Optimization of pocket cycle machining process in computer numerically controlled milling machining

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Abstract. The objectives of this study were: (1) to analyze the ratio of the time required for the roughing process of making a pocket (pocket) from several different strategies for the roughing process, and (2) to analyze the wear of cutting tools for the roughing process of making a pocket from several kinds of roughing cutting method. The research method used was experiment. The materials used are the work piece of mild steel (ST37) and the cutting tool HSS End mill with a diameter of 10 mm with 2 flutes. The machine used was a CNC milling machine and the software used was Master Cam X7. Retrieval of data using a built-in time-measuring instrument, vernier caliper, micrometer, and a digital micrometer with a magnification of 600x to 1000X. Data were analyzed by comparing the time required for each cutting method (8 kinds of methods) on CADCAM and the time on the actual CNC milling machine. The results showed: the fastest time required for roughing the pocket size 80 mm x 80 mm in 6 mm was the zigzag cutting method with straight-in feed (41 minutes 46.68 seconds in the CAM simulation and 42 minutes in machining using a CNC Milling machine), and the longest time is the true spiral cutting method with a ramping in-feed (62 minutes 20.59 seconds in the Master Cam X7 simulation and 62 minutes 21 seconds in the machining process using a CNC Milling machine). The wear of tools for the zigzag cutting method is greater than the true spiral cutting method. The optimization of the pocket making process in a CNC milling machine is calculated based on time and wear, if machining time is the goal, the zigzag cutting method is chosen and if the durability of the cutting tool is the goal, the true spiral cutting method is chosen.

1. Introduction
The manufacturing process for metal products is currently more efficient with the presence of computer-controlled machine tools (CNC = Computer Numerically Controlled) and the use of CADCAM (Computer-Aided Design and Computer-Aided Machining) software. CNC machine tools are used in all manufacturing industries in the form of lathes, milling machines, grinding machines, drilling machines, and non-conventional machines (EDM, ECM, and Laser Machining). CNC machining is a manufacturing process in which pre-programmed computer software control the movement of cutting tools and machine. The process can be used to control a range of complex machining, from turning, milling, drilling, boring, grinding, and routers. With CNC machining, three-dimensional cutting tasks can be accomplished in a single set of prompts. In CNC laboratories at schools or university campuses, the use of CNC machines by implementing CADCAM software is not
optimal due to the limited capabilities of machines, materials, and cutting tools. This can be seen from the absence of products that can be used or marketed to industry or consumers.

The advantages of CNC machine tools are precision and speed. CNC machines eliminate much work, hence saving time and make production processes more efficient. Manufacturing processes using numerical controls also reduce human error and can be operated at any time[1]. CNC machines are operated via a CNC program that can be written manually or created using CADCAM software. High-performance CNC machine can increased productivity and labor cost savings, which has a huge impact on corporate profitability [2]. The production process in the industry at this time is demanded by the speed of production time because of the demands of mass products, for example, motorcycle products must be able to produce 10 million units per year by 2025 [3]. With the demands for productivity and advances in manufacturing technology using CNC, it is required to make the production process efficiency or shorten the processing time so that more products are produced.

CNC programming for simple-shaped work pieces can be written directly on the CNC machine, while for complex product, CNC programs are created with the help of CADCAM software. CADCAM is used to create designs, prototype products, finished products, and execute production processes [4]. An integrated CADCAM system offers one complete solution for design through manufacturing. By using the CADCAMCAQ device, industry players have applied smart technology to the manufacturing process. Therefore, to face increasingly fierce global competition, manufacturers absolutely must apply or use smart technologies. Changes in the manufacturing sector and other industries are always occurring and sometimes unexpected. Industrial managers, for example, the manufacturing sector should activate a new and integrative process chain upgrade based on CADCAMCAQ. In addition, a program between CADCAM and NC was developed by [5] called STEP-NC which aims to simplify the manufacturing process. STEP-NC or ISO 14649 is the next generation of data models between CADCAM and CNC system controls. After a decade of investigation, the STEP-NC technology is still under developed.

Research on the optimization of the machining process has been carried out by Anggraini, et.al [6]. The study resulted in optimization parameters of the CNC milling programming machine on the processing time and its effect on the efficiency. This study aimed to investigate the effect of depth of cut, feed rate and maximum step down on processing time in CNC milling programming. Besides, the best machining parameters that resulted in optimal processing time on CNC milling programming was also studied. Results showed that maximum step-down, feed rate and depth of cut gave significant influence on processing time of CNC milling programming by using MasterCAM software. It also showed that by optimizing those parameters could result in cost reduction and improved tool life time.

