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A Framework of Compositional Machining Simulation for Versatile Machining Simulation *

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Abstract

This paper presents a framework of a compositional machining simulation. Because the machining process involves complex physical phenomena, various fragmented process simulations, such as cutting force, thermal behavior, vibration, and so on, have been investigated. The authors have proposed a concept of the compositional machining simulation which enables a versatile machining simulation. The concept is based on the building block type construction of the various machining process simulators. An association framework and systematic description of fragmental process models are explained. As an example of the framework, fragmented simulations of endmilling process are organized as a multi-aspect simulation.

Key words: Compositional Simulation, Endmilling, Versatile Simulation, Multi-Aspect/Multi-Scale Simulation

1. Introduction

In the competitive environment of manufacturing, the machining process is requested to adapt to new situations such as functional materials (e.g. titanium alloy, composite materials, and so on), continuously improved cutting tool (edge shape and coating) and newly developed mechanism (1). In order to achieve the appropriate machining in the dynamic situations, a model-based approach is eagerly desired to become an alternative to a conventional trial and error approach. The concept of model-based approach has been investigated by many researchers. A total model-based approach for the machining operation was proposed in 1990s (2). Geometrical simulation software packages then have become essential tools in multi-axis machining. Furthermore, some commercial Finite Element Method (FEM) software packages are widely applied to the tool design processes. Recently, a concept of virtual machine tool has been proposed as a model-based machine tool design (3). These energetic investigations indicate the model-based approach must be a promising approach.

However, the model-based approach is not applied in the actual machining situations. One of important reasons can be said that most of the machining simulators have been developed for the developer's own usage rather than for the sharable common tools. Therefore, most machining simulators are difficult to use in spite of their effectiveness.

In order to overcome the situation, a method for the versatile machining simulation which is applicable to the non-developer's usage is investigated. The authors have proposed a framework of compositional machining simulation which enables a versatile machining

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simulation [4]. The framework is based on a building block type construction [5] of the various machining process simulators by associating the fragmented simulators.

In this paper, the association mechanism to achieve the model composition is introduced to implement the compositional machining simulation.

2. Framework of compositional machining simulation

In order to realize building block type compositional machining simulation, basic unit of simulation should be defined. Because many machining simulators based on the various modeling approach have been investigated for many years, a systematic method which classify the developed simulators should be introduced.

Based on the survey of proposed simulation methods, three indexes are introduced to express the functionalities of machining simulators. They are aspect of models, scale (granularity) of modeling and scope of entities. The aspect of models indicates the empirical viewpoint of machining process such as elasticity, thermal behavior, vibration, and so on. The scale of modeling is determined by the principle which is applied to model the process. A hierarchy of the principles such as empirical-mechanistic-theoretical is a key to organize the modeling scale. The scope of entities indicates the region of the consideration. A general structure model of machining equipments should be determined to express the scope clearly.

Based on the proposed classification indexes, a framework of compositional machining simulation has been proposed. Figure 1 illustrates a schematic framework of the proposed compositional machining simulation. Various fragmental physical simulations are associated with experimental and empirical information. The framework consists of three types of association which are corresponding to the indexes. The first is an association of different aspect models for a same object. The second is an association of different scale models for a same phenomenon. The third is an association of different scope of entities such as association between machine tool behavior simulation and machining process simulation [3].

Because various types of aspect models can be developed, the variety of simulation cannot restrict in advance. Then, the association of different aspect models is an important issue for the versatile machining simulation.

