Proposal of a machining features recognition method for 5-axis index milling on multi-tasking machine tools

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Abstract
Multi-tasking machine tools that can deal with several kinds of machining methods including turning and 5-axis control milling are attracted to achieve highly efficient machining in recent years. However, the machining process is generally complicated and the preparatory time becomes longer because there are a lot of available machining methods and the operational parameters such as the tool posture. Therefore, a computer aided process planning (CAPP) system is indispensable to reduce the efforts for the preparation and to improve the efficiency of machining process on multi-tasking machine tools. For this purpose, this study aims to propose a novel features recognition method can be applied to process planning of 5-axis index milling that is a characteristic machining method for mechanical parts having complex shapes on multi-tasking machine tools. In this method, machining primitives are obtained by dividing the removal volume, and cylindrical machining primitives for turning are additionally obtained even when the target shape does not have a cylinder part. Then, available combinations of tool postures are prepared for each machining primitive depending on the directions in which the machining primitive can be machined. The tool postures during 5-axis index milling are determined by referring specific information such as the number of tool postures. The machining primitives are divided again in each determined tool posture to recognize machining features in order to remove unmachined volume. Thus, the proposed method could be easily applied to process planning of 5-axis index milling on 5-axis controlled machining centers. The results of case study confirm that process planning of 5-axis index milling on multi-tasking machine tools is effectively realized based on the proposed method.

Keywords: Process planning, Multi-tasking machine tool, Machining feature, 5-axis index milling

1. Introduction

Complex shapes machining is required in present manufacturing industry, and there is always strong impetus to improve the efficiency of machining process. Thus, multi-tasking machine tools that can deal with several kinds of machining methods including turning and 5-axis control milling are attracted to achieve highly efficient machining in recent years. However, the machining process is generally complicated and the preparatory time becomes longer because there are a lot of available machining methods and the operational parameters such as the tool posture. Therefore, a computer aided process planning (CAPP) system is indispensable to reduce the efforts for the preparation and to improve the efficiency of machining process on multi-tasking machine tools.

In particular, it is well known that 5-axis index milling is an effective machining method on the multi-tasking machine tools and is suitable to machine complex product shapes. In 5-axis index milling, the tool posture is inclined against a machining surface using two rotary axes, and the problems in 3-axis control milling such as requirement of a long overhang length can be solved. On the other hand, the tool posture determination is still a challenging issue in 5-axis index milling. Thus, Huang and Inui proposed an algorithm for automatically determining the optimal overhang length (Huang and Inui, 2010). In addition, Kaneko et al. proposed a fast estimation method that visualizes both the machinable area and the distribution of the minimum overhang length as a color image for each tool posture candidate (Kaneko et al., 2014). Yamada et al. clarified the tool postures to ensure stable cutting in terms of cutting forces and proposed a
calculation method of optimum indexing angle candidates for machining surfaces (Yamada et al., 2007). Though there are many studies on finishing as mentioned above, there are few studies focusing on roughing by 5-axis index milling. For example, Yamada proposed a method to derive the tool posture where the cutting removal quantity becomes the maximum (Yamada et al., 2016). However, a free-form surface was treated as the target shape in the study. Therefore, this study aims to propose a novel features recognition method can be applied to process planning of 5-axis index milling of mechanical parts having complex shapes.

In the proposed method, machining primitives are obtained by dividing the removal volume, and the combinations of tool postures are prepared for each machining primitive depending on the directions in which the machining primitive can be machined. Moreover, by generating a simplified target shape consisting of some cylinders, cylindrical machining primitives are newly obtained for turning even when the target shape does not have a cylinder part. The tool postures during 5-axis index milling are determined by referring specific information such as the number of tool postures. The machining primitives are divided again in each determined tool posture to recognize machining features in order to remove unmachined volume. By dividing the machining primitive after determining the tool posture, the number of machining primitives are appropriately limited to shorten the time for process planning even when a lot of tool posture candidates exist against a complex shape. Thus, the proposed method could be easily applied to process planning of 5-axis index milling on 5-axis controlled machining centers. In order to confirm the availability of the proposed method, case studies are conducted by assuming complex shapes machining. The results confirm that process planning of 5-axis index milling on multi-tasking machine tools is effectively realized based on the proposed method.

