 6 | mm |
| Motion strategy | Strategy | One-way | Zigzag | Spiral | - |

We have to do 243 tests in full mode. The number of experiments based on the Taguchi method and Table L27 has decreased. The use of this type of table depends on the number of variables considered in the test design software.

Table (3): Preliminary tests performed according to Table of Taguchi L27

| No. | Input variables | | | | | |
|---|---|---|---|---|---|---|
| | V | F | $a_p$ | Step over | | Output variable (Ra) |
| 1 | 110 | 500 | 0.1 | 4 | oneway | 0.91 |
| 2 | 110 | 500 | 0.1 | 4 | zigzag | 0.925 |
| 3 | 110 | 500 | 0.1 | 4 | spiral | 0.945 |
| 4 | 110 | 700 | 0.2 | 5 | oneway | 1.535 |
| 5 | 110 | 700 | 0.2 | 5 | zigzag | 1.455 |
| 6 | 110 | 700 | 0.2 | 5 | spiral | 1.76 |
| 7 | 110 | 900 | 0.3 | 6 | oneway | 1.66 |
| 8 | 110 | 900 | 0.3 | 6 | zigzag | 1.775 |
| 9 | 110 | 900 | 0.3 | 6 | spiral | 1.635 |
| 10 | 130 | 500 | 0.2 | 6 | oneway | 1.395 |
| 11 | 130 | 500 | 0.2 | 6 | zigzag | 1.605 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 12 | 130 | 500 | 0.2 | 6 | spiral | 1.52 |
| 13 | 130 | 700 | 0.3 | 4 | oneway | 1.1 |
| 14 | 130 | 700 | 0.3 | 4 | zigzag | 0.855 |
| 15 | 130 | 700 | 0.3 | 4 | spiral | 1.045 |
| 16 | 130 | 900 | 0.1 | 5 | oneway | 1.135 |
| 17 | 130 | 900 | 0.1 | 5 | zigzag | 1.375 |
| 18 | 130 | 900 | 0.1 | 5 | spiral | 1.235 |
| 19 | 150 | 500 | 0.3 | 5 | oneway | 1.075 |
| 20 | 150 | 500 | 0.3 | 5 | zigzag | 0.94 |
| 21 | 150 | 500 | 0.3 | 5 | spiral | 1.205 |
| 22 | 150 | 700 | 0.1 | 6 | oneway | 1.085 |
| 23 | 150 | 700 | 0.1 | 6 | zigzag | 1.305 |
| 24 | 150 | 700 | 0.1 | 6 | spiral | 1.475 |
| 25 | 150 | 900 | 0.2 | 4 | oneway | 1.757 |
| 26 | 150 | 900 | 0.2 | 4 | zigzag | 1.965 |
| 27 | 150 | 900 | 0.2 | 4 | spiral | 2.125 |

## Evolutionary optimization

A genetic algorithm is a search technique to find approximate solutions to optimization problems. Genetic algorithms are a special type of evolutionary algorithms based on evolutionary techniques such as inheritance and mutation.

