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Tool Path Optimization and Cost Analysis for Manufacturing Process of Master Cylinder Piston of Motorcycle Brake

Anita Susilawati,[a,*] Nico Atmadio[a] and Heri Siswanto[a]

[a)] *Department of Mechanical Engineering, Universitas Riau, Indonesia*

*Corresponding author: anita.susilawati@unri.ac.id

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ABSTRACT

The tool path optimization is an important issue to get a low cost of manufacture parts using the CNC (Computer Numerical Control) machines. Programming to produce an optimum tool path for CNC machines is a key performance indicator for obtaining minimized machining time and good surface quality of parts. This paper purposes to optimized the CNC tool path generation programming and analyze the cost of manufacturing process of master cylinder piston of motorcycle brake. A Computer Aided Manufacturing (CAM) software was used to simulate an optimal tool path, which finding an efficient solution to shorten the cutting tool path generation. The simulation was performed on a roughing surface process of the work piece using 3 tool path schemes: longitudinal, diametrical and surface to parallel. The each scheme employed tool-path generation based on absolute and incremental reference methods of a CNC lathe machine. An analysis of simulation tool path time for each scheme and machining cost was investigated to get optimum and economies machining process. Hence, it was compared to actual time of machining process on CNC lathe in term of the manufacturing cost machining. The optimal processing time and the most economical cost for making a master cylinder piston of motorcycle brake was a parallel to surface scheme. Therefore, an optimization of tool path generation can minimize machining lead time, which lead to lowest cost of manufacturing parts, with keep maintain product quality.

KEY WORDS: *CAM software, CNC Lathe Machining, Cost analysis, Tool path optimization.*

1.0 INTRODUCTION

The manufacture of a part of the product is important to shorten the production time but the resulting part remains of good quality. Similarly, the short tool path time can reduce the manufacturing time, which also means improving machining efficiency. The tool path movement time of the CNC machine can be influenced the machining cost of manufacturing processes of parts [1,2].

(Pinar *et al*., 2005) [3] suggested to minimize machining process time can be done in two ways, that is minimize tool path and optimize cutting parameters. The minimize tool path can be used CAD/CAM systems. The CAD/CAM systems have ability to simulate and analyze tool paths generation for minimize machining time, which lead to lowest cost of manufacturing processes of parts [3,4]. Other hand, by CAD/CAM system can be performed the optimum process plan of tool path generation and CNC machining program that is have a less machining time in properly surface finish.

Many researchers conducted a study on minimizing time of tool path and optimizing manufacturing parts cost based CAD/CAM software and CNC machines. According to Umamaheswarareddy and Veeranjaneyulu (2014) [5] studied a simulation of tool path optimizing for generation of curved surfaces on machining process by CNC lathe turning. Zahida et al (2014) [6] studied a method to optimize roughing processes of manufacturing part in CNC machining by splitting approach of roughing orientations to minimize time and tool contact of parts machining. More, Patil and Pande (2002) [7] proposed to minimizing of tool path generation and parametric NC code by modeling sequencing of the features. Furthermore, [4] studied tool path generation and cost analysis of complex parts manufacturing for turn-mill machining based CAD/CAM system.

The tool path optimization is a shortest time to generate tool paths with less time of machining takes. The study of optimal tool paths planning is done for CAD/CAM/CNC for milling operation such as using method of iso-parametric [8], iso-planar [9,10] and iso-scallop [11-12]. Whilst, Morimoto *et al* (2012) [13] developed a method to optimize tool path layout of lathe turning machine by

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un-axisymmetric axis of curved surface. Types of tool path on the process of machining lathe are such as longitudinal, transversal/diametrical and parallel to surface [14]. Longitudinal tool path that is the movement of the carving path while doing machining process parallel to the axis of work piece. The transversal/diametrical tool path is perpendicular to the axis rotate the work piece. The parallel to surface tool path is a tool movement when performing the machining process following the surface shape of the work piece.

The study of tool path for lathe machines that affect machining time, such as depth of cut, scaling distance to the work piece (entry amount) on the Z axis, the finishing distance of the X axis (retract), and the angle of withdrawal (entry angle). While the study of cutting parameters can be described include cutting speed, feed rate, and depth of cut. Therefore, the minimizing tool path time and optimizing cutting parameters for the machining process of manufacture part can find the most efficient time in CNC machining process. Sub-sequence, by knowing the time efficient process may be lowest the cost of manufacture parts. Furthermore, it is necessary to investigate the optimal tool path generation, which minimizes the manufacturing process time and cost of parts-making operations. In this paper purposes to find an efficient solution to shorten the cutting tool path generation and cost analysis of manufacturing process of master cylinder piston of motorcycle brake based CAM software simulation and actual approach using the CNC lathe machine.

