NC Milling Programs Optimization with 3D Geometric Modeling

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Abstract

This paper will present a method for NC control programs optimization (milling) using 3D geometric modeling. Optimization improves surface quality and accuracy. Calculation of material removal rate is described, structure of the proposed CAM system is given, and an example of an optimized NC program is discussed.

Keywords:CAM, NC, optimization, milling, modeling.

1. INTRODUCTION

In the field of manufacturing it is commonly accepted that milling is the most inaccurate method among all cutting treatments. Primarily, the reason lies in the appearance of oscillations in the Machine Tool→Spindle→Cutter system while removing a non-uniform machining allowance. These factors all lead to cutting force oscillations, and damages the surface quality of the product. Non-uniformity of the allowance comes from either the part's geometry, or it appears when a part of a complex shape is treated for the second time (e.g. extra allowance is removed for maintenance/repair purposes). Additonally, as the material removal rate varies, the force that moves the spindle away from the workpiece varies as well. Due to the spindle's modulus of elasticity, its oscillating movement raises the surface's roughness and expands the tolerances beyond the preset values.

2. PROBLEM STATEMENT

It is possible by decreasing the RPM, and increasing the feed rate to smooth out these spindle oscillations. However such a variations can create a big problem should the part be of a complicated shape. The purpose of the present research is the development of a CAM system for optimizing NC programs. This optimization is aimed at cutting force's stabilization and improving the quality of surfaces produced by milling. Should we know the material removal rate for each frame of the program we would be able to vary the feed rate in order to keep the cutting force within a narrow range (allowing ±20% deviations at worst). This would provide equal surface quality along the entire part regardless of the complexity of its shape. Note that the existing CAM systems (MasterCAM, DelCAM, Gemma) do not perform this kind of optimization. The latest release of MasterCAM only varies the feed rate while the cutter goes in and out the workpiece. DelCAM's advertises an optimization module at a prohibitive price without revealing its basic principles. We have been unable to see it working at several major software exhibitions.

3. NC PROGRAMS OPTIMIZATION

In the course of our investigations, we have developed a Pc-based CAE system for NC programs optimization. The machine under consideration is a 3-axis milling NC machine. The system consists of the following modules:

- data acquisition module;
- workpiece and tool models generation module;
- syntax analysis module;
- implementation of machining commands;
- implementation of linear interpolation;
- implementation of circular interpolation;
- cutting process simulation module;
- material removal rate measurement module;
- program verification module;
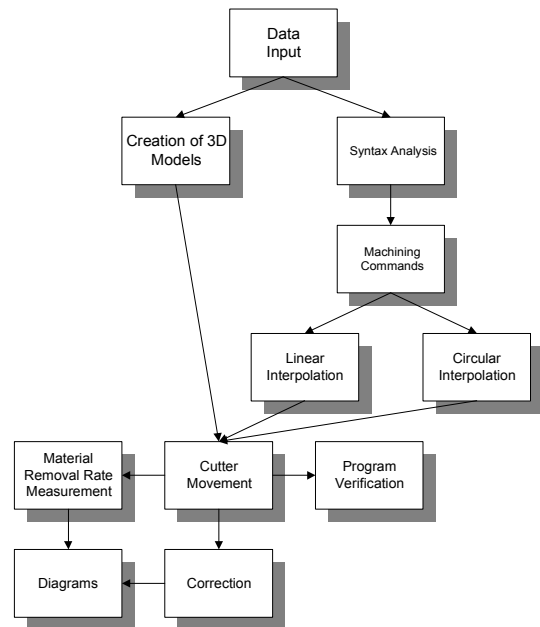- output module.

The system's structure is shown in Figure1:

Figure 1. The structure of the system.

The proposed CAM system has been implemented as a VisualLISP application for AutoCAD2002. The major reason

for choosing AutoCAD has been, not only its extreme popularity, but also the fact that it's actually the only 3D system that features its own built-in programming environment. As our experience shows developing applications with VisualBASIC, or API functions for other CAD systems (SolidWorks, Compas), is next to impossible for the reasons of complexity and unreliability.