Other research on the milling machining process was carried out by Karuppanan [7]. They proposed a new method in order to sequence cutting segments in CNC milling in more efficient way. They used genetic algorithm and particle swarm optimization in order to provoke quality solutions in optimizing the process. Genetic algorithm and particle swarm optimization were implemented in MATLABR2016b computing environment due to its simple coding method and platform’s flexibility. The optimization procedure then was validated by comparing computing results with the other programs such as Mastercam and Autodesk Inventor. Results showed that the proposed method saves up 40% of the tool’s airtime during machining.

Mustafa, et al [8] produced research: a tool path was generated for pockets with islands by using the data obtained through the developed offsetting method. The used offsetting method is a method with high applicability where errors could easily be defined and eliminated. Pockets with complicated shapes and with or without islands were enabled to be processed in CNC milling machines in a short term. In addition, there are researchers who develop CADCAM to increase efficiency in tool selection and time. They proposed a new approach in automatic programming of CNC machine. They used artificial intelligence in solving complex problem of machine tool program. Results showed that the system could run efficiently and automatically without assistance for a simple prismatic product [9].

Apart from selecting the machining method, it is necessary to observe the wear of the cutting tool in the machining process for several machining parameters. The same machining parameters can also
be examined regarding the wear of the cutting tool based on the machining time and or the process of the cutting tool feed to the work piece.

A real-time process monitoring as well as the control of the process by the use of decision-making algorithms. The current paper explores the opportunities with this regard in the area of tool wear prediction in end milling of Ti-6Al-4V alloy at various operating conditions. A series of slot milling passes were made at various parameter combinations of feed, speed, and depth of cut until the flank wear on tool crosses the failure criterion. The cutting force data acquired in the process with the dynamometer and the texture features from the image of the milled surface are used to build a model for predicting the flank wear through the Kalman filter approach [10]. Several machining parameters that affect wear and surface roughness were also investigated by [11]. The results of the research are at each level of tool flank wear, the effects of cutting speed, feed, and radial depth-of-cut on surface integrity were investigated respectively. End milling can produce surface finish between 0.1μm and 0.3μm under most of the conditions. Roughness is generally higher in step-over direction than feed direction. No obvious white layer is observed in subsurface microstructure.

The process of creating a CNC program in CADCAM software consists of several menus and sub-menus, each menu and sub-menu is selected according to the characteristics of the work piece shape and characteristics of the cutting tool and the shape of the basic material. The existing menu needs to be studied further regarding its efficiency and effectiveness. Efficiency in terms of the time required and effectiveness means the quality of the machining process. In terms of productivity, the production time parameter that describes efficiency needs to be examined because it is a predictable parameter for the achievement of the production process. Based on the explanation above, this research aims to compare the machining time required for the roughing process of making pocket from several different roughing process methods. In addition, the size of the tools wear needs to be observed to get an optimization between the machining time and the tool wear rate.

2. Method
This research method was the experimental method. The experimental steps were as follows: (1) determining the pocket image to be made (rectangular pocket with a size of 80 mm x 80 mm x 6 mm), (2) making a CNC program using Master CAM for 8 cutting methods, (3) preparing the work piece from Mild Steel St37 (120 mm x 120 mm x 15 mm) and 10 mm diameter cutting tools (2 flutes) of HSS material, (4) Recording the time required for the machining process by simulation in CAM, (5) CNC program from CAM transferred to a CNC Milling machine and the machining process is carried out and the time is recorded. The resulting data is the required machining time in CAM and real machining time in CNC machines. The variables of this research were the cutting method for roughing pockets (8 methods) and the machining time. The cutting methods for roughing are: zigzag, constant overlap spiral, parallel spiral, parallel spiral with clean corners, morph spiral, high speed, one way, and true spiral. The process of making pockets uses motion feeding (F = 100 μm / rev for sideways and 30 μm/rev for of in-feed), spindle rotation (S = 1200 rpm), and depth of cut (a = 2 mm). The software and machines used were Master CAM X7 software, and CNC Milling Feeler machines with the Mitsubishi M70 control system with operations by Fanuc standards [12][13]. The measuring instruments used were a built-in stopwatch, calipers accuracy 0.05 mm, micrometer accuracy 0.005 mm, and digital microscope 600x - 100x. Data analysis used a comparison of machining time in CAM software and the time required for machining on a CNC Milling machine. The machining process is said to be efficient if the time required is the least. Analysis of the wear of cutting tool that has occurred in the pocket making process is used to compare the size of the wear between the fastest and the longest machining time.

3. Result and Discussion
The machining process with simulation in CAM uses cutting conditions or machining parameters: F = 100 sideways motion and F = 30 in feed, S = 1200 rpm, and a cutting depth of 2 mm. The difference in
the machining process is the cutting method and the variation in the steps of the cutting tool (straight, helix, and ramping). There are 8 types of cutting methods that are programmed with MCAM. The results of time recording can be seen in table 1. An example of a CNC program produced for the zigzag straight in-feed cutting method is shown in Figure 1.

