A NEW MACHINING COST CALCULATOR (MC^2)

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INTRODUCTION

A common objective in manufacturing research is to increase productivity and efficiency while decreasing cost. In machining, dramatic gains in productivity were realized with the introduction of computer numerically controlled (CNC) machines. Further advances in computer technology led to programs that could provide three-dimensional renderings of parts before they were machined. To complement these programs and to aid in the generation of the required code for CNC machine tools, computer aided manufacturing (CAM) software was developed. This software also supplies visualization of the machining steps and calculation of the time required to complete the CNC program. With this time estimation, users are able to select efficient strategies that reduced cost by reducing machining time. However, this time is calculated without considering the time required to accelerate to the desired feed rate and decelerate to a stop.

To provide a more accurate time estimate and, ultimately, improved cost prediction, a Matlab-based graphical user interface (GUI), entitled the Machining Cost Calculator (MC^2), was developed that considers the acceleration and deceleration times in the calculations. The GUI consists of a user-selected internal pocket shapes and machining strategies.

TIME CALCULATIONS

Traditional time calculations in CAM software are completed by dividing the move distance by the user-selected feed rate. In the MC^2 time calculation there are multiple steps that are followed to respect the actual acceleration/ deceleration values. First, it must be determined over what distance the acceleration will occur. Equations 1 and 2 are used to calculate this distance.

$$t = \frac{v_1 - v_0}{a} \tag{1}$$

$$d_1 = \frac{1}{2}at^2 + v_0 t + d_0 \tag{2}$$

In Eq. 1 v_1 is the commanded feed rate, v_0 is the initial feed rate, a is the machine axis acceleration, and t is the time required to reach the commanded feed rate. In Eq. 2 d_1 is the distance to reach constant velocity and d_0 is the starting position. For all line segments within the part path, it is assumed that the starting velocity and position are zero.

Once d_1 is calculated, it is compared to the commanded distance. If d_1 is greater than half of the total move distance, then the tool does not reach the desired feed rate. In this case, the time to move the required distance is calculated using Eq. 3,

$$t = \frac{d}{a} \tag{3}$$

where d is half the commanded distance. However, if the distance required to accelerate to the desired feed rate is less than half the total move distance, then the commanded feed rate is reached for only a portion of the move. In this case, the distance over which the commanded feed rate occurs and the corresponding time must be calculated. To calculate the distance of the full feed rate portion of the move, twice the distance to accelerate to the feed rate is subtracted from the total move distance. The result is the distance over which the tool will travel at the commanded feed rate. Then, this distance is divided by the feed rate to calculate the associated travel time. With this value, the total move time is calculated by summing the full feed rate time with twice the time required to accelerate to the feed rate. The time to accelerate to the feed rate is doubled to account for the acceleration and deceleration time, where acceleration and deceleration times were assumed to be equal. Finally, once all of the times to complete the commanded pocket path are calculated, these times are summed to determine the total time, t_m, required to machine the pocket given the user-selected machining conditions.

COST CALCULATION

The final output from the program uses the calculated machining time to compute the machining cost based on user inputs. Equation 4 describes the cost equation. The cost per part, C_p (\$), is calculated using the machining time, t_m (min), and user input values for the machining rate, r_m (\$/min), the tool change time t_{tch} (min), the cost per tool, C_t (\$), and the tool life, T (min), for the selected cutting conditions.

$$C_p = t_m r_m + \frac{(t_{tch} r_m + C_t) t_m}{T} \qquad (4)$$

Table 1. Calculated and actual times for the test pocket when including acceleration.

Strategy	MC^2 time (sec)	Actual time (sec)	% difference
1000 mm/min			
Straight line	453	452	0.22
Zig-zag	325	327	0.61
Spiral-in	231	233	0.86
3000 mm/min			
Straight line	195	210	7.14
Zig-zag	118	128	7.81
Spiral-in	84	89	5.62

VALIDATION

To validate the program a set of tests were completed to compare the calculated machining time (with and without considering acceleration) to the actual time required to machine a pocket on a Mikron UCP-600 Vario CNC machining center. The selected internal pocket 50 mm square and 10 mm deep. The tool was a 10 mm, four-flute square endmill. The spindle speed was 5000 rpm and two feed per tooth values of 0.1 mm/tooth and 0.3 mm/tooth were applied. The rapid plane height was specified at 10 mm above the part surface and the rapid velocity was 0.33 m/s. Average acceleration values of 1.08 m/s^2 and 1.53 m/s^2 were measured independently using an accelerometer and used for the two feed rates of 1000 mm/min and 3000 mm/min, respectively. Tables 1 and 2 display the results and provide a percent difference to show the improvement in the accuracy of the time estimation using the acceleration-based approach.

