Toolpath Strategy and Optimum Combination of Machining Parameter during Pocket Mill Process of Plastic Mold Steels Material

Y T Wibowo*, S Y Baskoro and V A T Manurung
Politeknik Manufaktur Astra,
Jl. Gaya Motor Raya No. 8, Sunter, Jakarta 14330, Indonesia

*Corresponding author: yohanes.trijoko@polman.astra.ac.id

Abstract. Plastic based products spread all over the world in many aspects of life. The ability to substitute other materials is getting stronger and wider. The use of plastic materials increases and become unavoidable. Plastic based mass production requires injection process as well mold. The milling process of plastic mold steel material was done using HSS End Mill cutting tool that is widely used in a small and medium enterprise for the reason of its ability to be resharpened and relatively inexpensive. Study on the effect of the geometry tool states that it has an important effect on the quality improvement. Cutting speed, feed rate, depth of cut and radii are input parameters beside to the tool path strategy. This paper aims to investigate input parameter and cutting tools behaviors within some different tool path strategy. For the reason of experiments efficiency Taguchi method and ANOVA were used. Response studied is surface roughness and cutting behaviors. By achieving the expected quality, no more additional process is required. Finally, the optimal combination of machining parameters will deliver the expected roughness and of course totally reduced cutting time. However actually, SMEs do not optimally use this data for cost reduction.

1. Introduction
Nowadays, in industrial world, the usage of plastic material has been unstoppable anymore. Plastic based good penetrates in so many aspects of life. This condition needs support from plastic injection process as well mold manufacturing. Plastic injection process is kind of mass production process while mold manufacturing process is make to order process. Make to order process is categorized as high cost process so needs good and mature planning, implementation, and quality checking to keep cost component on the right track.
In the mold manufacturing, as described at figure 1, defect was caused by machining process dominates times contribution. Managing machining process will deliver good quality aspect, beside prevents another unexpected additional process. Simply, additional process can be classified into two mains group which are additional process due to quality mismatch [1] and truly needed additional process. Additional process due to quality mismatch would be the focus of this discussion topic. Surface roughness within mold unit, has certain contribution related to mechanical performance and aesthetics performance. In mechanical performance aspect, it contributes to amount of needed plastic material while in aesthetic performance it is related to how easy the surface visible to the eye or how much the surface is exposed.

Milling machine is machine tools to form any shape which is non-cylindrical forms. In cutting process, milling machine has three main motions that are cutting tool spindle motion (spindle motion), cutting feed motion (feed motion) and depth of cutting motion (depth of cut motion). Combination among these three main motions will deliver expected surface quality, or in simple word would be stated that needed surface roughness would be achieved by combining these three motions in structured combination. The cutting tools selection should be taken to increase the efficiency [2]. The selected cutting tool material is High Speed Steel based because it is widely used and can easily be found in the market and Small Medium Enterprise [3]. The cutting tools are used to change the shape of material into particular desired shapes or certain products should ensure the continuity of the process of cutting/forming with optimum result and should have better properties comparing to the workpiece material [4].

In this paper, examination on surface roughness performed by inserting cutting tools radii aspect and tool path strategy (cutting pass model). Research topic to find out optimum result is still performed. Cutting tools makers have not enough ability to provide parameter formulation convincingly to achieve needed and expected result. The given parameter being provided by the makers are common use parameters such as spindle speed, feed rate, and depth of cut without being completed with value of surface roughness level from machining process as performed on current suggested value. There is information gap between supplied information from the maker and demand information from user.

The current condition drives some research to investigate the relationship among cutting tool spindle motion, feed rate, depth of cut, radii and cutting tool strategy (cutting pass) model. The most influencing factor in surface roughness machining is spindle rotation, cutting speed and then followed by depth of cut [5]. Other side informs that generally, by increasing cutting speed, the tool chip interface temperature will increase. It will affect surface roughness decreasing [6]. The cutting pass model especially Contour-in has simple path compared to zigzag strategy but has competitive point in cutting time reducing. By simplifying the tool path, the number of turning point and corner regions can be reduced. In turn, the effect of them such as high cutting temperature and excessive cutting force can be eliminated [7]. Contour-in cutting strategy is known also as helix cutting pass model. Within this
research, the effects of listed input parameters were expected to be known, so the result should be used as reference to achieve needed quality standard.

2. Methods
The method used in this research consists of some phases which are field observation, study of literature, and data collecting. Within this observation, some discussions are conducted to dig related information with this research. On the study of literature, searching and reviewing references are carried out to have broaden view from theoretical aspect and data collecting of research testing was conducted at Manufacturing 2 Laboratory of Politeknik Manufaktur Astra Jakarta with the supporting of industrial partner.

