Study on Collision Free Machining using Simulation and CNC Openness

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Abstract: While the usage of 5-axis machine has dramatically expanded, issues for application technology of 5-axis machine such as collision remain in practical use. Recently, the usage of Geometric simulation before cutting to prevent collision has prevailed in 5-axis and multitasking machine. However, collision accident when used manually still occurs, and both user and machine builder are highly focusing in collision free machining. In this paper, a development of on-line collision check system that is used by Geometric simulator and CNC openness is presented, and discuss the effectiveness.

Keywords: Simulation, Machining, Monitoring, Collision Free

1. Introduction
Using 5-axis machine or multitasking machine not only reduces machining operations and simplifies jig fixture, but by controlling the multiple axes simultaneously, it also enables twisted surfaces and compound contours to be machined. However, at the same time, due to the many controlling axes in multiple axes machining, movements outside the programmer’s and operator’s expectations often arise, causing the workpiece, jig fixture, cutting tool and NC machine to collide. Once a collision occurs, tremendous amounts of money and time are required for machine repairs, causing a loss to manufacturer and problems for customers. To prevent collisions, dry-run or checking system that replaces dry-run is required. In recent years, simulation technologies have been focusing on solving the collision problems [1, 2, 3]. Simulation can be divided generally into two types: off-line and on-line verification. Off-line verification is widely used to verify the collision of workpiece, cutting tool, jig fixture configuration and setting point when making a NC program. On the other hand, on-line verification is synchronized with the motion of actual machine, and verifies the collision in real-time, forcing the machine to stop when a collision is detected. This function is effective in preventing collisions for automatic operation when workpiece is set up at positions different from planned positions and for manual operation when workpiece is set up by an operator. In this paper, we introduce one of the methods for avoiding collision using Open CNC and simulation on a multitasking machine.

2. Basic Concept
2.1 On-line Simulation System
There are several ways to avoid a collision on an on-line verification. One basic method is to set a collision area in advance, and to prevent the axis coordinates from approaching the area inside the CNC. Further, as an improved method, there is one that can check a collision in the CNC on real-time by bordering a simple configuration such as cylinder and/or cube that includes the elements of workpiece, jig fixture, and cutting tool. However, considering the sequential alteration of workpiece configuration while machining, it is difficult to detect reliable collision. Therefore we propose a method of collision check by machine simulation using predicted points and stopping the machine movement forcibly when collision is detected (Fig. 1). This enables accurate collision check even for a workpiece that varies on configuration in accordance with the material removal. In order to achieve this collision check function, it must satisfy the Eq. (1).

\[ T_f - T_m > T_c \] (1)

\( T_f \) presents the predicted time from the actual point to the predicted point, \( T_m \) presents the time necessary to stop the machine forcibly, and \( T_c \) presents the time necessary for collision check.

2.2 System Design
In our research, we developed an Open CNC communicator and Geometric simulator that can be used by plugging into a CNC that is installed in a commercially available multitasking machine (Fig. 2). Open CNC communicator receives a predicted trajectory from Open CNC and conveys axis position to Geometric simulator. Geometric...
3. Key Technology

3.1 Geometric Simulator

Methods of realizing material removal simulation and interference detection on a virtual machine have been studied throughout the years. Z-mapping method and Voxel method feature simple structure and fast computation time, although they need to be expanded in basic design when machining a complex model using a 5-axis machine or setting a constant accuracy for workpiece configuration regardless of its geometry. In addition, combining with machine movement simulation needs further improvement. On the other hand, Discrete method and Analytical method have better capability in defining complex model or cutting accuracy and integrating machine movement simulation, but are characterized by increased computation time and memory usage. These technologies are continuously improving and are difficult to determine their relative advantages [4, 5]. In our research, we decided to use Analytical method (Polygonal B-rep) which we have been already using (Fig. 3).

This Geometric simulator inputs axis positions conveyed from Open CNC communicator, and conducts interference detection of machine movement while removing a material from the workpiece. Concurrently, we are able to visibly check the movement by animation rendering. Material removal and geometric calculation of machine movement are performed by Boolean subtracting the swept volume of each component that is represented by polygon solid such as workpiece, jig fixture, and cutting tool. When collisions between workpiece, jig fixture, cutting tool and machine are detected, a collision message is outputted from Geometric simulator. Furthermore, by using graphic characteristic of polygon solid, we are able to rotate and zoom in/out the screen during simulation.

3.2 Open CNC Communicator

Recent openness of CNC enabled us to obtain actual position of NC machine in operation as a coordinate value from External I/F. Additionally some CNC enabled us to obtain coordinate value of position (predicted point) that is ahead of time from present position (actual point)[6]. In this research, we use machine actual point coordinate, machine predicted point coordinate (obtained in a period of time), predicted time, operation mode and its situation. We developed an Open CNC communicator that calculates axis coordinate of machine by receiving a predicted trajectory intermittently and runs Geometric simulator. This enables a safe machining operation without collision, by acting as a mediator between Open CNC and Geometric simulator, and conducting collision check in every sampling cycle time ($T_s$) (Fig. 4). Relationship between actual trajectory, predicted trajectory of machine and long/short sampling cycle time is shown below (Fig. 5).

Figure 2: On-line collision check system.