Table 2. Calculated and actual times for the test pocket when acceleration is not considered.

Strategy	Infinite acceleration time (sec)	Actual time (sec)	% difference
1000 mm/min			
Straight line	393	452	13.1
Zig-zag	317	327	3.07
Spiral-in	225	233	3.43
3000 mm/min			
Straight line	143	210	37.9
Zig-zag	106	128	17.2
Spiral-in	75	89	15.7

Based on these results, a clear improvement is seen when including acceleration in the machining time calculation. By more accurately calculating this time, a more accurate cost estimate can be made enabling manufacturers to better predict part costs.

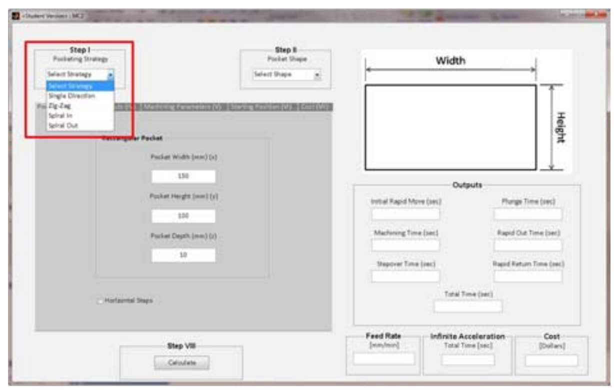

Figure 1. Pocketing strategy selection.

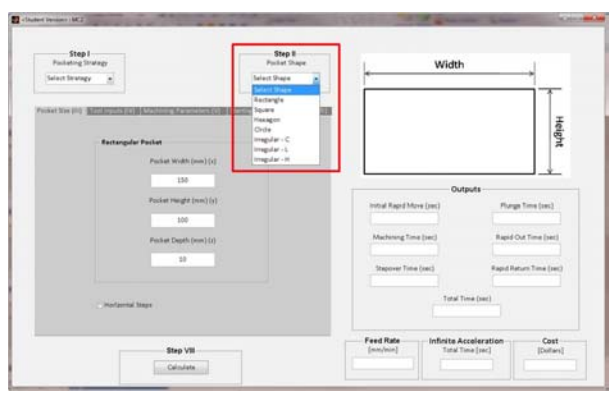

Figure 2. Pocket shape selection.

MC^2 DEMONSTRATION

In this section, examples are provided to demonstrate the MC^2 GUI interface, including the inputs and outputs. MC^2 enables the user to input the required information and select the pocket geometry and strategy. Based on the user input, the machining time and cost is estimated. The first input, labeled Step I, appears as a drop down menu. This menu enables the user to select from the four machining strategies, shown in the red box in Fig. 1 (straight line, zig-zag, spiral-in, and spiral-out). The second drop down menu allows one of seven pocket shapes to be selected (rectangle, square, circle, hexagon, H, C, and L). The menu is labeled Step II and is identified by the box in Fig. 2.

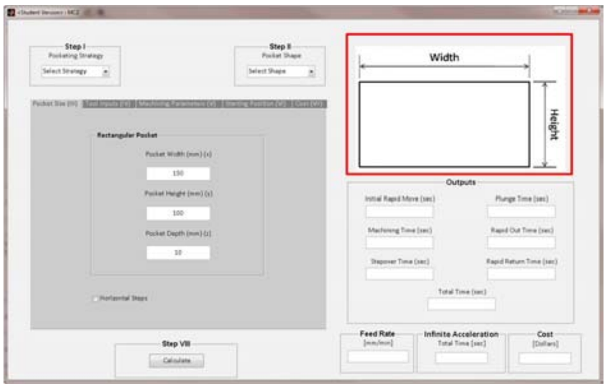

Figure 3. Pocket shape graphic.