2. Computer aided process planning (CAPP) system

In order to reduce the time for preparing machining process, CAM systems are needed to minimize the effort to generate NC programs. However, it is necessary to manually determine the operational parameters including machining features and the machining sequence in commercial CAM systems. Therefore, a computer aided process planning (CAPP) system is expected to be developed to shorten the preparation time. Feature recognition has been considered as an important technology in the development of CAPP systems. Machining feature means a characteristic shape pattern that can identify the specific machining method.

Shi et al. reviewed various studies on feature recognition thoroughly (Shi et al., 2020). Graph-based method is one of the typical feature recognition methods. The boundary representation of the part is transformed to a graph showing the topology. This graph is then analyzed to extract subsets of nodes and arcs that match with any predefined template (Li et al., 2010). Rahmani and Arezoo combined the graph-based method with a rule-based method that recognizes features based on hints such as the attributes of face patterns (Rahmani and Arezoo, 2007). An artificial neural network is also one of the promising feature recognition methods. For example, Sunil and Pande proposed a feature recognition method using unique 12-node vector scheme (Sunil and Pande, 2009). However, in most of studies, machining features are recognized from a target shape. Machining features should be recognized from removal volume in nature, because the removal volume changes depending on the workpiece shape. Some researchers have attempted to recognize machining features from the removal volume. Fu et al. recognize machining features by decomposing the removal volume into multiple sub-volumes and convert them into a graph to determine the machining details using graph-grammar rules. (Fu et al., 2013). Nishida and Shirase also recognize machining features by decomposing the removal volume to store and use machining case data (Nishida and Shirase, 2018). Moreover, in the former studies, 3-axis milling and drilling are assumed as available machining methods on machine tools in the feature recognition methods. Though there are few recognition methods proposed for multi-tasking machine tools that can deal with several kinds of machining methods (Dwijayanti and Aoyama, 2014), 5-axis index milling has not been treated as the targeted machining method.

On the other hand, the authors have also proposed unique machining features and the recognition method (Ueno and Nakamoto, 2015), and have already developed a CAPP system for multi-tasking machine tools that have special functions such as chucking switch (Inoue and Nakamoto, 2020). In the recognition method, machining primitives are first acquired by dividing the removal volume into simple shapes such as a cylinder or a cuboid. Then, boundary faces where the removal volume and the target shape come into contact are detected. Additionally, the boundary faces are extended to the inside of the removal volume so that machining primitives are obtained by using the extended boundary faces to divide the removal volume. Finally, machining features are recognized by allocating a machining sequence to each machining primitive. Figure 1 shows an example of recognized machining features. It is possible to allocate the machining sequence
by, for example, following the descending order of volume of machining primitives, or their distances from the fixed area. A machining operation could be determined by enumerating machining methods following the machining sequence. In addition, machining methods such as turning and milling are assigned to machining features by referencing its shape.

By creating new partial target shapes, the recognition method is adapted to chucking switch of a workpiece between two confronting turning spindles on a multi-tasking machine tool. Figure 2 shows an example of creating the new partial target shapes before and after the workpiece chucking switch. A face having the largest circumscribed rectangle area among faces perpendicular to the center axis of turning spindle is detected as the dividing face to separate both the workpiece shape and the target shape. Then, the separated workpiece shape at one turning spindle side and the separated target shape at the other turning spindle side are merged to be treated as a new partial target shape. Machining features that machined before and after the workpiece chucking switch are recognized at each turning spindle side, respectively.

Recently, 5-axis index milling has been popular on multi-tasking machine tools to improve the efficiency of complex shapes machining. Therefore, in this study, a novel features recognition method is proposed for realizing process planning of 5-axis index milling on multi-tasking machine tools. Since machining features are recognized to remove unmachined volume, the proposed method could be easily applied to 5-axis index milling on 5-axis controlled machining centers.

3. Proposed machining features recognition method

In a novel features recognition method, both workpiece and target shapes are prepared as the input CAD models created so that Z axis of the CAD coordinates system agrees with the center axis of turning spindle of multi-tasking machine tools. Then, the tool holders are preliminary prepared to calculate the required overhang length through the interference check. Simple Modeler (AIKOKU ALPHA Corp.) is used as a CAD software, and the API functions of Simple Modeler and C# are used to develop a CAPP system based on the proposed features recognition method.
3.1 Obtainment of machining primitives

Machining primitives are obtained by dividing the removal volume, and machining features related to turning are recognized from only cylindrical machining primitives. However, in the previous study, cylindrical machining primitives are not obtained and machining features related to turning are not recognized when the target shape does not have a cylinder part as shown in Fig. 3. Therefore, in this study, cylindrical machining primitives for turning are obtained regardless of the target shape in order to increase the flexibility of machining process on multi-tasking machine tools.

