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Effects of Depth of Cut on Cylindrical Milling Process in Steel Casting: A Numerical Study

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Abstract : The complexity of the milling process has led us to study different parameters, among which are the cutting speed, feed speed, chip volume, cutting time and associated costs, which are the focus of this study. For this purpose, a calculation algorithm was designed in which fixed parameters were left and the cutting depth was varied from 2 to 8 mm. This resulted in an increase in process times and costs, which was expected due to the removal of more material and a negative impact on the surface finish of the part.
Keywords : Milling, chip, speed, cutting, depth.

1. Introduction

The milling process is one of the most widely used methods of forming with chip removal today. For this reason, they have been strongly studied and have been looking for opportunities for improvement for a long time (1). These investigations have analyzed factors such as dimensional and geometrical defects since they seriously affect the quality of chip removal processes on CNC machines. To avoid these defects, the position error of the tool tip is predicted using finite elements (2). Another application of finite elements was used to identify the influence of thermoelastic deformations of the workpiece during the milling process (3).

Similarly, these studies presented a model for predicting the cutting force deduced for the milling process of circular ends (4), in which the effects of the curvature of the tool path on the thickness of the chip are analyzed, as well as the angles of entry and exit. Similarly, a dynamic model was constructed for a new workpiece clamping system to analyze workpiece deformation to achieve higher surface quality (5).

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On the other hand, the mircrofesados has been studied. because this method is capable of machining complex structures. To predict the overall three-dimensional components of shear force in these processes, a force prediction model has been proposed and tested with experimental measurements (6). In addition, given the great importance of precision in micro milling due to the small tolerances involved, a real-time monitoring system is proposed to predict surface roughness with an estimation error of 9.5%, using the vibration signal emitted during the milling process (7).

We also sought to predict shear force, surface finish and power utilization using a neural inverse propagation network approach based on three process parameters, such as spindle speed, feed rate and depth of cut (8). In the same way, we searched for the discreet optimal control method to suppress the vibration of the milling process, for which we used the delayed-state feedback control to efficiently suppress the vibration in the process (9). Additionally, the effect of speed when machining with a relatively large blade at low cutting speeds was analyzed based on simulation and experimental studies and concluded that spindle dynamics should be carefully evaluated and chosen when testing the machinability of metals (10).

Finally, the contribution of this study is directed towards the analysis of the variation of output parameters in a cylindrical machining process when changing the cutting depth in a steel foundry. These parameters are cutting speed, feed rate, chip volume, cutting time and associated costs. This in order to find the optimum point for a cost effective milling process.

2. Materials and Methods

Next, a clear description of the process studied is presented, where each one of the objects that compose them can be observed and the variation of the conditions in which it will be studied will be detailed, in the same way the fundamental equations that govern the described process will be shown.

2.1 Processdescription

For this study, cylindrical milling was used as shown in **Error! Reference source not found.**. Where is the working material (1) which is a steel casting, and the cutter (2) which removes the material as it rotates over the working material.

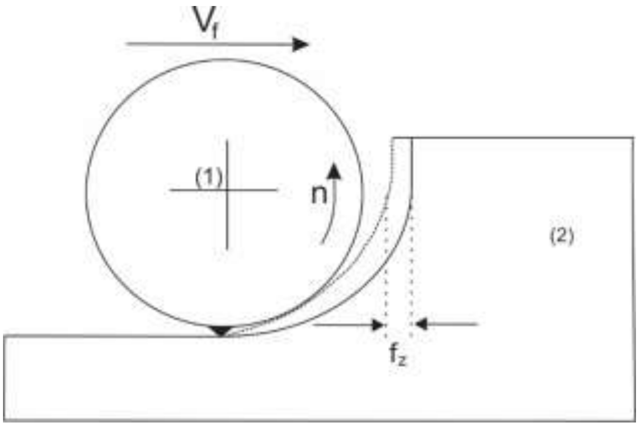

Figure 1. Process Diagram

In the study the parameters shown in table 1 were left fixed and the depth of cut was varied from 2 to 8 mm and for this variation an algorithm was used, which was captured in a spreadsheet which gave us the analyzed results.