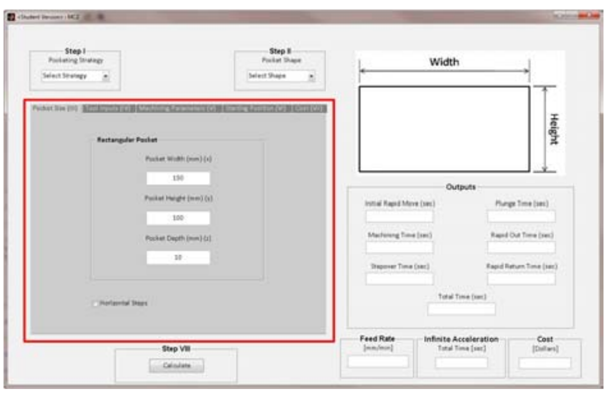

Figure 4. Pocket size inputs.

Based on the selected pocket shape, the upper right figure switches the image to show the dimensions required to fully define the pocket. Figure 3 identifies this image. The third user input is the first tab on the dark grey panel and it changes its display to enable the proper inputs for the pocket shape depicted in Fig. 3. Figure 4 displays the tab, labeled Pocket Size (III), for the rectangular pocket in this example. The part path for the selected pocket is exhibited in a separate figure window. An example for the rectangular pocket to be machined using a spiral-in strategy is provided in Fig. 5.

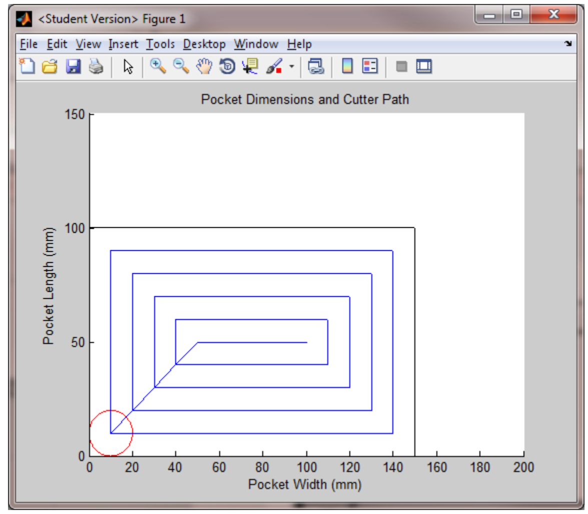

Figure 5. Path for a rectangular pocket with a spiral-in strategy.

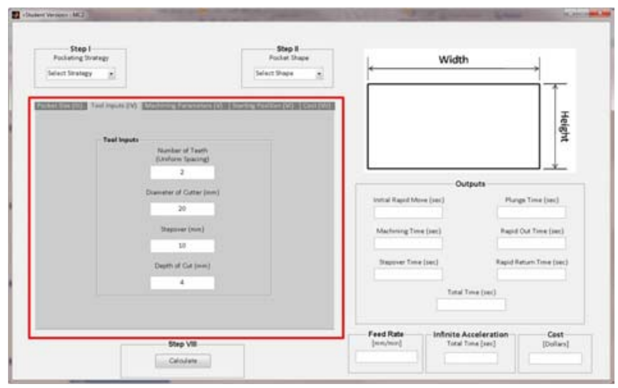

Figure 6. Tool definition in Step IV.

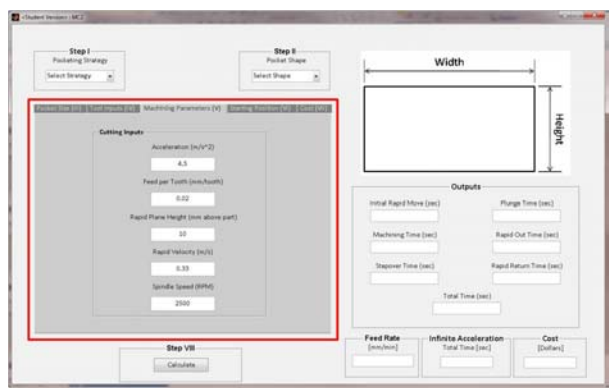

Figure 7. Machining parameters for Step V.

Tool Inputs (IV) is the fourth step in the program. This second tab requires the user to define the number of teeth on the tool, the diameter of the cutter, the stepover, and (axial) depth of cut. All the inputs are labeled with their accompanying units; see Fig. 6. The Machining Parameters (V) tab is used to input additional specifications for the operation, including the machine axis acceleration, the feed per tooth, the rapid plane height, the rapid velocity, and the commanded spindle speed. Figure 7 shows this third tab with the default values for each input. The sixth step requests the location initial tool location before it approaches the part to begin machining. This fourth tab is labeled Starting Position (VI) and is displayed in Fig. 8.