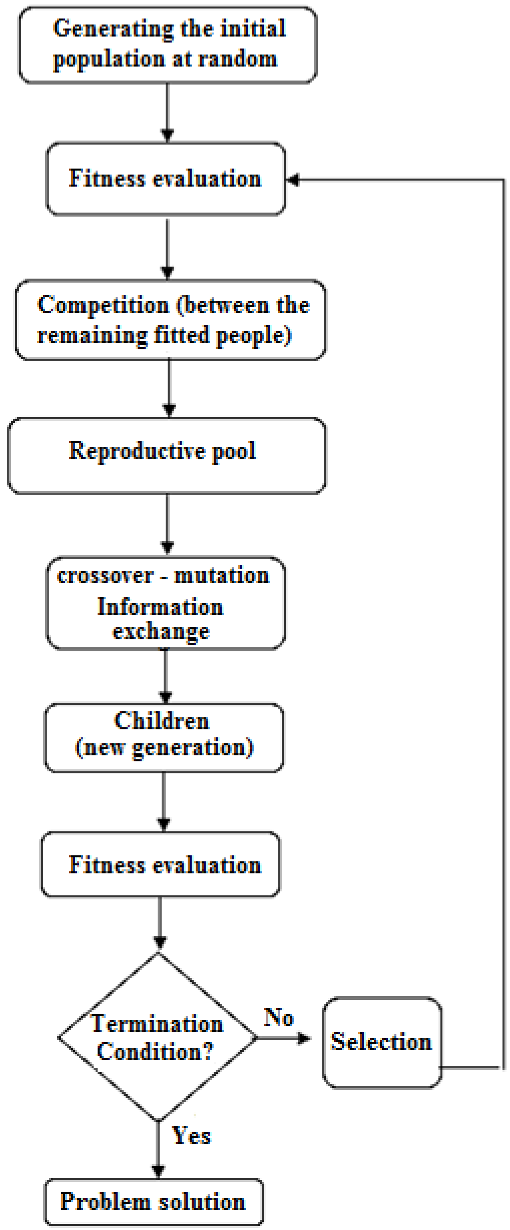


Figure (3): Genetic algorithm

Genetic algorithms use Darwin's natural selection principles to find the optimal formula for predicting or matching patterns. Genetic algorithms are a good option for implementing regression-based prediction techniques. Problem inputs are turned into solutions in a process inspired by genetic evolution. Such solutions are evaluated as candidates by the evaluator function. The execution of the algorithm ends as soon as the condition for termination of the problem is met. A genetic algorithm is generally an iteration-based algorithm whose components are often selected in a random process.

Many parameters affect the final surface roughness of the part in the end milling process. In this research, five parameters including cutting speed, feed rate, depth of cut, step over, and tool path strategy have been selected. The L27 Taguchi has also been used to design experiments. After the experiments, the surface roughness of each work piece was measured four times in a row and the average values obtained were recorded. Subsequently, a suitable model using regression was extracted for the relationship between surface quality and input parameters. The obtained model is used as the objective function or the basis of the optimization work. Our objective in this section is to determine the levels of the parameters in order to achieve the desired output. This process is performed using an intelligent genetic algorithm. In addition to rapid convergence towards the final solution, this algorithm has good computational accuracy. Subsequently, the Taguchi prediction method was used to determine the optimal levels. The results of the Taguchi method were almost close to the results obtained from the genetic algorithm. Only a significant difference was observed in the tool path strategy. In this research, MINITAB 16.2 software has been used to implement the Taguchi method. This software calculates all the calculations related to the Taguchi method including the signal-to-noise ratio, and plots the obtained results.

## Results

### 1- Problem optimization of the end milling process

The purpose of end milling optimization is to find the values of the parameters affecting the process and to achieve the minimum roughness at the surface of the part. In this section, an artificial neural network model and a meta-heuristic algorithm called genetic algorithm are used to optimize the process output. To implement this algorithm, the Genetic Toolbox is used in Matlab2011 software.

### 2- Input parameters and definition of optimization relationships

In this study, five parameters have been investigated as input variables of the milling process. There are four parameters of the continuous type. Also, there is only one discrete parameter called tool path strategy includes three levels one-way, zigzag and spiral. For this reason, optimization operations for each level of the strategy parameter are performed separately (in three separate steps). Because artificial neural network models have strong interpolation and weak extrapolation capabilities, the upper and the lower bounds for each of the input parameters are considered.

Table (4): Variation range of input parameters

| V (m/min) | F (mm/min) | $a_p$ (mm) | Step over (mm) |
|---|---|---|---|
| 110-150 | 500-900 | 0.1-0.3 | 4-6 |

In optimizing the surface roughness of the one-way strategy, we consider the fifth parameter, i.e. the path strategy parameter on the first level, and the first four parameters are set according to Table (4). Then the genetic algorithm is executed. The parameters of the genetic algorithm producing the best solution are reflected in Table (5).

Table (5): Initialization parameters of genetic algorithm

| Population size | Crossover method | Probability of mutation | Selection operator | Termination condition |
|---|---|---|---|---|
| 50 | Two point | 0.21 | roulette wheel | 600 iterations |

After adjusting the above parameters and running the genetic algorithm several times, the results of the five operations with the lowest surface roughness are presented in Table (6).