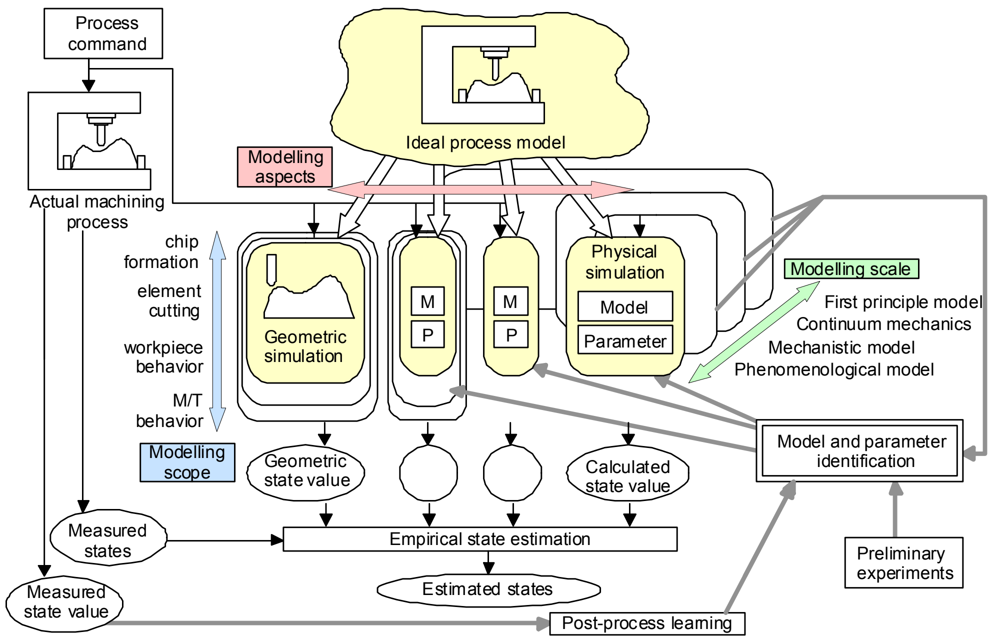

Fig. 1 Framework of compositional machining simulation

When the association problem can be resolved, the multi-aspect simulation will be realized easily by the compositional simulation approach. Therefore, it can be expected that the compositional machining simulation helps to evaluate the machining process from various aspects by reusing the simulation modules.

3. Foundation of Compositional Machining Simulation

3.1 Compositional machining state representation

As a theoretical background of the compositional simulation, a representation method for versatile machining simulation is introduced.

As described in previous section, the concept of aspect is introduced as an empirical viewpoint of machining process such as elastic aspect, thermal aspect, vibrational aspect, and so on. Based on the concept of aspect, we can define a representation scheme of machining process. In this research, a whole machining state is represented by an aggregation of fragmental states which are respectively defined in a certain aspect. Furthermore, the geometric state is assumed as the essential and common information among the states. From these assumptions, the relation among the aspects is resolved into a set of correspondences between the geometric state and each of physical states. Physical states based on the certain aspect are independently connected to the geometric state as illustrated in Fig.2. According to this scheme, the machining state is represented as a combination of geometries and aspect states.

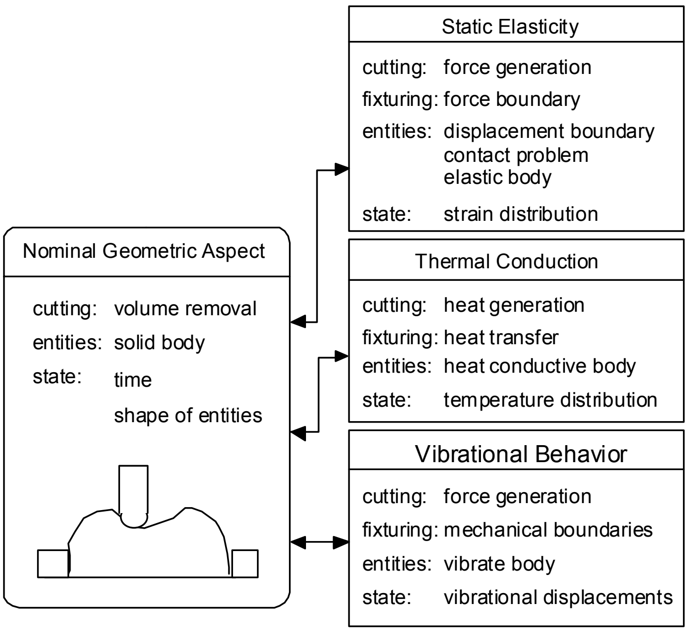

Fig. 2 Example of machining states in aspects

3.2 Procedures of compositional machining simulation

Concerning the implementation of the machining state, most of all physical states are not expressed explicitly in advance. Therefore, a derivation procedure of state also should be defined.