Taguchi method is method to improve product quality as well as the process with capability to suppress cost. Taguchi which has another name as Design of Experiments showed to be very robust method and allowed to improve the surface roughness, and for a specific range of parameters, the experimental result could identify the best cutting parameters [8]. This experiment was taken using method of Design of Experiments to not expend extra cost for the optimized result [9][10] and for confirming best possible of optimized result, ANOVA was chosen [11]. In this experiment, there are 3 parameters, and will be 3 levels for each parameter. Considering data adequacy and best possible result, Taguchi array that using is L$_{27}$ (3$^{13}$) orthogonal array. There will be 27 runs of experiments.

This research examination was taken by using computerized numerical controlled based machine which has certain reliability. This examination purpose is to produce surface roughness level from plastic mold steel material using specific machining process named pocket milling in certain area. The machine used for this research is Makino CNC Milling Machine S-33 series, as figured at figure 2.

![Makino CNC Milling Machine Series S-33](image)

**Figure 2.** Makino CNC Milling Machine Series S-33

The data collection was retrieved from surface roughness of workpiece. The used measuring tool was surface roughness measuring tools made by Tesa named Rugosurf 10. The displayed measured result is roughness average (Ra) because Ra is the most used common result representing surface roughness [14] as figured at figure 3.
In this research, there are three cutting pass models used. These models are three most common used by CADCAM user [12]. The first cutting pass model is zig or one way cutting pass as figured on figure 4. The grey curve represents shape of workpiece. The black curve simply represents basic shape of contour. The green line represents cutting motion and the red line represents non-cutting motion.

Figure 4. Zig or One Way Cutting Pass Model

Figure 5. Zig zag or Two Way Cutting Pass Model
The next two cutting passes are zig zag and Helix as figured on figure 5 and figure 6. On the both of next two cutting pass models, non-cutting toolpath (red line) is mostly eliminated for efficiency reason.

The data from this research and testing were summarised and presented in this paper. The data were discussed based on achieved result.

3. Results and discussion

3.1. Machinery Testing

Testing process initiated by specimen hardness testing to identify the homogeneity of testing specimen hardness. This testing was taken on four sides with specified two testing points on every side as listed on table 1.

| Surface | Testing Point | Hardness - HRc |
|---------|---------------|----------------|
| 1       | 1             | 36             |
|         | 2             | 37             |
| 2       | 1             | 36             |
|         | 2             | 36             |
| 3       | 1             | 37             |
|         | 2             | 36             |
| 4       | 1             | 36             |
|         | 2             | 36             |

Machining process that will produce surface roughness quality was carried out by implementing input parameters below such as using defined spindle speed, defined feed rate, defined depth of cut, and as well-defined cutting pass model. By implementing defined listed parameters, expected result should be achieved. The listed parameters are as informed on table 2.
Table 2. Machining Process Parameter

| No | Feed Rate (mm/min) | Depth of Cut (mm) | Cutting Mode |
|----|--------------------|------------------|--------------|
| 1  | 35                 | 0.07             | Zig          |
| 2  | 35                 | 0.07             | Zigzag       |
| 3  | 35                 | 0.07             | Helix        |
| 4  | 35                 | 0.14             | Zig          |
| 5  | 35                 | 0.14             | Zigzag       |
| 6  | 35                 | 0.14             | Helix        |
| 7  | 35                 | 0.20             | Zig          |
| 8  | 35                 | 0.20             | Helix        |
| 9  | 35                 | 0.20             | Zigzag       |
| 10 | 121                | 0.07             | Zig          |
| 11 | 121                | 0.07             | Zigzag       |
| 12 | 121                | 0.07             | Helix        |
| 13 | 121                | 0.14             | Zig          |
| 14 | 121                | 0.14             | Zigzag       |
| 15 | 121                | 0.14             | Helix        |
| 16 | 121                | 0.20             | Zig          |
| 17 | 121                | 0.20             | Zigzag       |
| 18 | 121                | 0.20             | Helix        |
| 19 | 277                | 0.07             | Zig          |
| 20 | 277                | 0.07             | Zigzag       |
| 21 | 277                | 0.07             | Helix        |
| 22 | 277                | 0.14             | Zig          |
| 23 | 277                | 0.14             | Zigzag       |
| 24 | 277                | 0.14             | Helix        |
| 25 | 277                | 0.20             | Zig          |
| 26 | 277                | 0.20             | Zigzag       |
| 27 | 277                | 0.20             | Helix        |

3.2. Examination Using Machining Process
In inform earlier, machining process with defined input parameters will generate surface roughness at work piece surface. The surface roughness was measured using Tesa Rugosurf 10. To prevent mistake on data collecting as well as make sure the result, every work piece would be measured three times. The result then logged and was compared with two other measurements. The maximum allowable disparity is 0.1 micron. In case of the range was exceeded, measuring process would be re take for conforming the result within disparity range.