4. DATA INPUT

As the system is run, the first step is to:

a.   provide data on the workpiece and cutter's geometry and position,
b.   to load the NC program,
c.   to specify the simulation's accuracy and other parameters (frame-by-frame tracing, trajectory displaying etc.)
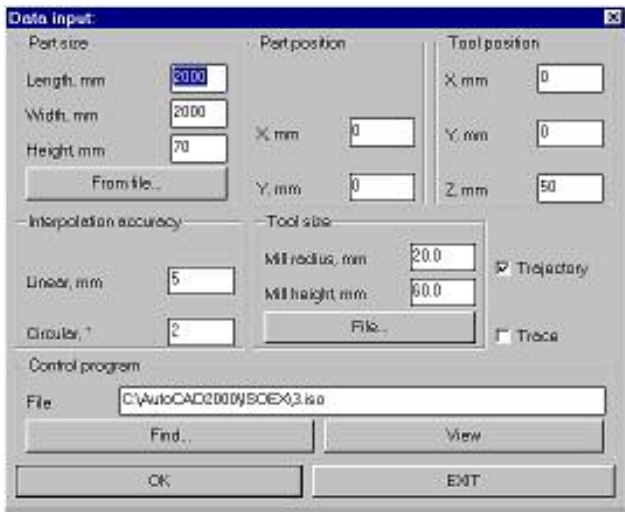
The main dialog window can be seen at Figure 2:

Figure 2. The main dialog window.

Following the identification of the parameters, the syntax analysis module performs an analysis of the loaded NC program,
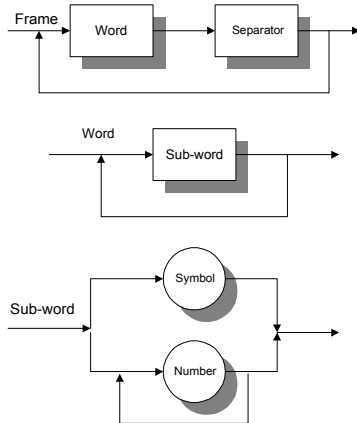

Figure 3. Syntax diagrams for the ISO7bit language.

which is represented as ISO7bit codes. The syntax analysis is based on the syntax diagrams for the ISO7bit languages. The program is divided into frames; each frame in its turn is divided into words, symbols and numbers. The diagrams are represented at Figure 3. The result of the syntax analysis is an internal representation of the program suitable for the simulation.

5. MILLING PROCESS SIMULATION

In the course of the simulation, a 3D solid model of the cutter moves according the program's commands while the appropriate volume of material is subtracted from the solid model of the workpiece. This portion of the program will also determine the volume of the material removed at each step and save it as digital information in a file. The simulation generates a result displayed as a visual representation of the milling process as shown in Figure 4.
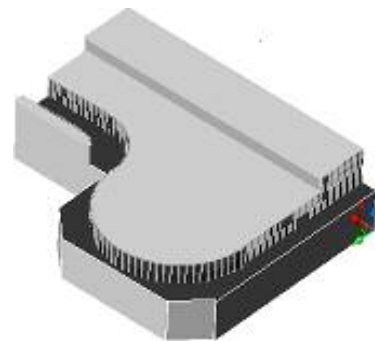

Figure 4. A solid model of a part generated in the course of optimization.

The cutter's movement can be divided into two categories: rectilinear, and circular. During its rectilinear movement, the cutter moves along step by step equal to the linear interpolation accuracy. It should be small enough to create a smooth surface after numerous 3D subtractions. On the other hand, the smaller the step the longer the simulation. For the circular interpolation it is necessary to specify an angular step a. It can be calculated as

$$a = \frac{\pi \cdot x}{180} \text{ ,} \tag{1}$$

where x is the interpolation accuracy specified by the user. In circular interpolation there exists a clear distinction between a clockwise and a counterclockwise movement. The movement's direction is set by the G code.