In the machining operation, most of fragmental physical states are derived from the geometric state. Moreover, all aspects affect to the geometric state through the deformations of entities in principle. These facts cause the circulation of reference in the derivation procedure. Then, we introduce two kinds of geometric state for the approximated derivation. One is a nominal geometric state, and the other is a resultant geometric state. The former is the geometric state without any physical consideration. The latter is the geometric state which is integrated with the physical effects. Since a nominal geometric state can be considered as a rough approximation of the resultant one, the nominal one is used as the reference information of physical aspects. Then, the resultant one is derived by integrating deformations of every aspect.

For the precise derivation of the machining state, the nominal geometric state is not applicable as the reference information. In this case, the derivation procedure contains iterative operations to secure the consistency.

By means of the proposed representation, the consistent model aggregation can be achieved for the multi-aspect compositional machining simulation. Based on the proposed representation and derivation scheme, the multi-aspect machining simulation can be executed as following procedures.

1. Calculate the machining simulation from the geometric aspect.
2. Execute the aspect simulation according to the geometric states.
3. Aggregate the results obtained by each aspect simulation.
4. Estimate the machining states applying empirical modeling techniques.

By aggregating and regulating the process models appropriately, users of the machining simulators can utilize the machining simulation with less implementation. The proposed framework which regulates the model composition helps the systematic aggregation of process models.

4. Association of Fragmental Machining Simulation

Many machining simulators for endmilling in various aspects such as machining error estimation, a thermal simulation, and vibrational simulation have been developed. In order to associate these different aspect simulators so as to organize the compositional simulation, it is necessary to find corresponding states between the different aspects. Based on the survey of the conventional researches for machining simulations, it becomes clear that there are three types of simulations from the view of the state updating. To be concrete, there are a time driven update, tool movement driven update, and arbitrary update. As shown in Fig. 3, details of these types can be summarized as follows,

Time driven update (A-type): The simulated states are updated according to the temporal transition like the transient heat conduction simulation.

Tool movement driven update (B-type): The simulated states are updated according to the tool movement like geometric milling simulation of workpiece.

Arbitrary update(C-type): The simulated states are shifted between the predetermined machining situations like modal analysis. The simulated situations are determined based on the empirical evaluation of state characteristics and calculation time.

A corresponding state of A-type simulation ($t\alpha$ in Fig.3) to a state of B-type simulation ($m\gamma$) can be found by parsing the NC-program based on the machine tool movement model which is implemented in geometric machine tool simulator. Therefore, it become possible to associate between A-type simulation and B-type simulation by preparing this correspondence table at the first time execution of machining simulation. Concerning the C-type simulation, we introduce "machining scenario" method (2) as a description method of the predetermined evaluation points. The representation scheme is based on a hierarchal data structure which contains four level expressions; “Scenario”, “Block”, “Scenes” and “Point”. The level of “Scenario” expresses the outline of whole machining process. The level of “Block” is based on the NC program structure. The level of “Scenes” can be defined based on the machining features. The level of “Points” expresses a snap-shot of machining process. Then, all machining points in machining process can be identified by introducing the machining scenario representation scheme. Because the machining scenario is NC-program based state representation method, the association between C-type and B-type can be derived automatically. These relations are illustrated in Fig. 3.