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Table 1. Parameters

Parameter	Value
Length (cm)	50
Thickness (cm)	9,2
Cutter diameter (cm)	12,5
Cost of tool (US$/h)	36
Tool carrier cost (US$/h)	55
Number plates	22
Non productive time (s)	20
Machine and operator cost (US$/h)	32
Number of pieces	400
Feed (mm/tooth)	0,006

2.2 Fundamental equations

The mathematical equations of manufacturing processes used in this study are widely used and available in the literature (11). This shows that by means of equation 1 the cutting speed can be calculated in the cylindrical milling operation

$$V_c = \frac{(\pi)(D)(n)}{1000}. \qquad (1)$$

Likewise, the distance travelled by the tool against the part per time unit is the feedrate of the tool, which is calculated with equation 2 as

$$V_f = (f_z)(n)(z). \qquad (2)$$

By having this and clearing up the feed per tooth (f_z) can be achieved as shown in equation 3 as

$$f_z = \frac{V_f}{(n)(z)}. \qquad (3)$$

Another important parameter to evaluate how much money is lost per unusedmaterial is the chip volume calculated with equation 4 where p is the part width

$$\mathrm{V} = \frac{(a)\,(f_z)(p)\,V_f}{1000}. \qquad (4)$$

In order to reduce production costs in machining, some methods have been developed, including the least costly. This method seeks the right operating conditions for the production of parts to be achieved with a minimum of operating costs. One operating condition is cutting speed is calculated with equation 5

$$V_{mc} = V_1\left(\frac{n}{1-n}\cdot\frac{X}{(X t_{rf} + Y)}\right)^{n}. \qquad (5)$$

In the above equation X is the operator and machine costs per unit time, Y is the cost per sharpening,V_1speed limit and$t_{rf}$is is the tool reset time. Another calculated parameter is the tool life, which is calculated replacing the equation 5 in the Taylor line equation thus achieving equation 6

$$T_{me} = \frac{1-n}{n} \cdot \frac{X t_{rf} + Y}{X} . \qquad (6)$$

Similarly, there are methods to increase production in machining and this work will focus on maximum production. The machining speed and minimum production time are also calculated for this with equation 7 and 8 respectively

$$V_{mp} = V_1 \cdot [n/(1-n) \cdot T_1 / t_{rf}\ ]^n \qquad (7)$$

$$T_{mp} = (1-n)/n \cdot t_{rf}\ . \qquad (8)$$

3. Results and Discussion

With the variation of the cutting depth the first parameters that were analyzed were the feed rate, the volume of chips produced and the cutting time. Figure 2 shows the behavior of these parameters as the cutting depth increases.

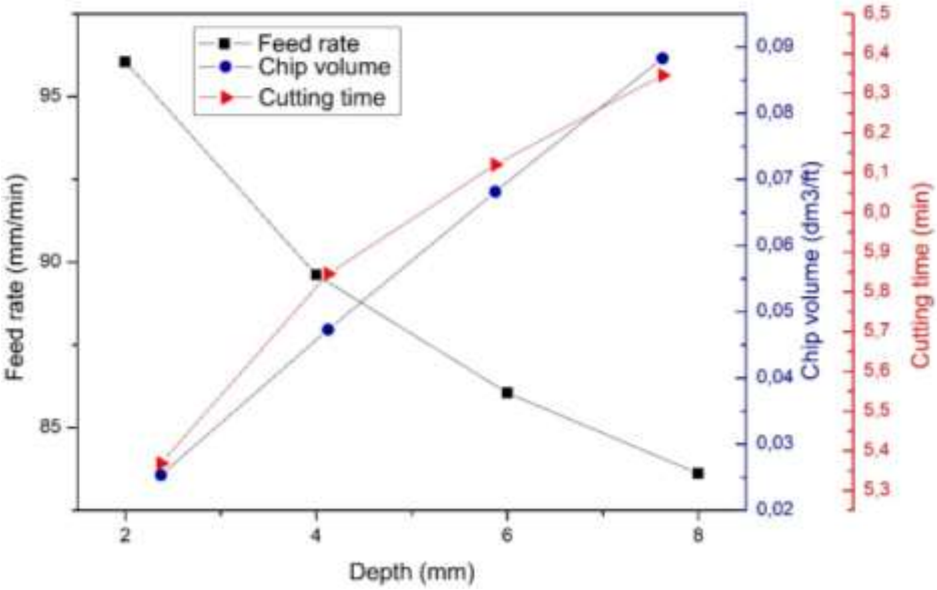

Figure 2. Feed rate, chip volume and cutting time

For the feed rate the increase in the cutting depth generates a decrease in the feed rate, this is due to the fact that starting more material per pass requires more power which induces a decrease in the speed. On the other hand, the chip volume is increased as expected by increasing the cutting depth. Finally, this figure also shows an increase in the cutting time, an increase presented by the decrease in the feed rate.

Likewise, the cutting speed and RPM were studied and their results are shown in figure 3. Here it is observed that as the depth increases the cutting speed decreases, when the cutting speed goes from a depth of 2 to 8 mm, the cutting speed decreases by 12.94%, being a significant decrease, giving the highest speed drop in the variation from 2 to 4 mm, reaching 6.69%.