Figure 4(a) shows an example of target shape. The target shape is firstly divided by planes including target shape’s faces perpendicular to the center axis of turning spindle as shown in Fig. 4(b). Then, the smallest cylinders that contain each divided shape are created so that the center axis agrees with the turning spindle as shown in Fig. 4(c). The original target shape is simplified by combining these created cylinders as shown in Fig. 4(d). By using the simplified target shape and the workpiece shape, additional cylindrical machining primitives are obtained by dividing the removal volume as shown in Fig. 4(e). The additional cylindrical machining primitives are used in the recognition of machining features together with machining primitives obtained from the removal volume between the original target shape and the workpiece shape.

Fig. 3 Example of machining primitives obtained by dividing removal volume. When the target shape does not have a cylinder part, cylindrical machining primitives are not obtained and machining features related to turning are not recognized in the previous study.

Fig. 4 Creation of simplified target shape. (a) shows detected target shape’s faces perpendicular to the center axis of turning spindle axis. (b) shows the target shape divided by planes including each detected face. (c) shows created cylinders containing each divided target shape. (d) shows the target shape simplified by combining created cylinders. (e) shows obtained additional machining primitives according to the simplified target shape.

Moreover, a screw thread is also removed and the target shape is approximated before obtaining machining primitives. The procedure is similar to the approximation of target shape having a chamfer or fillet part proposed in the previous study. The detected screw thread is removed and the target shape is changed to a simple cylinder as shown in Fig. 5. Then, the difference between the approximated target shape and the original target shape is treated as a special machining primitive that the last machining sequence is allocated for tapping.
Preparation of tool posture combination

In order to determine tool postures and to recognize machining features for process planning of 5-axis index milling, available combinations of tool postures for each machining primitive are prepared depending on machinable directions derived from a target shape. Figure 6 shows the procedure to prepare the tool postures combination. Directions parallel or perpendicular to generated surfaces where the machining primitive and the target shape come into contact, are first detected as shown in Fig. 6(a). If the target shape has a cylindrical generated surface shown in the upper side of Fig. 6, the directions parallel to the cylinder axis are adopted as face-based directions. Otherwise, the directions parallel or perpendicular to the edge shared by generated surfaces are also adopted as the face-based directions. Then, machinable directions are selected from the face-based directions. The face-based directions in which the inner products with the normal of all generated surfaces are not negative are defined as the machinable directions as shown in Fig. 6(b). Finally, a combination of machinable directions that can machine all generated surfaces becomes a tool postures combination as shown in Fig. 6(c).

For determining tool posture combination, the required overhang length in each machinable direction is calculated through the interference check between the target shape and tool holders by following the previously proposed method (Komatsu and Nakamoto, 2020). A plane perpendicular to the machinable direction is created at a position adjacent to the machining primitive, and a generated surface of the machining primitive is projected on the plane and also expanded by the maximum tool holder radius for safety as shown in Fig. 7(a). Then, the expanded generated surface is moved along
the machinable direction until no interference is detected. The distance from the machining primitive is treated as the required overhang length since the expanded generated surface is equivalent to the locus of the bottom of tool holder as shown in Fig. 7(b). Finally, the machinable directions without any collision are combined to create all generated surfaces as a tool postures combination. The required overhang length calculated can be used as the threshold to reduce the machinable directions to make combinations of tool postures.

3.3 Determination of tool postures combination

After obtaining the tool postures combination, an arbitrary tool postures combination is first assigned for each machining primitive. Figure 8 shows examples of the assigned tool postures combination for the same product shape having two machining primitives. It is recognized that different tool postures combination is determined by minimizing the number of tool postures throughout machining process in (a) and by minimizing the required overhang length required to machine the machining primitives in (b).