2.0 METHODOLOGY

2.1 Tool Path for NC Lathe Machine

The tool path is the steps of tool movement on the surface of the work piece while performing the machining process to produce the desired geometry of the work piece. In general, CNC machines usually have two movement modes, the linear interpolation mode, and the circular interpolation mode. The linear interpolation mode, the control moves the cutter from point to point on a straight line path. The circular interpolation mode, the control moves the cutter from point to point along a circular arc path.

The lathe operations include roughing, chamfering to remove sharp edges, grooving to produce recesses and shoulders, facing to finish the ends of a work piece, parting to cut off finished pieces from the stock, and thread chasing with tools to produce the desired thread form. The rough cutting tool is moved along parallel lines either perpendicular or parallel to the axis of rotation, from intersection to intersection either cutting metal or in air. The tool path should be traversed in an appropriate sequence to minimize in-productive motion. The total manufacturing time to machining part using CNC machine include tool path travel time, switch time that is the time to the cutting tool changing for next operation and the cutting time that is cutting tool moves with cutting speed in air or in work piece [4].

In this paper is conducted the steps methodology that cover the design of work piece geometry, tool-path design, tool-path simulation, and execution to the machine NC lathe. The tool path optimize on CNC lathe machining process is investigated only for roughing. The roughing part machining can be considered as one of the times consuming processes [6]. So, it is important to investigate the correlation between tool path variation to optimal optimum time in which the resulting product is still relatively smooth and the machining cost is relatively low.

In this paper, the method to optimize the CNC tool path generation based on several variations of simulation. The simulation of tool path was used the Master CAM V9 software by doing 3 schemes of tool path i.e. longitudinal, diametrical and parallel to surface (Figure 1). The design of the tool path on the master cylinder piston used absolute and increment reference systems for each scheme. Therefore, there was 6 variation of simulation to be investigated. In term of tool path simulation design was decided speed of spindle, feeding and the depth of cut that assumed the same values for all schemes.

Based simulation results are produced the tool path time, which used to compute and analyze the cost of manufacturing process of master cylinder piston of motorcycle brake. The calculations and analysis of the cost of production of master cylinder piston was conducted by comparing the time of 6 variations of simulation schemes.

Sequence, two of potentially schemes was executed to manufacture of work piece used the CNC lathe machine Hyundai-KIA SKT160A Fanuc Series 0i-TC. So, the real/actual time on the machining processes of work piece can be obtained. At the machine to test the effect of tool path time on cutting effect, spindle rotation and speed of movement of feed remains constant as well. That condition was arranged to get total time for each tool path variations development. Then, from 2 variations of tool path execution on the NC lathe machine was evaluated, which one most efficient and low machining cost. Furthermore, analyzing the cost and time was compared between actual cost of machining at the CNC lathe machine and simulation results.

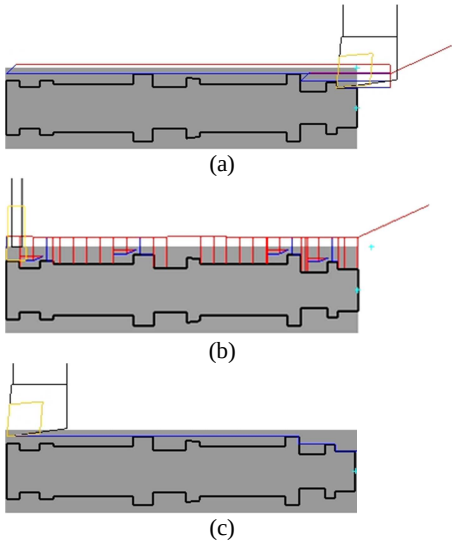

Figure 1: The tool path schemes (a) longitudinal, (b) diametrical and (c) parallel to surface

2.2 Manufacturing Cost

The manufacturing cost involves the cost of material, machining and assembly that is determined by the processing time for the cost rate calculation of the resource utilization [15]. Determining

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the cost of machining time is very influential on the product to be produced, the longer a product is made then the cost of production is high. The production time of part consist of cutting time (t_c), tool replacement time (t_{dcT}), non productive time (t_a) and machining rate time that are formulated as following [16]:

$$t_c = \frac{Lt}{Vf} \text{ (minutes)} \quad (1)$$

t_c = *cutting time,* L_t = *length of cut (mm),* V_f = *cutting velocity (mm/minutes).*

$$t_{dcT} = t_c \cdot \frac{tc}{T} \text{ (minutes/product)} \quad (2)$$

T= end process time (minutes)