6. MATERIAL REMOVAL RATE MEASUREMENT

The most important feature of this system is its ability to effect a detection of the volume of material removed at any specified moment. Before the cutter's solid model is subtracted from the workpiece an intersection operation is performed. The resulting body's volume is equal to the volume of material removed. The volume may again be saved to a file for further generation of a

diagram "Material Removal Rate vs Time". The AutoCAD implementation of this algorithm includes the following steps:

1. Save the present state of the 3D scene (UNDO/MARK command)
2. Make a copy of the cutter's model.
3. Execute the INTERSECT command with the models of the cutter and the workpiece.
4. Execute the MASSPROP command to determine the volume of the last solid.
5. Save the volume to file.
6. Roll back to the previously saved scene's state (UNDO/BACK).

You should particularly note that exact timing is vitally important since the ultimate result is a MRR v. time diagram. Duration of each frame can be obtained from the specified feed rate [mm/min], and the trajectory's length. These calculations allow saving data at certain intervals, e.g. every second.

7. EXAMPLE OF OPTIMIZATION

A test run of the system has produced the material removal rate v. time diagram represented in Figure 7 (diagram 1).
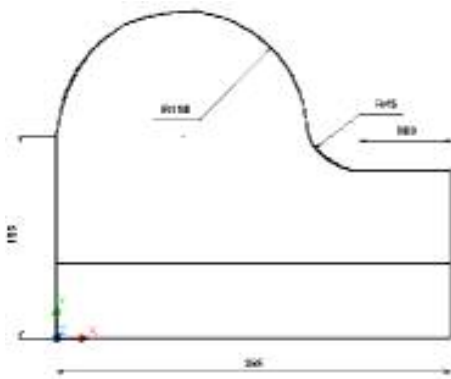
Figure 5. Part for optimization.

```
N001 G17
N002 F60 G91 G01 Z-150 M03
N003 Y+195
N004 G02 X+220 Y0 I+110 J0
N005 G03 X+45 Y-45 I+45 J0
N007 G01 X+100
```

Figure 6. Original NC program (ISO codes)
for the part shown in Figure 5.

The diagram's peaks correlate to the initial penetration of the cutter into the workpiece and the treatment of the circular segment. Speaking mathematically, the diagram's first derivative, which represents the velocity of its variation with time, is not "flat" enough. A slight modification of the control program (see Figure 8) slows down the feed rate at the most difficult points. The resulting diagram 2 (Figure 7) is obviously

better. Sharp peaks have been removed and the entire diagram has been smoothed. In short, the data indicates that the cutting force would be more stable, and less spindle oscillations would occur.
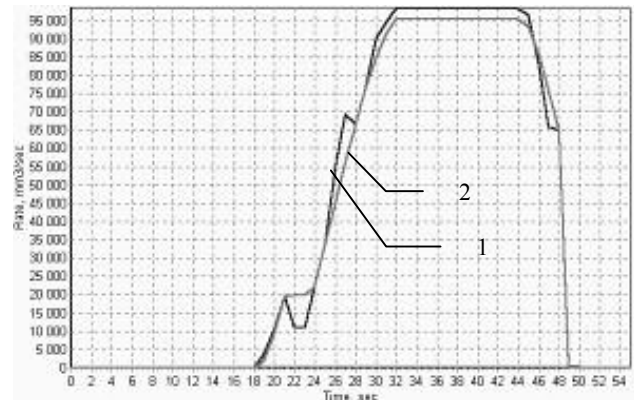
Figure 7. A MRR vs time diagram. Diagram 1 is the MRR before optimization. Note the peaks and the general roughness of the diagram. Diagram 2 is the MRR after optimization.

An important question is now presented: "How often may we change the feed rate?" Frequent variations could cause impact loads in the feed drive and damage the tool and the surface. Such indicates that further investigation is required here.

```
N001 G17 LF
N002 F60 G91 G01 Z-150 M03
N003 Y+195
N004 F15 G02 X+220 Y0 I+110 J0
N005 G03 X+45 Y-45 I+45 J0
N007 F60 G01 X+100
```

Figure 8. Modified NC program. Added codes are highlighted.

8. CONCLUSION

The NC optimization system described in this present paper has been able to improve productivity and surface quality in milling treatment. The algorithm is based on 3D geometric modeling and is suitable for any NC programs and any part configurations. Further research is aimed at experimental testing of the optimization, and adding extra functionality to the system.

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