![Image toolpath with back plot and image simulation results with verify](image)

**Table 1.** Time records for 8 cutting methods and 3 types of in-feed using CAM

| No. | Cutting Methods       | Time 1 (in feed straight) | Time 2 (in feed helix) | Time 3 (in feed ramping) |
|-----|-----------------------|---------------------------|------------------------|--------------------------|
| 1   | Zigzag                | 00:41:53                  | 00:43:05               | 00:45:50                 |
| 2   | Constant overlap spiral | 00:42:02               | 00:44:51               | 00:47:47                 |
| 3   | Parallel Spiral       | 00:42:02                  | 00:44:51               | 00:47:47                 |
| 4   | Parallel spiral Clean corner | 00:45:09            | 00:47:57               | 00:50:53                 |
| 5   | Morph Spiral          | 00:56:00                  | 00:58:16               | 01:01:11                 |
| 6   | High Speed            | 00:42:32                  | 00:45:40               | 00:48:37                 |
| 7   | One way               | 00:49:35                  | 00:51:07               | 00:53:52                 |
| 8   | true spiral           | 00:57:03                  | 00:59:27               | 01:02:21                 |
Based on the data above, it is obtained a time comparison of 24 kinds of pocket machining processes. The fastest time is the zigzag cutting method with straight-in feed (41 minutes 53 seconds) and the longest time is the true spiral cutting method with lean in-feed. Based on this data, then the CNC program generated from the CAM is transferred to the CNC Milling machine to obtain machining time data on the actual machine. To measure the actual machining time, 5 cutting methods are taken on straight in-feed (fastest machining data) and 2 methods on ramping in-feed (longest machining data). Based on the data in table 2, it can be concluded that the machining time in the simulation using CAM is not different from using a CNC Milling machine.

| No | Cutting Methods                  | Time 1 (straight in-feed) | Time 3 (ramping in-feed) |
|----|----------------------------------|---------------------------|--------------------------|
| 1  | Zigzag                           | 00:42:00                  | -                        |
| 2  | Constant overlap spiral           | 00:42:00                  | -                        |
| 3  | Parallel Spiral                  | 00:42:00                  | -                        |
| 4  | Parallel spiral Clean corner     | 00:45:00                  | -                        |
| 5  | Morph Spiral                     | -                         | 01:01:00                 |
| 6  | High Speed                       | -                         | -                        |
| 7  | One way                          | 00:50:00                  | -                        |
| 8  | true spiral                      | -                         | 01:02:00                 |

The fastest pocket machining is the zigzag in-feed straight cutting method with a CAM simulation time of 41 minutes 53 seconds and a CNC milling machine time of 42 minutes. The longest pocket machining process is the one using true spiral in-feed cutting method with a time of 62 minutes 21 seconds in CAM simulation and 62 minutes in CNC milling machines. The image of the object resulting from 2 of the pocket machining process can be seen in figure 2.

Figure 2. Tool path for pocket machining with: (a) zigzag in feed straight cutting method (fastest time) and (b) true spiral in feed ramping cutting method (longest time)

After obtaining data on the fastest and longest machining time for the pocket making process, it is then observed the size and shape of the wear that occurs for both processes. The results of observations with a microscope obtained an overview of the wear of the cutting tool on the side of the main incision as shown in figure 3. The zigzag cutting method with straight in-feed causes wear on the end of the cutting tool and the center of the cutting tool. Comparison of the fastest and longest machining process wear from the figure shows that the cut tool wear for straight in-feed processes is greater than for ramping in-feed. From figure 3 it can be seen that the wear for the zigzag cutting method is greater than the true spiral cutting method. Based on this data, it can be concluded that the
optimization of the pocket making process in a CNC milling machine is calculated based on time and wear, if machining time is the goal, the zigzag cutting method is chosen and if the durability of the cutting tool is the goal, the true spiral cutting method is chosen.

![Picture of cutting tool wear comparison](image)

**Figure 3.** Comparison of cutting tool wear at the edge and center ends for the fastest machining time (a and b) and the longest machining time (c and d). The wear of (a) and (b) is bigger than (c) and (d)

4. Conclusion

Based on the research results, it is concluded that: the fastest time required for roughing the pocket size 80 mm x 80 mm x 6 mm was the zigzag cutting method with straight-in feed (41 minutes 46.68 seconds in the CAM simulation and 42 minutes in machining using a CNC Milling machine), and the longest time is the true spiral cutting method with a ramping in-feed (62 minutes 20.59 seconds in the CAM simulation and 62 minutes 21 seconds in the machining process using a CNC Milling machine). The optimization of the pocket making process in a CNC milling machine is calculated based on time and wear, if machining time is the goal, the zigzag cutting method is chosen and if the durability of the cutting tool is the goal, the true spiral cutting method is chosen.

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