3.4 Feature recognition according to tool postures

Machining features are recognized from machining primitives according to the above tool postures without any collision. If there are multiple tool postures in one tool postures combination for a machining primitive, the used tooling consisting of a cutting tool and a tool holder may be changed depending on the tool posture. Therefore, after the tool postures combination is determined, the machining primitive is individually divided according to the tool postures to separate the machining operation. The smallest rectangular solid is created to contain each generated surface that is neither parallel nor perpendicular to the tool posture as shown in Fig. 9. The overlapped part between the machining
primitive and the created rectangular solid is defined as the volume that cannot be machined with the tool posture in this study. Then, the overlapped part is removed from the original machining primitive, and the remained part becomes a machining primitive machined with the tool posture. The removed part becomes a new machining primitive machined with another tool posture. By repeating this procedure for whole tool postures, the original machining primitive is divided repeatedly in order to remove unmachined volume. Finally, after machining sequence is allocated to the machining primitives based on specific conditions such as machining volume order, machining features are recognized following the previous study.

Fig. 9 Division of machining primitive according to tool posture. A machining primitive is divided by removing unmachined volume in each tool posture. A cuboid is created to detect unmachined volume, and the overlapped part between the machining primitive and the created rectangular solid is defined as unmachined volume with the tool posture.

4. Case study

A case study is conducted to confirm that the proposed method of machining features recognition is useful to effectively deal with process planning of 5-axis index milling on multi-tasking machine tools.

The assumed multi-tasking machine tool has a milling function with 5-axis control, two confronting spindles and a lower turret with plural cutting tools. In terms of the tool holders, the assumed maximum radius is 50 mm. As the cutting tools, a single point turning tool for turning, two types of square end mills (6 and 12 mm in diameter), and a drill (8 mm in diameter) are supposed, and it is assumed that all machining primitives are machined by these cutting tools. Moreover, cylindrical primitives that the center axes match with the turning spindle are machined by turning, and other machining primitives are machined by milling or drilling. Both workpiece and target shapes are prepared as the input CAD models as shown in Fig. 10, they are created so that Z axis of the CAD coordinates system agrees with the center axis of turning spindle. In addition, tool postures for machining primitives are determined by using direction vectors in the CAD coordinate system. Because the workpiece rotates in turning, the tool postures for turning are assumed to be parallel to the X axis direction.

In this case study, three process patterns (A, B and C) are supposed by using the multi-tasking machine tool. In Pattern A, machining features are recognized by the previous method for turning and 3-axis control milling on multi-tasking machine tools. In Pattern B, machining features are recognized by using the proposed method in this study for turning and 5-axis index milling. In Pattern C, cylindrical machining primitives for turning are additionally obtained even when the target shape does not have a cylinder part for the same machining features recognition in Pattern B. In Pattern A, each tool posture is fixed as the normal vector of the generated surface of machining primitive. In Patterns B and C, the tool postures combinations are determined to minimize the required overhang length for machining primitives that are machined by 5-axis index milling. In any pattern, turning has the priority for early machining sequence compared to any method of milling, and the machining primitive that is farther from the center axis of turning spindle has the priority in turning. In 5-axis index milling, the tool posture that can machine larger volume has the priority, and the machining primitive that is farther from the center axis of turning spindle has the priority for early machining sequence in the same tool posture.

Table 1 summarizes the recognized 12 machining features in Pattern A. In the machining sequence 1, turning is selected as the machining method for cylindrical machining feature Face C + Boss C defined in the previous study, and
3-axis control milling is selected as the machining method for other machining features. In the sequences 11 and 12, tool postures (1,0,1) and (-1,0,1) are conveniently determined for 3-axis control milling because the tool posture is fixed as the normal vector of the generated surface. However, these tool postures are impossible in 3-axis control milling and their machining primitives are not machined completely by 3-axis control milling. Therefore, the previous method cannot deal with machining primitives that are required to be machined by using inclined tool postures.

![Workpiece and target shapes](image)

**(a) Workpiece shape**

**(b) Target shape**

**Fig. 10 Workpiece and target shapes for case study.**

**Table 1** Result of recognition of machining features in Pattern A. There are 1 feature machined by turning and 11 features machined by 3-axis control milling. Each tool posture is fixed as the normal vector of the generated surface of machining primitive.

| Turning                                                | 3-axis control milling |
|--------------------------------------------------------|------------------------|
| Seq. 1: Face C + Boss C                                 | Seq. 2: Step           |
| Dv : (1, 0, 0)                                          | Dv : (0, 1, 0)         |
| Tool posture                                           | Dv : (1, 0, 0)         |

| 3-axis control milling                                  |
|--------------------------------------------------------|------------------------|
| Seq. 6: Step                                           | Seq. 7: Step           |
| Dv : (1, 0, 0)                                          | Dv : (-1, 0, 0)        |
| Seq. 8: Step                                           | Seq. 9: Step           |
| Dv : (0, -1, 0)                                         | Seq. 10: Through hole  |
| Seq. 11: Face P                                        | Seq. 12: Face P        |
| Dv : (1, 0, 1)                                          | Dv : (-1, 0, 1)        |