![Figure 2: On-line collision check system.](image)

![Figure 3: Data flow of geometric simulator.](image)

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![Figure 4: Process flowchart of Open CNC communicator.](image)

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![Figure 5: Deviation for long/short sampling cycle time.](image)

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Deviation between machine’s actual trajectory and predicted trajectory depends on sampling cycle time. Longer sampling cycle time increases the possibility of detecting incorrect collision, or worse, not even detecting a collision.
Thus, setting sampling cycle time as short as possible is preferable, although due to the continuous process of Open CNC communicator that verifies the results of Geometric simulator, it is generally necessary to set the Open CNC communicator sampling cycle time longer than the duration time of collision check which Geometric simulator conducts as Eq. (2).

\[ T_f > T_s > T_c \]  

(2)

Therefore, in using the developed simulation system, it is important to set proper sampling cycle time in order to operate machining without collision. In our research, 17 to 50 ms of Geometric simulation processing time was necessary from the collision tests which we have conducted by using machine’s manual operation with an actual workpiece set on a machine (Fig. 6). Furthermore, with boolean subtraction, interference detection, animation rendering running when collision check is calculated, we found that approximately 50 ms is the limit of the current computer’s processing capacity, and as such, we have set the sampling cycle time to 50 ms.

4. Method of Calculation Time Reduction

4.1 Reduction of Geometric Simulation Process Time

We developed the weeding of a portion of sampling predicted point data in order to shorten the required calculation time of each collision check, and minimize the number of calculation processing collision check, and incorporated into Open CNC communicator (Fig. 7).

![Figure 7: Process flowchart of Open CNC communicator with weeding function.](image)

Time and processing number of calculation in a Geometric simulation using polygon solid can be reduced by minimizing the number of increasing composite surface when material is removed from the workpiece. In order to achieve this, it is preferable to conduct collision check by using interpolation mode or coordinate of starting/end point of each block of NC data, although in our testing condition, coordinate of machine predicted point was the data we could obtain from CNC in a period of time, thus we proposed the weeding method which can be possible under such condition.

4.2 Weeding Method and Conditions

In order to weed midpoints of each block of NC data from the predicted point coordinate which can be obtained from Open CNC, it is possible to determine weeding by verifying a continuous movement (whether the velocity of each axis are the same) in a period of time of an axis coordinate which is calculated each sampling cycle time (Fig. 8), (Table 1). This axis coordinate of which the continuous movement has been completed is the necessary axis coordinate for Geometric simulation.

Weeding is possible only within the time duration after deducting time necessary to stop the axis and time necessary to complete a collision check from the predicted time. Thus the number of continuous point that can be weeded \((N_w)\) can be expressed as Eq. (3).

\[ N_w < \frac{(T_f - T_m - T_s - T_c)}{T_s} \]  

(3)

Typically, the necessary time to stop the axis \((T_m)\) is expressed as a function of feed rate, although maximum stopping time of each axis was used in this report’s test. Due to the returning calculation to the last weeding point in the adjacent area of NC data block end point, it is necessary to add \((T_s+T_c)\) to \(T_m\), and then subtract from \(T_f\).

![Figure 8: Example of sweeping shape and midpoint of cutting tool and tool holder.](image)

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<th>No.</th>
<th>X [m/min]</th>
<th>Y [m/min]</th>
<th>Z [m/min]</th>
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5. Evaluation Test

5.1 Test Overview

We conducted machining test using a sample part (diameter: 80.0 mm, length: 300.0 mm) on a multitasking machine (rapid traverse of each axis: X16000, Y16000,
Z40000) with Open CNC which has a user available PC (clock speed: 1.6 GHz, RAM: 1 GB) (Fig. 9). Six cutting tools were used and cutting parameters of each process are shown in Table 2. In this test, we conducted the cutting process that represents the general machining on a multitasking machine (turning for outer and inner diameter, index milling, drilling) and we verified the effectiveness and advantage of simulation system by measuring the variation of Geometric simulation’s calculation time for each machining process in two ways: (a) without weeding (hereinafter Standard) (b) with weeding (hereinafter Weeding).

Table 3 shows the comparison of processing number for collision check and number of polygons and total calculation time between Standard and Weeding method. Compared to the Standard method, Weeding method reduced the processing number for collision check by 39% and reduced the total calculation time by 43%.

Table 3: Effectiveness of weeding.

<table>
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<th>Standard</th>
<th>Weeding</th>
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<td>Processing number</td>
<td>18104</td>
<td>11094</td>
</tr>
<tr>
<td>Number of polygons</td>
<td>7944</td>
<td>7970</td>
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<tr>
<td>Total calculation time [ms]</td>
<td>577856</td>
<td>332308</td>
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</table>

6. Conclusion

(1) Developed a basic mechanism for on-line collision check system by connecting Open CNC communicator with Geometric simulator (using Polygon) and Open CNC. (2) Reduced total simulation time and simulation processing number by using weeding function for Open CNC communicator. (3) Confirmed the effectiveness of on-line collision check system by conducting a test on a multitasking machine. (4) Shortening 50 ms of sampling cycle time is an important issue and needs to be furthermore improved. (5) Number of polygons were almost the same between Standard and Weeding method, thus need to conduct additional test using complex configuration that needs the process of simultaneous 5-axis machine or die machine.

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References