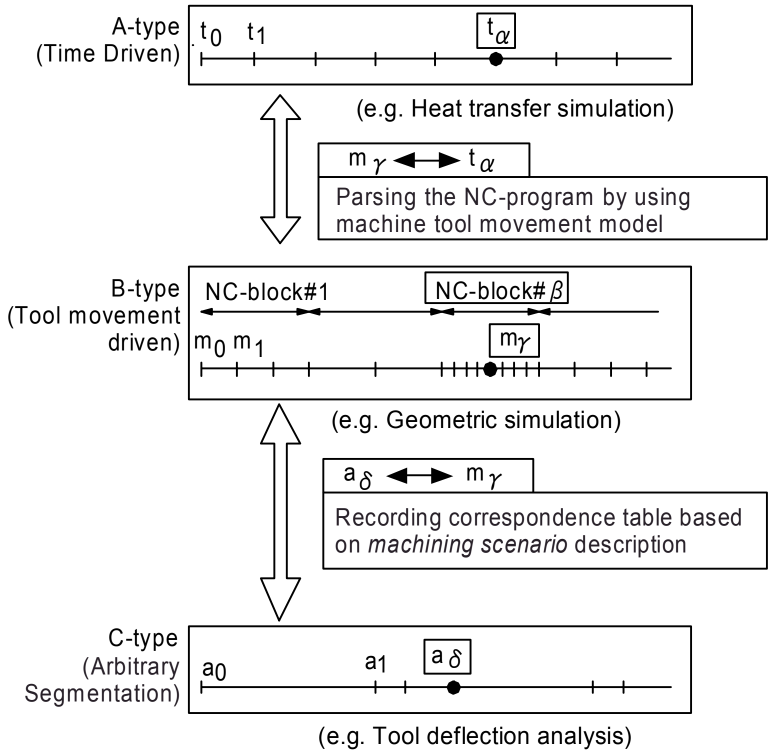

Fig. 3 Correspondence between the aspects

5. Example of Compositional Machining Simulation

As an example of the proposed association procedure, an example for multi-aspect simulation of endmilling is investigated.

Figure 4 illustrates an outline of the example problem which is a case of endmilling from the initial workpiece shape (Fig. 4(a)) to the final workpiece shape (Fig. 4(b)). Tool path of the machining is also shown in Fig. 4(c).

In order to simulate the problem, four fragmental simulations of workpiece behavior are calculated. They are a thermal simulation, a geometrical simulation, an error simulation which is caused by tool deflection and an elastic simulation.

The thermal simulation is an example of a time driven simulation. A finite element method for heat transfer problem is applied to the simulation. Based on the estimation of cutting force and predetermined inflow ration, the heat flux for the thermal simulation is estimated(6). The geometrical simulation and the error simulation are examples of tool movement driven simulation. The geometrical simulation calculates intermediate workpiece shape at every NC step during the machining process. Cutting forces and machining error at every NC step are also calculated based on a Tsai's process model (7). The elastic simulation is an example of an arbitrary simulation. Because of difficulties of mesh generation and calculation time, the elastic simulation of workpiece caused by the fixturing force should be calculated at minimum case. Therefore, simulations of workpiece deformation are calculated at heuristic situations.

These simulation results represent in independent machining situations. By applying the proposed association scheme, these independent results can be associated systematically. The relationships between the simulations are illustrated in Fig. 5. As shown in the figure, the system can find the corresponding statuses between the aspects. In order to utilize these results, an powerful user interface which enables an effective visualization and easy operation is necessary. Development of the user interface is an important future work of the research.

