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PROPOSAL OF MODIFICATION STRATEGY OF NC PROGRAM IN THE VIRTUAL MANUFACTURING ENVIRONMENT

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Abstract: Virtual manufacturing will be a key technology in process planning, because there are no evaluation tools for cutting conditions. Therefore, virtual machining simulator (VMSim), which can predict end milling processes, has been developed. The modification strategy of NC program using VMSim is proposed in this paper.

Key words: virtual machining, machining strategy, cutting force, machining error

1. INTRODUCTION

Recent computer systems have been enhancing the manufacturing performance. In the design stage, the concept of concurrent engineering has been introduced and it has changed the conventional sequential process to overlapped process for the design process efficiency. The concept of CAD embedded CAE also has been realized, so evaluation of product shape can be carried out easily and quickly in the computer environment. In the machining stage, some advanced CAM systems can achieve the effective process planning, NC program generation and so on. But there are no evaluation tools for cutting conditions, so the test cutting is carried out for the evaluation and modification of cutting conditions after CAM generates

NC programs. It is not a feasible solution, however, especially for the small amount product such as mould and die, because it is based on trial-and-error.

Virtual manufacturing technique is regarded as the innovative solution for the reason that machining status can be verified effectively. So, the CAM embedded virtual manufacturing system is proposed in this research.

Some machining simulator related to virtual manufacturing has been studied and developed. The various approaches of geometric verification for NC machining have been studied based on solid modeling technique[1]. The cutting simulation system using a physical model has been developed to evaluate machinability and adjust the cutting conditions before the real machining operation[2]. In addition, the radial depth of cut is controlled by modifying a tool path distance at the circle path segment and adding tool path segments at the corner in terms of evaluating the physical models[3].

The objective of this research is to show the feasibility of CAM embedded VMS by proposing the modification strategy using the cutting process simulator termed VMSim (Virtual Machining Simulator).

2. OVERVIEW OF A PROPOSED SYSTEM

At first, the definition of virtual manufacturing is introduced. Generally to say, virtual manufacturing is the manufacturing in the computer environment. But this definition is too abstract to develop the system, hence some advanced definitions are proposed so far. The definition of "The use of computer models and simulations of manufacturing processes to aid in the design and production of manufactured products"[4] are selected from these definitions, because this definition is suitable for this research.

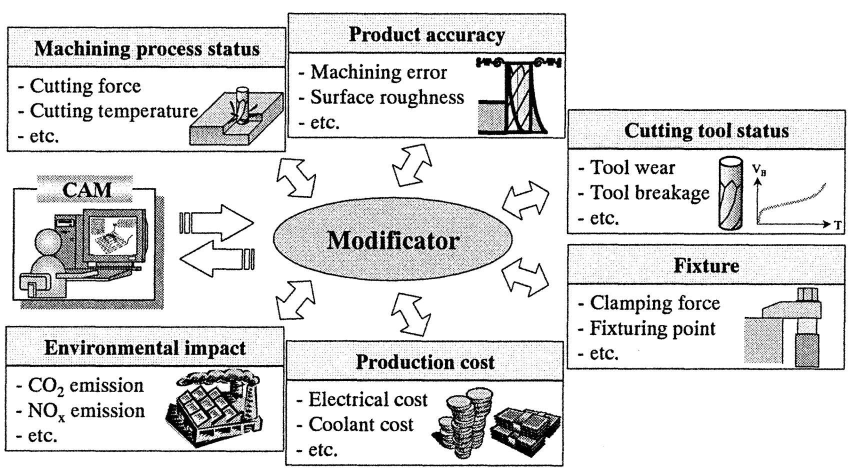


Figure 1. Overview of a CAM embedded virtual manufacturing system

Figure 1 shows the overview of a proposed system in this research. This is a CAM embedded virtual manufacturing system and consists of a CAM, a modificator and 6 evaluation blocks which are machining process status, product accuracy, cutting tool status, fixture, production cost and environmental impact. The modificator decides the machining method automatically or interactively by referring the results of 6 evaluation blocks. The contents of this paper correspond to modificator, machining process status and product accuracy evaluation blocks.