**Dv:** Direction vector of tool posture
Table 2 summarizes the recognized 15 machining features in Pattern B. In the machining sequence 1, turning is similarly selected as the machining method for machining features. On the other hand, 5-axis index milling is selected as the machining method for other machining features. Comparing the machining features recognized in Pattern A, it is found that machining feature Step of sequence 6 with the fixed tool posture in Pattern A is recognized as two machining features Step and Face of sequences 6 and 12 with the suitable tool postures in Pattern B as shown in Fig. 11. Therefore, it is understood that machining features can be recognized for 5-axis index milling by the proposed method to determine tool postures and to divide machining primitive for removing the unmachined volume.

Table 2 Result of recognition of machining features in Pattern B. There are 1 feature machined by turning and 14 features machined by 5-axis index milling. The tool postures for each machining primitive are determined with respect to the required overhang length, and machining features are recognized to remove the unmachined volume.

| Tool posture | Unmachined volume |
|--------------|--------------------|
| Machining feature in Pattern A | Machining features in Pattern B |

Unmachined volume

Seq. 6 : Step

Seq. 6 : Step

Seq. 12 : Face

Tool posture

Seq. 6 : Step

Fig. 11 Comparison of machining features recognition in Patterns A and B. In Pattern B, machining primitive is divided according to tool postures to remove unmachinable volume, and two machining features are recognized from the original machining primitive.
Table 3 summarizes the recognized 18 machining features in Pattern C. In the machining sequences 1 to 4, turning is selected as the machining method for machining features, and 5-axis index milling is selected as the machining method for other machining features. Figure 12 shows that the created simplified target shape and the obtained additional cylindrical machining primitive in Pattern C. It is found that the machining features machined by turning can be recognized regardless of the target shape by creating a simplified target shape having a cylinder part for turning.

The results of case study confirm that machining primitives are divided according to the tool postures combination to remove unmachined volume and machining features are successfully recognized for 5-axis index milling by the proposed machining features recognition method. Moreover, cylindrical machining primitives for turning are additionally obtained even when the target shape does not have a cylinder part to increase the flexibility of machining operations on multi-tasking machine tools. As a result, it is found that process planning of 5-axis index milling would be realized based on the machining features recognition method.

Table 3  Result of recognition of machining features in Pattern C. There are 4 features machined by turning and 14 features machined by 5-axis index milling. Cylindrical machining primitives for turning are obtained even when the target shape does not have a cylinder part.

| Tool posture | 5-axis index milling |
|--------------|----------------------|
| Seq. 1: Face C + Boss C | Seq. 2: Face C + Boss C | Seq. 3: Face C + Boss C | Seq. 4: Face C + Boss C | Seq. 5: Step |
| Dv : (1, 0, 0) | Dv : (0, 1, 0) |
| Seq. 6: Step | Seq. 7: Step | Seq. 8: Step | Seq. 9: Step | Seq. 10: Step |
| Dv : (0, 1, 0) | Dv : (1, 0, 0) | Dv : (-1, 0, 0) |
| Seq. 11: Step | Seq. 12: Step | Seq. 13: Through hole | Seq. 14: Face P | Seq. 15: Face P |
| Dv : (-1, 0, 0) | Dv : (0, -1, 0) | Dv : (1, 0, 1) |
| Seq. 16: Face P | Seq. 17: Face P | Seq. 18: Face P |
| Dv : (-1, 0, 1) | Dv : (0, 1, 2) |

Dv: Direction vector of tool posture
As Pattern D, another case study is conducted to confirm that the proposed method can also be applied to process planning of 5-axis index milling on 5-axis controlled machining centers. The assumed 5-axis controlled machining center has two rotational axes B and C. The supposed maximum tool holder radius and the cutting tools are the same as the case study mentioned above, and all machining primitives are machined by 5-axis index milling using milling tools. The target shape and workpiece shape are also the same, and it is assumed that Z axis of the CAD coordinates system agrees with Z axis of the machine coordinate system. The tool postures combinations are determined to minimize the required 5-axis index milling.