Table (6): Obtained results of genetic algorithm for input parameters

| | Proposed values of genetic algorithm for input parameters | | | | | Output |
|---|---|---|---|---|---|---|
| No. | V (m/min) | F (mm) | $a_p$ (mm) | Step over (mm) | strategy | Ra (μm) |
| 1 | 149.99 | 577.20 | 0.1 | 4 | oneway | 0.867 |
| 2 | 144.55 | 587.80 | 0.101 | 4 | oneway | 0.868 |
| 3 | 144.96 | 585.43 | 0.1 | 4.002 | oneway | 0.868 |
| 4 | 143.98 | 585.59 | 0.1 | 4.005 | oneway | 0.868 |
| 5 | 144.431 | 587.431 | 0.101 | 4.002 | oneway | .0868 |

Based on the results in the table above, the genetic algorithm for obtaining the minimum surface roughness in the one-way strategy offers a cutting speed of 144 m / min, which is close to the third level of this parameter, i.e. 150 m / min. In fact, the genetic algorithm for maximizing surface roughness suggests the use of maximum cutting speed. Also, this algorithm proposes the following parameters to achieve the minimum surface roughness: feed rate equal to 585 mm/min, depth of cut equal to 0.1 mm and step over equal to 4 mm, i.e. the minimum value of all three parameters leads to the best final result.

Table (7): Proposed values of the genetic algorithm in the zigzag strategy

| | Proposed values of genetic algorithm for input parameters | | | | | Output |
|---|---|---|---|---|---|---|
| No. | V (m/min) | F (mm) | $a_p$ (mm) | Step over (mm) | strategy | Ra (μm) |
| 1 | 149.960 | 502.00 | 0.1 | 4.665 | Back&Front | 0.860 |
| 2 | 149.885 | 500.79 | 0.1 | 4.662 | Back&Front | 0.860 |
| 3 | 149.976 | 500.42 | 0.1 | 4.659 | Back&Front | 0.860 |
| 4 | 149.000 | 500.00 | 0.1 | 4.644 | Back&Front | 0.866 |
| 5 | 149.998 | 501.092 | 0.1 | 4.666 | Back&Front | 0.866 |

According to Table (7), GA has suggested the highest value for cutting speed, the lowest value for feed rate, the lowest value for depth of cut and also the value of 4.66 mm for step over (close to the minimum value).

Table (8): Proposed values of genetic algorithm in spiral strategy

| | Proposed values of genetic algorithm for input parameters | | | | | Output |
|---|---|---|---|---|---|---|
| No. | V (m/min) | F (mm) | $a_p$ (mm) | Step over (mm) | strategy | Ra (μm) |
| 1 | 149.960 | 502.00 | 0.1 | 4.665 | Back&Front | 0.860 |
| 2 | 149.885 | 500.79 | 0.1 | 4.662 | Back&Front | 0.860 |
| 3 | 149.976 | 500.42 | 0.1 | 4.659 | Back&Front | 0.860 |
| 4 | 149.000 | 500.00 | 0.1 | 4.644 | Back&Front | 0.866 |
| 5 | 149.998 | 501.092 | 0.1 | 4.666 | Back&Front | 0.866 |

The results of the third stage optimization for the spiral strategy on the three parameters i.e. feed rate, depth of cut, and step over are the same as the other two strategies, but the value of 124 m/min is proposed for the cutting speed parameter in the spiral strategy, which is close to the second level.

## 3. Conclusion

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The overall results show that to achieve the minimum surface roughness in the end milling, we have to set the cutting speed at the highest level (third level), the feed rate at the lowest value, the depth of cut at the lowest value, and the step over at 4 mm. The results for the strategy parameter show that the zigzag strategy produces less surface roughness. The difference in surface roughness in the three strategies is about 0.01 µm, which can be ignored.

**4. Analysis of end milling process test results by Taguchi method**

The quality variable in this study is the amount of surface roughness obtained in the end milling process. Because the minimum value of the variable is desirable for us, the objective of the study is to minimize surface roughness (Ra).

Table (9): Signal to noise values for end milling process parameters

| Level | V | Feed | $a_p$ | Step over | Sterategy |
|---|---|---|---|---|---|
| 1 | -2.618 | -1.151 | -1.123 | -1.686 | -2.040 |
| 2 | -1.799 | -2.015 | -4.426 | -2.144 | -2.302 |
| 3 | -2.824 | -4.074 | -1.691 | -3.410 | -2.898 |
| Delta | 1.026 | 2.923 | 3.303 | 1.724 | 0.859 |
| Rank | 4 | 2 | 1 | 3 | 5 |

In the Taguchi method, the signal-to-noise ratio level must be maximized to achieve the lowest roughness. As you can see, the second column of the second level of the cutting speed parameter has the highest value of signal-to-noise ratio, i.e. Taguchi introduces the second level of cutting speed of 130 meters per minute as the optimal value, which leads to the lowest roughness.