Average machining time:

$$t_m = t_a + t_c + t_{dcT} \text{ (minutes)} \quad (3)$$

According to Rochim (1993), the manufacturing of part in production need costs such as: material cost (*CM*), price data and age of machine, machine rental fees (*Cf*), operator wages per machine (C_d), machine power costs (*Ci*), total machine operating cost (*Cj*) and total cost per product (*Cu*), which is formulated as following:

$$CM = CMO + CMI \text{ (Rp/piece)} \quad (4)$$

CM= material cost, CMO= purchase price, CMI=material freight cost (assumed in %).

$$Cf = \text{machine cost / (depreciation time x 365 days x 24 hours)} \quad (5)$$

$$Cd = \frac{regional\ minimum\ wage}{Hour\ of\ work\ x\ days\ per\ month} \text{ (Rp/hours)} \quad (6)$$

$$Ci = \text{machine nominal power x Price per Kwh} \quad (7)$$

$$Cj = Cf + Cd + Ci \text{ (Rp/Product)} \quad (8)$$

$$Cu = CM + Cj \text{ (Rp/Product)} \quad (9)$$

3.0 RESULT AND DISCUSSION

3.1 The Tool Path Generation

The CNC lathe machining process can performed the several types of cutting operations such as facing, roughing, grooving, chamfer, finishing and cut off. Based on these operations there are set of tool paths that affect the time of CNC machining process. In thus paper, the optimization tool path on CNC lathe machining process to make master cylinder piston of motorcycle brake was limited on roughing for analyzing. Tool path generation of roughing process was designed using Master CAM V9 software, which in the scheme of tool path that was longitudinal scheme, parallel to surface scheme and diametrical scheme with each scheme using absolute and increment programming system. The result of simulation of 6 variations for work piece can be seen in Figure 2-4.

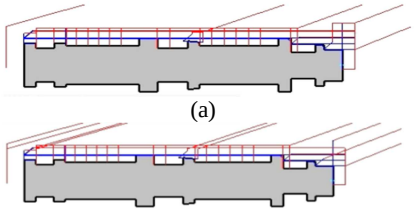

Figure 2: The tool path simulation for longitudinal scheme result: (a) used absolute and (b) incremental coordinate programming

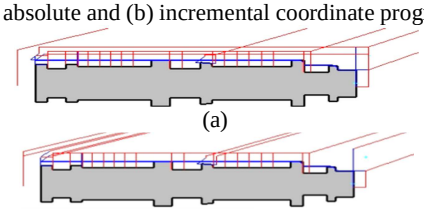

Figure 3: The tool path simulation for parallel to surface scheme result, (a) used absolute and (b) incremental coordinate programming

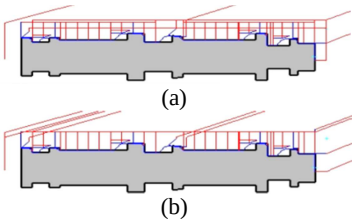

Figure 4: The tool path simulation for diametrical scheme result: (a) used absolute and (b) incremental coordinate programming

Simulation results between the absolute programming system and the increment programming system for each scheme resulted in the processing time for increment less then absolute. The difference of each scheme of the two programming system was found in the resulting NC code, which in the absolute programming point reference point based on the point 0 tools, while the system programming incremental, reference point based on the last point of the tool in each process.

Simulation results in the software produced the process time on longitudinal scheme, which 3 steps tool path generation for roughing process lengthwise for absolute of 14 minutes 45 seconds and increment of 14 minutes 5 seconds. The process time was generated on parallel to surface scheme, which 1 step tool path generation for roughing process for absolute of 14 minutes 30 seconds and increment of 13 minutes 48 seconds. The process time was generated on diametrical scheme for absolute of 17 minutes 39 seconds and increment of 17 minutes 12 seconds with rough work perpendicular to the axis of the work piece using a groove for each tool path. Then, 2 variation of six was executed in NC Machine Hyundai-KIA SKT160A Fanuc Series 0i-TC.

Program input method in the form of NC code manual that has been adjusted with the ability of this machine caused some mismatch between simulation design using software Master CAM V9 with the manufacture of direct work piece using CNC lathe machine. This can be seen from the cycle of tool path and on the process of workmanship that was in the process of completion in

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the form of grooving work. Some of these mismatches affect the outcome of the manufacturing process of the piston master cylinder, causing differences in some geometry shapes and work piece sizes.

Factors that affect the result of machining process between Master CAM V9 software and CNC lathe machine Hyundai-KIA SKT160A Fanuc Series 0i-TC may include: machine capability, NC-code, limited tools, clamping, and cutting force during machining and work piece geometry. The overall processing time of master cylinder piston manufacture in NC lathe machine using schematic tool path parallel to surface was 13 minutes 20 seconds. The total length of the process of the longitudinal tool path scheme was 14 minutes and 6 seconds. The result of making piston master cylinder for parallel to surface scheme on CNC lathe machine can be seen in Figure 5.