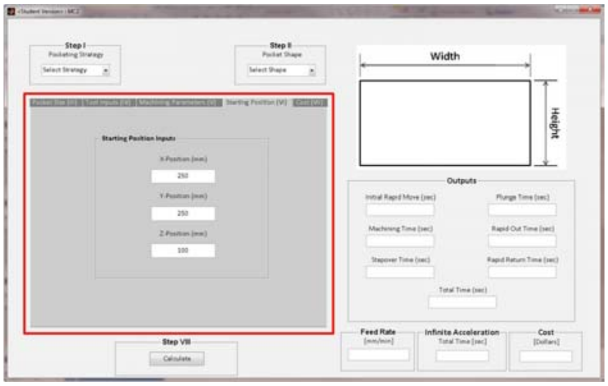

Figure 8. Starting position entry (Step VI).

The right-most tab in the dark gray panel requests the cost inputs, including the tool change time, the expected tool life, the machining rate, and the cost per tool. These are used in the total machining cost estimate; see Fig. 9. Finally, the Calculate button (Fig. 10) prompts the program to calculate the machining times and cost based upon the user inputs identified in the previous steps.

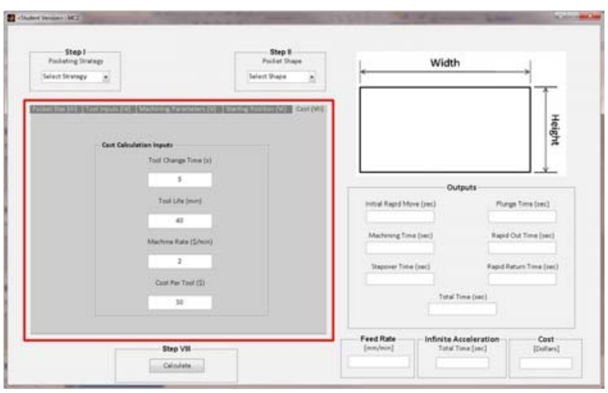

Figure 9. Cost inputs (Step VII).

The outputs for the selected conditions are displayed in the lower right panel. The output times include the cutting and non-cutting times along with the total time of the operation. The output times depend on the selected machining strategy. Three other outputs are also displayed. The first is the feed rate, which is calculated from the user defined feed per tooth, spindle speed, and number of teeth on the cutting tool. The second is the infinite acceleration time, or the time it would take to machine the pocket if the acceleration and deceleration times were neglected. Finally, the cost for the selected pocketing operation is displayed; see Fig. 11.

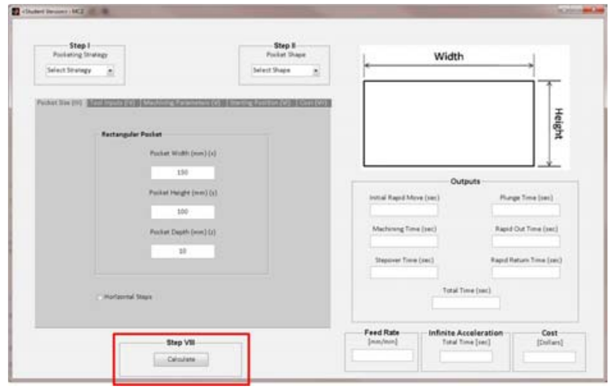

Figure 10. Calculate button (Step VIII).

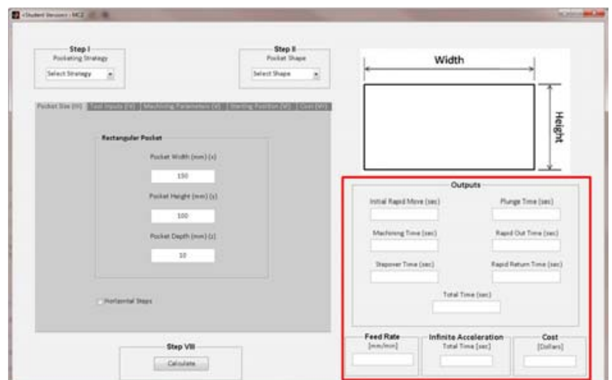

Figure 11. Outputs supplied by MC^2.

CONCLUSIONS

The Machining Cost Calculator (MC^2) was described. It considers acceleration in time and cost calculations for various pocket geometries and machining strategies.

ACKNOWLEDGEMENTS

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