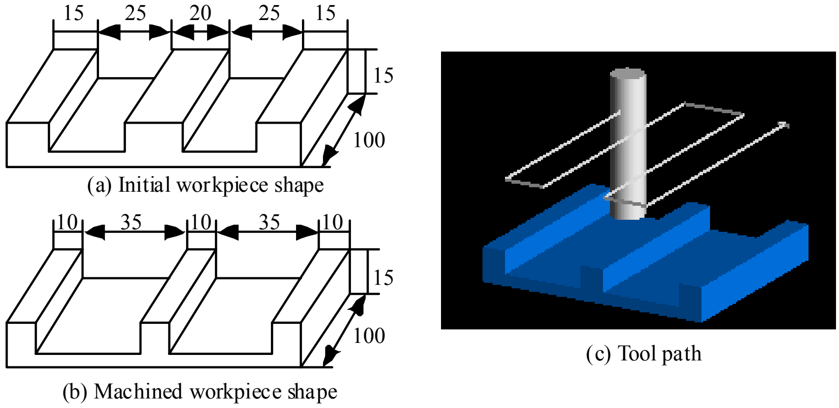

Fig. 4 Example problem

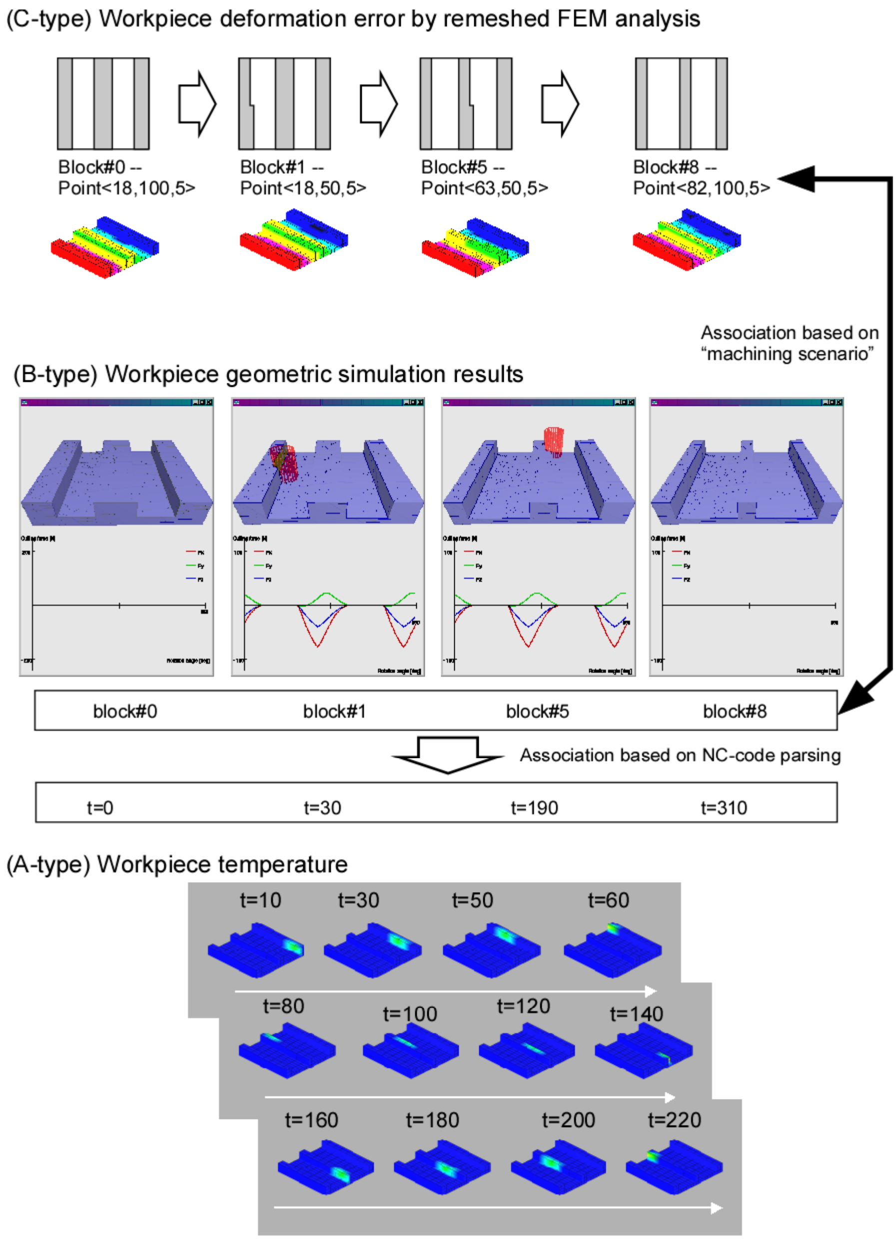

Fig.5 Example of states association

6. Conclusion

In order to realize the versatile machining simulation, the state representation scheme and the framework of compositional machining simulation are proposed. An association scheme is explained with the example. The example shows the feasibility of the proposed framework. Applying the method to realistic problems and development of user interface are future works of the research.

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