Figure 5: Result of the master cylinder piston used NC lathe machine for parallel to surface scheme

3.2 Manufacturing Cost of Master Cylinder Piston of Motorcycle Brake

Manufacturing costs calculations of the master cylinder piston of brake motor cycle are as follows:

Material Cost (CM)

The material used in the implementation of this research was the aluminum shaft Ø½"x 80mm. Aluminum material prices in the market based on kilogram was assumed Rp. 100.000,-/Kg. The aluminum material used in this study has a weighs of 27.5 grams. Based on Equation (4) was calculated the cost of materials as follows:

CM = CMO + CMI (assumed 10% CMO)
= (Price per gram x Material weight) + (10% CMO)
= Rp. 3,025.00/ stock

Price of CNC lathe machine Rp. 500,000,000 and the depreciation time of 10 years. Then, based on Equation (5) was obtained the machine rental fees (Cf) of Rp. 5,707.76/hour.

The machine operator wage was based regional minimum wage of cities such as Pekanbaru in 2017 was Rp. 2,352,570.00. Using Equation (6), the wage of the machine operator (C_d), was Rp. 13,336.87/hour.

The machine power costs (Ci) was calculated using the data of nominal power of 2.5 Kwh; price/Kwh of Rp. 961.00. Based Equation (7), Ci = Rp. 2,402.50.

Total cost of CNC lathe machine operation ($Cj_{theorist}$) was used Equation (7) that was Rp. 21,447.13 /hour = Rp. 357.452/minute. Whilst, Cj actual was the CNC lathe machine rent cost covering of Cf, Cd and Ci, which had been determined by the machine owner that was Rp. 100,000,00/hour or Rp. 1,667.00/ minute.

The total manufacturing cost of 6 variations of simulation is depicted in Table 1. The total cost per product (*Cu*) was computed using Equation (9), which implemented in two condition of total cost of CNC lathe machine operation ($Cj_{theorist}$) = Rp 357.4522/minutes and Cj actual = Rp. 1,667.00/ minute.

Table 1: The manufacturing cost of 6 variations of simulation based Master CAM V9

Simulation Schemes	Total machining time	Total cost per product (Cu) Rp/Pcs	
		(Cj theorist)	(Cj actual)
Longitudinal Absolute	14.75 minutes	8,297.42	27,613.25
Longitudinal Increment	14.08 minutes	8,057.93	26,496.36
parallel to surface Absolute	14.50 minutes	8,208.06	27,196.50
parallel to surface Increment	13.80 minutes	7,957.84	26,029.60
Diametrical Absolute	17.65 minutes	9,334.03	32,447.55
Diametrical Increment	17.20 minutes	9,173.18	31,697.40

Then, two of six schemes, which have minimum total machining time and lowest total cost per product, were picked to do machining at the CNC lathe machine Hyundai-KIA SKT160A Fanuc Series 0i-TC. The actual machining time to produce master cylinder piston of motorcycle brake at the CNC lathe and total cost per product are described in Table 2. Therefore based Table 1 and 2, the increment programming system is more optimal compared to the absolute programming system. The scheme of parallel to surface of increment has the optimal processing time and the most economical cost for making a master cylinder piston of motorcycle brake.

Table 2: Actual machining time on NC lathe machine and total cost per product

Machining work piece on CNC lathe schemes	Total machining time	Total cost per product (Cu) Rp/Pcs	
		(Cj theorist)	(Cj actual)
Longitudinal Increment	14.10 minutes	8,065.08	26,529.70
parallel to surface Increment	13.33 minutes	7,791.03	25,251.67

4.0 CONCLUSION

The purpose of this paper is to know the optimal path tool and economical cost of machining process of CNC lathe making of master cylinder piston of motorcycle brake by comparing machining process time generated based on Master CAM V9 software and making of work piece in CNC lathe machine.

Obtaining the optimal value of tool path time and manufacturing costs based on simulation in Master CAM V9 software was on parallel to surface Increment scheme. That is 13.80 minutes of total machining time, total cost per product theorist of Rp. 7,957.84 and actual of Rp. 26,029.60. Whilst, the scheme of parallel to surface to make work piece on CNC lathe machine awarded the optimal time was 13.33 minutes total cost

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per product theorist of Rp. 7,791.03 and actual of Rp. 25,251.67.

Careful selection of optimum tool path generation may affect to reduce time during machining of parts on CNC lathe machine that lead to get most economists manufacturing cost. The study on correlation between tool path generation and manufacturing cost optimization should also involve investigating the quality of work piece. That can be the future work for this paper.

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