3. MODIFICATION PROCESS OF NC PROGRAM

Figure 2 shows the process flow of NC program modification in this paper. The modification system of NC program consists of 4 process blocks: NC program interpreter, NC program re-generation, modificator and cutting process simulator. The input data to modification system are NC program, tool list, workpiece and tool geometry, simulation parameters, requirement to the machining operation. Requirement to the machining operation is threshold of cutting force, machining error and so on, and simulation parameters are used to predict the machining status in cutting process simulator (VMSim). Modification of NC program is also divided to 2 more modules, which are feed rate modification and tool path modification. When an NC program is modified, feed rate is modified at first. If the requirement can not be satisfied by the feed rate modification, tool path is modified. The modification processes, which are feed rate modification and tool path modification, are described in next chapter.

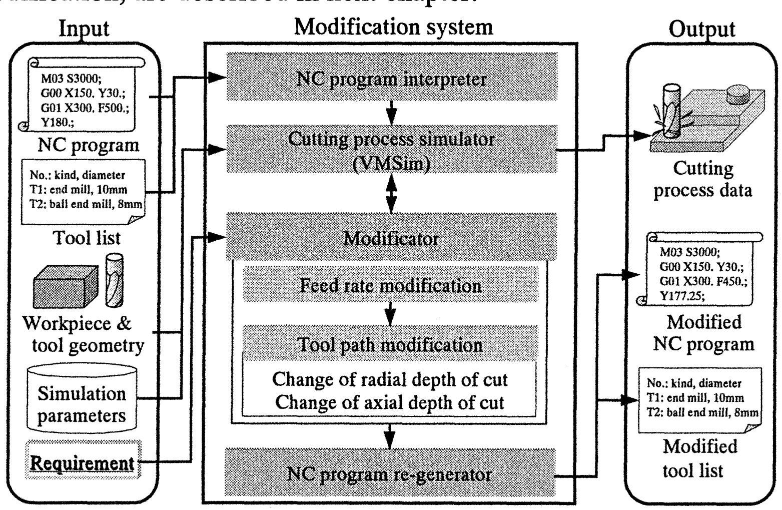


Figure 2. Process overview of NC program modification

4. CUTTING PROCESS SIMULATOR

In this research, a cutting process simulator termed VMSim (Virtual Machining Simulator) for end milling operation shown in Figure 3 has been developed to evaluate the machining process and to adjust the cutting conditions automatically by changing the feed rate[5]. The VMSim consists of a geometric simulator and a physical simulator.

The geometric simulator calculates change geometries of the product machined and extracts cutting conditions like a radial depth of cut, axial depth of cut, spindle speed and feed rate from a workpiece geometry, a tool geometry and NC data. The physical simulator estimates instantaneous cutting force and machining error based on the cutting models from the extracted cutting conditions, cutting coefficients and rigidity. The estimated result of the cutting force and the machining error has already been verified to coincide with the measured result of them.

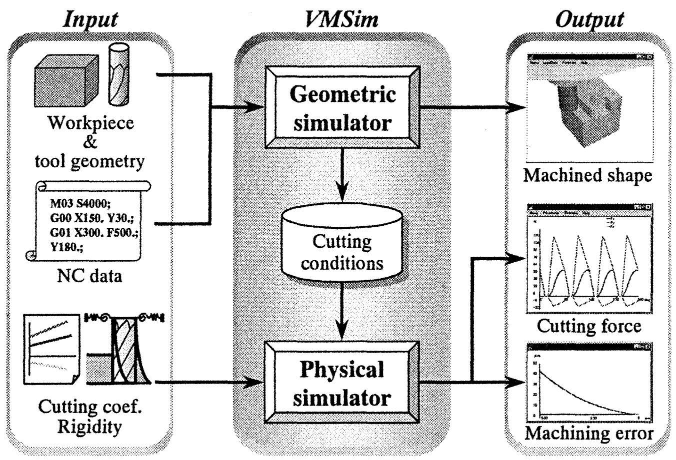


Figure 3. System architecture of VMSim (virtual machining simulator)

5. MODIFICATION OF CUTTING CONDITIONS

5.1 Modification of feed rate

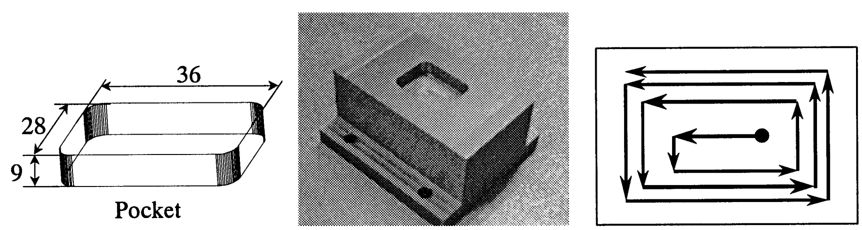
A procedure of the feed rate modification with considering the cutting force is described at first. The feed rate value is calculated by equation (1).

$$F = F_c \cdot \frac{CF_o}{CF_{\max}} \qquad (1)$$

where F_c is a current feed rate value, CF_{max} is absolute value of maximum or minimum cutting force predicted from F_c, and CF_o is a threshold of cutting force. After that, the modificator iterates to change the feed rate value in small steps until satisfying the requirement (threshold) value by referring to VMSim. The procedure with considering the machining error is the same, too. Also, this calculation process is adapted not only over the thresholds but also under them to shorten the total machining time.