Table 4  Result of recognition of machining features in Pattern D. All features are machined by 5-axis index milling on a 5-axis controlled machining center.

| 5-axis index milling | 5-axis index milling | 5-axis index milling |
|----------------------|----------------------|----------------------|
| Seq. 1: Step | Seq. 2: Step | Seq. 3: Step | Seq. 4: Step | Seq. 5: Step |
| Dv : (0, 1, 0) | Dv : (1, 0, 0) | Dv : (0, 0, 1) |
|  |  |  |  |  |
| Seq. 6: Step | Seq. 7: Step | Seq. 8: Step | Seq. 9: Through hole | Seq. 10: Face C + Boss C |
| Dv : (-1, 0, 0) | Dv : (-1, 0, 0) | Dv : (0, 0, 1) |
|  |  |  |  |  |
| Seq. 11: Face P | Seq. 12: Face P | Seq. 13: Face P | Seq. 14: Face P | Seq. 15: Face P |
| Dv : (1, 0, 1) | Dv : (-1, 0, 1) | Dv : (0, 1, 2) |

Dv: Direction vector of tool posture
overhang length for machining primitives. The tool posture that can machine larger volume has the priority for early machining sequence, and the machining primitive that is farther from the center axis of turning spindle has the priority for early machining sequence in the same tool posture. Table 4 summarizes the recognized 18 machining features in this case study. It is found that machining features are recognized for 5-axis index milling and the proposed method can be easily applied to process planning of 5-axis index milling on 5-axis controlled machining centers.

Machining time in each case study is estimated by using a commercial CAM system (ESPRIT 2015, DP Technology Corp.). The workpiece material is assumed to be carbon steel, and cutting conditions are determined based on a tool catalog according to the previous study (Inoue and Nakamoto, 2020). A single point turning tool is selected to machining features of the cylinder type for turning. The drill is applied to machining features of the cylinder type when the tool diameter is the same as the diameter of the machining feature. Square end mills are adopted for the other machining features, and the largest tool is used within the smallest distance between confronting generated surfaces. Table 5 summarizes the estimated machining time, not including the time for tool changes. In Pattern A, two unmachinable primitives are remained because the available tool posture is limited in 3-axis control milling. Though the machining time becomes longer in Pattern B, whole machining primitives are completely machined by 5-axis index milling. In Pattern C, the machining time is the shortest by obtaining additional machining primitives for turning that the cutting speed is relatively high. On the other hand, the machining time is the longest in Pattern D because the target shape is machined only by 5-axis index milling on the 5-axis controlled machining center. From the result, it is found that 5-axis index milling on multi-tasking machine tools realized by the proposed machining features recognition method results in reducing the machining time successfully.

Table 5  Machining time estimated by a commercial CAM system for the four patterns. In Pattern A, unmachinable primitives are remained. Though the machining time becomes longer in Pattern B, whole machining primitives are completely machined by 5-axis index milling. Machining time becomes the shortest by obtaining additional machining primitives for turning in Pattern C. In Pattern D, all machining primitives are machined only by 5-axis control milling.

|                  | Multi-tasking machine tools | 5-axis controlled machining center |
|------------------|-----------------------------|-----------------------------------|
|                  | Pattern A  | Pattern B  | Pattern C  | Pattern D   |
|                  | by turning and 3-axis control milling | by turning and 5-axis index milling | by turning and 5-axis index milling | by 5-axis index milling |
| Time [min]       | 233.3      | 266.4      | 181.1      | 456.8       |

*1 Unmachinable primitives are remained.  
*2 Machining primitives for turning are additionally obtained.

5. Conclusions

This study aims to propose a novel machining features recognition method that can be applied to process planning of 5-axis index milling that is an effective machining method for complex shapes on multi-tasking machine tools. In the proposed method, machining primitives are obtained by dividing the removal volume, and the combinations of tool postures are prepared for each machining primitive depending on the directions in which the machining primitive can be machined. Moreover, cylindrical machining primitives for turning are obtained regardless of the target shape in order to increase the flexibility of machining process on multi-tasking machine tools. The tool postures during 5-axis index milling are determined by referring specific information such as the number of tool postures. The machining primitives are divided again in each determined tool posture to recognize machining features in order to remove unmachined volume. From the conducted case study, it is confirmed that machining features are successfully recognized by the proposed method for 5-axis index milling on multi-tasking machine tools. Moreover, the proposed method is verified to be applied to process planning of 5-axis index milling on 5-axis controlled machining centers.
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