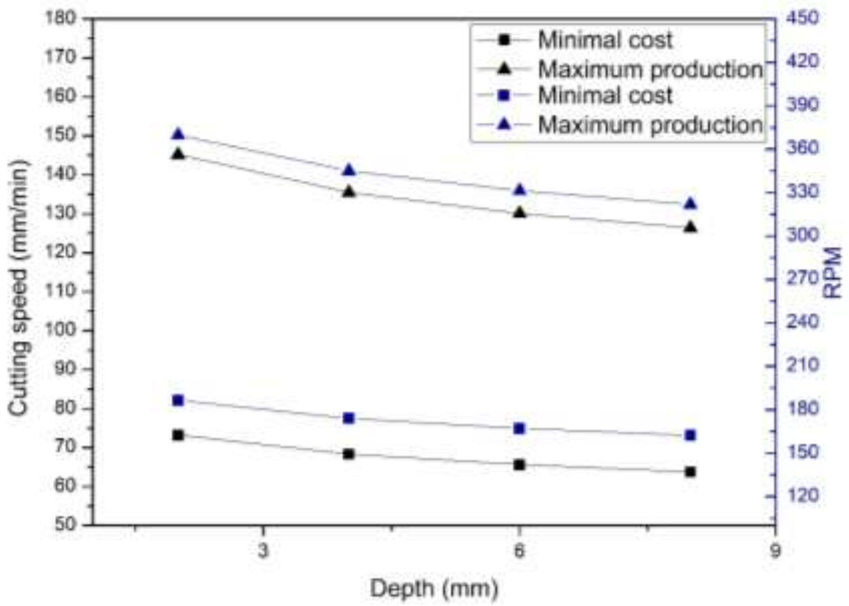

Figure 3. Cutting speed and RPM for each tooth feed rate

Likewise, the RPMs have the same behavior in terms of percentages of fall when the depth varies. In both cases these variations have the same percentage either for the minimum production cost or for the maximum production, the difference is that to reach the minimum costs the cutting speed as well as the RPM are 49.55% lower than the values reached by the maximum production.

Finally, the consequences of depth variation on both cutting and tool sharpening costs were reviewed. Figure 4 shows the increase in tool cost due to the fact that increasing the cutting depth the tool edge is more easily lost, which means that the tool has to be sharpened more constantly, which is an important cause of the increase in tool costs.

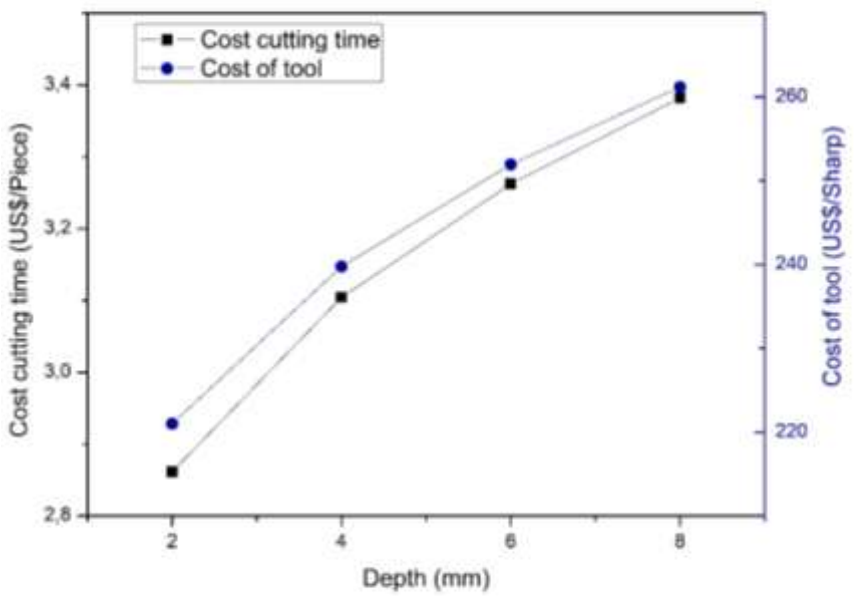

Figure 4. Cutting and tooling time costs

The cost of cutting time is increased by the increased power requirement of the process as the cutting depth increases. To achieve this power required by the process, the number of RPMs is reduced, which lowers the cutting speed and increases the cutting time, thus increasing the costs.

4. Conclusion

Finally this study helped us to conclude that it is not very appropriate to increase the cutting depth unless it is absolutely necessary. This increases the machining process times. Likewise, this increase leads to an increase in cutting times and thus an increase in costs for this time. Likewise, the cost of the tool increases due to the increase in the number of times it is sharpened. In addition, a greater cutting depth gives us a poor surface finish, which is undesirable when machining a precision part.

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