The maximum value of the signal-to-noise ratio for the feed rate parameter is observed in the first level, i.e. Taguchi introduces the first level of feed rate equal to 500 mm/min as the optimal value, which leads to the lowest roughness. The maximum signal-to-noise ratio for the depth of cut parameter is observed in the first level, which is equal to 0.1 mm. This means that the minimum value for depth of cut results in the lowest surface roughness.

The signal-to-noise ratio for the step over parameter in the first level is equal to the maximum value. This means that the lower the step over value, the lower the surface roughness. Finally, for the fifth parameter i.e. the tool path strategy, the signal-to-noise ratio at the first level (one-way strategy) has a maximum value, meaning that the one-way strategy produces less surface roughness than the other strategies.

The results showed that the depth of cut is the most effective parameter on the final surface roughness of the piece and then the parameters of feed rate, step over, cutting speed, and path strategy have the greatest impact on the final surface roughness of the piece, respectively.

**Conclusion**

In this research, different stages of modeling and optimization of the end milling process on AISI 4140 steel have been investigated. The results showed that to achieve the minimum surface roughness at the end milling, the parameters of cutting speed, feed rate, depth of cut and step over should be set to the highest level (third level), the minimum value, the minimum value and 4 mm, respectively. The results for the path strategy parameter show that the spiral strategy produces less surface roughness. At the same time, the difference in surface roughness between the three strategies is about 0.01 µm, which can be ignored.

In the Taguchi method, to achieve the lowest roughness, the signal-to-noise ratio level must be the maximum value. In fact, the Taguchi method introduces the second level of cutting speed of 130 meters per minute as the optimal value for the lowest roughness.
The genetic algorithm in the one way strategy proposes 144 m/min, 585 mm, 0.1 mm, and 4 mm for the parameters of cutting speed, feed rate, depth of cut, and for step over, respectively.
The genetic algorithm in the zigzag strategy proposes maximum, minimum, minimum, and 4.66 mm values for cutting speed, feed rate, depth of cut parameters, and for step over, respectively.
The results of process optimization for the spiral path strategy in the three parameters feed rate, depth of cut, and step over are the same as the two strategies. However, the proposed cutting speed parameter for the spiral strategy is 124 m/min.
The depth of cut parameter has the greatest effect on the final roughness of the piece. Then, the parameters of feed rate, step over cutting speed, and cutting path strategy have the greatest impact on the final surface roughness of the part, respectively.

## References


Alauddin, M., M. El Baradie, and M. Hashmi, Optimization of surface finish in end milling Inconel 718 .Journal of Materials Processing Technology, 1996. 56(1): p. 54-65.

Benardos, P. and G.C .Vosniakos, Prediction of surface roughness in CNC face milling using neural networks and Taguchi's design of experiments. Robotics and Computer-Integrated Manufacturing, 2002. 18(5): p. 343-354.

Benardos, P. and G.-C. Vosniakos, Predicting surface roughness in machining: a review. International journal of machine tools and manufacture, 2003. 43(8): p. 833-844.

Boothroyd, G., Fundamentals of metal machining and machine tools. Vol. 28. 1988: CRC Press.

Childs, T., Metal machining: theory and applications. 2000: Butterworth-Heinemann.

Oktem, K., application of response surface methodology in the optimization of cutting condition for surface roughness. journal of material processing technology, 2003. 170.

Routara, B., A. Bandyopadhyay, and P. Sahoo, Roughness modeling and optimization in CNC end milling using response surface method: effect of workpiece material variation. The International Journal of Advanced manufacturing Technology, 2009. 40(11-12): p. 1166-1180.

Selvaraj, D.P., P. Chandramohan, and M. Mohanraj, Optimization of surface roughness, cutting force and tool wear of nitrogen alloyed duplex stainless steel in a dry turning process using Taguchi method. Measurement, 2014. 49: p. 205-215.

Suresh, P., P.V. Rao, and S. Deshmukh, A genetic algorithmic approach for optimization of surface roughness prediction model. International Journal of Machine Tools and Manufacture, 2002. 42(6): p. 675-680.

Zhang, J., et al., Evolutionary optimization of machining processes. Journal of Intelligent Manufacturing, 2006. 17(2): p. 203-215.