Table 3 describes surface roughness result recorded by Tesa Rugosurf 10. Every workpiece was checked for 3 times. The displayed value was using micron unit. The specimen numbers represented no of testing workpiece.
Table 3. Surface Roughness Average (Ra) Measurement Result (in um)

| Specimen No | Check Poin 1 | Check Poin 2 | Check Poin 3 |
|-------------|--------------|--------------|--------------|
| 1           | 1.87         | 1.64         | 1.63         |
| 2           | 1.35         | 1.40         | 1.37         |
| 3           | 1.90         | 1.92         | 1.96         |
| 4           | 1.56         | 1.62         | 1.55         |
| 5           | 2.03         | 2.01         | 1.98         |
| 6           | 1.41         | 1.36         | 1.44         |
| 7           | 1.31         | 1.35         | 1.35         |
| 8           | 1.26         | 1.32         | 1.27         |
| 9           | 1.37         | 1.37         | 1.37         |
| 10          | 1.19         | 1.22         | 1.22         |
| 11          | 1.80         | 1.78         | 1.81         |
| 12          | 1.98         | 1.95         | 1.90         |
| 13          | 1.53         | 1.55         | 1.55         |
| 14          | 1.72         | 1.77         | 1.69         |
| 15          | 1.35         | 1.35         | 1.34         |
| 16          | 1.68         | 1.70         | 1.65         |
| 17          | 1.42         | 1.40         | 1.38         |
| 18          | 1.35         | 1.35         | 1.36         |
| 19          | 1.60         | 1.62         | 1.64         |
| 20          | 1.60         | 1.65         | 1.66         |
| 21          | 1.92         | 1.87         | 1.91         |
| 22          | 1.99         | 1.97         | 1.95         |
| 23          | 1.78         | 1.80         | 1.75         |
| 24          | 1.82         | 1.80         | 1.80         |
| 25          | 1.48         | 1.50         | 1.48         |
| 26          | 2.01         | 2.00         | 1.92         |
| 27          | 1.66         | 1.70         | 1.65         |

Table 4. Input Parameters and Average Ra Measurement Result (in um)

| Feed Rate (mm/min) | Ra (um) | Zig Cutting Pass Model | Zig Zag Cutting Pass Model | Helix Cutting Pass Model |
|--------------------|---------|------------------------|---------------------------|--------------------------|
|                    | 0.07    | 0.14                   | 0.29                      | 0.07                     | 0.14                   | 0.29                      |
| 35                 | 1.65    | 1.37                   | 1.93                      | 1.58                     | 2.01**                 | 1.40                      |
| 121                | 1.21*   | 1.80                   | 1.94                      | 1.54                     | 1.73                   | 1.35                      |
| 277                | 1.62    | 1.64                   | 1.90                      | 1.97                     | 1.78                   | 1.81                      |

Table 4 describes input parameter used for machining process, and the roughness level result as measured by Rugosurf 10. It also can be seen both of the best surface roughness level and the worst. The best had been achieved using the combination of input parameters as Zig cutting pass model, 121 mm/min as feed rate and 0.07 mm as depth of cut, while the worst is the combination of input parameters as Zigzag cutting pass, 35 mm/min as feed rate and 0.14 mm as depth of cut. The best surface roughness is 1.21 um (as indicated using *) and the worst is 2.01 um (as indicated using **).
4. Conclusion
Based on the results of testing that were completed with some mathematic calculations, it can be concluded that feed rate and depth of cut affect the level of surface roughness. Combined parameter of feed rate and depth of cut affects the level of surface roughness as well combined parameter of depth of cut and cutting pass model. Finally, interaction among some listed parameters, the lowest (finest) surface roughness level was achieved by combining of feed rate parameter at 121 mm/minutes, depth of cut parameter at 0.07 mm, and the cutting pass model is Zig even though on previous conclusion clearly informed that cutting pass model does not affect the level of surface roughness. The best (finest) achieved surface roughness level is that Roughness Average (Ra) 1.21 um which is equivalent to surface roughness level N7. On this experiment, optimum combination in producing the best surface roughness is described above that implemented on cutting process using zig toolpath strategy.

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