Modification method of NC program is the following. Cutting force data, machining error and cutting conditions are recorded with NC block number by VMSim verification. The cutting conditions may be difference at each tool position in same NC block, so one NC block is divided into some blocks according to need and feed rate is calculated with satisfying the requirement for divided NC blocks.

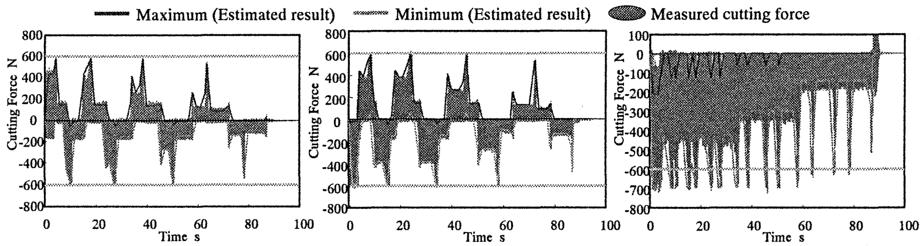
Experimental verification of this function is carried out. The test shape, machined shape and tool path pattern are shown in Figure 4 (a), (b) and (c), respectively. Work piece is cast iron (FC250), cutting tool is carbide square end mill with 10 mm diameter, 2 flute and 30° helical angle in this experiment. The requirement to the machining operation is that cutting force is between -600 to 600 N and the machining error of product surface is not over 30 μm.



(a) test shape *(b) machined shape* *(c) tool path pattern*

Figure 4. Test shape and tool path pattern of case study of feed rate modification

Figure 5 (a), (b) and (c) shows the relationship of changes of cutting forces and machining time of original NC program in X, Y and Z axes. Estimated cutting forces are indicated maximum and minimum cutting force, and measured cutting force are indicated all data in the figures. Figure 6 shows the comparison of measured and estimated machining errors of a finished surface pointed by red circle. Machining error caused by tool deflection is presented and biggest value means the one at the bottom of pocket. As shown in the figures, estimated cutting force and machining error coincide with measured them very well. Both of the cutting force and the machining error, however, exceed the requirement obviously. So, this NC program is modified by changing the feed rate value by referring to the VMSim.



(a) cutting force along X axis (b) cutting force along Y axis (c)cutting force along Z axis

Figure 5. Comparison of predicted and measured cutting force (original NC)

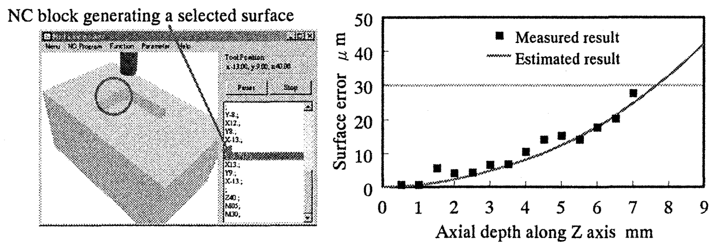
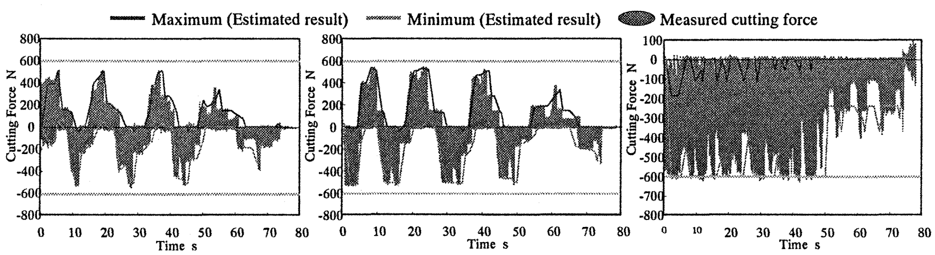


Figure 6. Comparison of predicted and measured machining error (original NC)



(a) cutting force along X axis (b) cutting force along Y axis (c)cutting force along Z axis

Figure 7. Comparison of predicted and measured cutting force (modified NC)

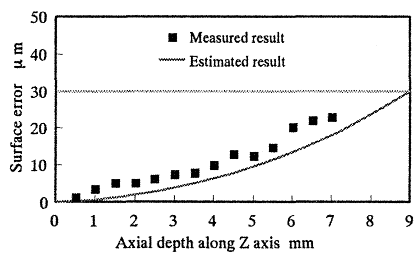


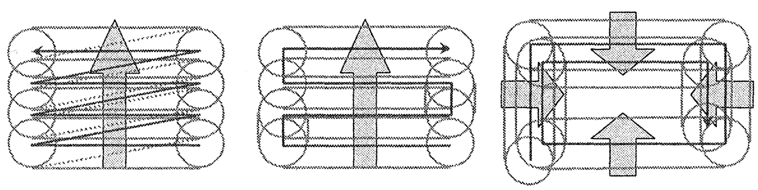
Figure 8. Comparison of predicted and measured machining error (modified NC)

In the modification process, rough machining of NC program is considered only cutting force and finish machining of one is considered cutting force and machining error. Rough and finish machining are distinguished automatically by using recorded cutting force and machining error data. Figures 7 and 8 show the cutting force results and a machining error result of modified NC program. It is clear that the cutting force and the machining error are limited within the required value. The modification system can modify cutting conditions to satisfy the requirement in this case. But, in case that the feed rate modification can not provide a feasible solution, the tool path has to be changed.

5.2 Modification of tool path

The procedure of the tool path modification is the following. First, tool path pattern is recognized based on generation process of tool swept volume and tool motion vector. In this research, tool motions are classified into 3 types, i.e., hole making motion, linear motion and arc motion. Tool swept volumes are generated based on 3 types of tool motion, and directions of these generation process are recognized like figure 9 (large arrow). For example, if the direction of generation process is one way, tool path pattern is unidirectional or zigzag pattern. In this case, these are recognized based on tool motion vector (small arrow). If the direction of generation process is in all direction, the tool path pattern is contour. The fault of machining process also may also be recognized. For example, if the cross feed is larger than tool diameter in zigzag pattern, cross feed and tool path have to be modified.

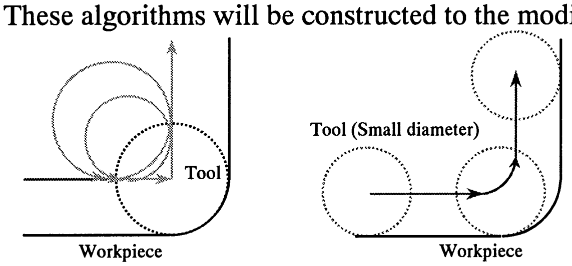
The change of axial depth of cut is the following. The modification is simple, because the tool path information is shifted to the upper Z value face and the feed rate is also calculated to adjust the machining status mentioned already. In some case, product shape of cross section of the upper Z value may be different from one of lower Z value. The system requires the tool path re-generation to CAM system with indicate the problematic NC blocks.



(a) unidirectional pattern (b) zigzag pattern (c) contour pattern

Figure 9. Recognition method of tool path pattern

The change of radial depth of cut is the following. If an initial one decided by CAM operator is large, the system requires the tool path re-generation to CAM system with indicate the problematic NC blocks. If there are some problems in some parts of the machining process, radial depth of cuts are changed in order to realize the constant cutting force machining automatically. Especially for the corner parts, 2 types modification are prepared for automatic modification shown in figure 10. In first type, the loop tool path[6] is generated, and if necessary, loop paths are generated until residual parts disappear. In second type, cutting tool is changed to smaller diameter, and small arc path is inserted to generate the required corner shape. These algorithms will be constructed to the modificator.



(a) first type modification (b) second type modification

Figure 10. Tool path modification for corner parts

6. CONCLUSIONS

1) The CAM embedded virtual manufacturing system is proposed to realize effective decisions of machining strategies.
2) The strategies for automatic and interactive modification of NC program using VMSim has been proposed. NC program modification is carried out in two stages, feed rate modification and tool path modification.
3) An NC program, which machines simple cavity shape, has been modified to satisfy the requirements. That is to say the feasibility of feed rate modification has been verified by experimental milling.

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