Machining Feature Extraction of Casting and Forging Components

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ABSTRACT

This paper addresses a machining feature identification procedure for casting and forging components. One of the important attributes of casting and forging components is that the machining does not start from a rectangular bounding box, but starts from a rough part model having a near net shape of the final part model. Machining feature extraction for casting components can be divided into two problems; 1) identifying machined areas (machined faces) from the final part model, and 2) grouping the machined areas into clusters, where each cluster can be matched to a machining feature. While the second step has received a significant amount of attention in terms of research, the first step has seen little investigation. One of the few previous approaches for the first step is to conduct a 3D Boolean difference operation to identify machined areas. The approach may be used for simple parts; however, it is not practical for complicated parts because of the computational difficulties of the 3D Boolean difference operation. The objective of this paper is to develop an efficient algorithm to identify machined areas by using the inherent attributes of the problem. The proposed algorithm employs well-known 2D geometric algorithms instead of 3D Boolean operations.

Keywords: machining process planning, feature extraction, casting and forging.

1. INTRODUCTION

In the manufacturing industry, process planning refers to determining the necessary manufacturing operations and their sequence in order to fabricate a given part economically and competitively. The purpose of computer-aided process planning (CAPP) is to generate a process plan automatically for manufacturing parts with minimal human intervention [12-14]. To accomplish this task, it is necessary to generate the appropriate manufacturing information from a product model. In this regard, the use of features is considered a technology that will act as a bridge between design and manufacturing. Depending on the application domain, there are various types of features, such as design features, machining features, assembly features and inspection features. This paper is restricted to machining features, which can be considered as a portion of a part having some machining significance and can be created by machining operations. Although CAPP has long been considered a key technology to improve the product development process, there remain gaps to implement a practical CAPP system. One of the major issues for the implementation of a practical CAPP system is how to extract machining features automatically.

As shown in Figure 1, machining mechanical components can be classified into two different categories according to the stock (rough part model): 1) a cube-shaped stock, and 2) a stock that is designed and manufactured by processes such as casting and forging so that it has a near net shape of the final part. While the former case assumes that a part is created entirely by machining operations starting from a rectangular bounding box, in the latter case the machining operations are carried out only on the portions where high accuracy is required, such as for fits and assembly. Since the latter type stock (casting, forging) has less material removal volume than a cube-shaped stock, it has been preferred in terms of reducing machining time [1, 3]. In the case of parts produced in high volumes, casting or forging stock is more desirable, and has been commonly used in automobile and machine tool manufacturing industries. This paper focuses on the machining feature extraction of casting and forging components.

There is a wide body of literature in the area of feature extraction, but most previous research in machining feature extraction assumes the case where the final part is produced by machining operations on a cube-shaped stock [5-10]. There are various approaches to generating machining features, such as a graph-based approach [5, 6], a convex hull decomposition approach [7], a cell-based decomposition approach [9, 10], and a hint-based approach [8]. When one of these approaches is applied to casting and forging stocks, problems inevitably arise because they assume a rectangular block as the stock.

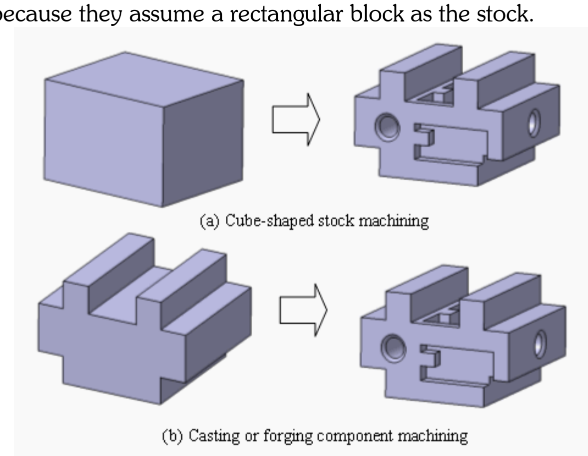

Fig. 1. Two types of stocks (rough part models)

Only a few research results [1-4] are available for the machining feature extraction of casting and forging components. Kim and Wang [3] proposed a method to generate a stock model for machining and used the stock model for machining feature extraction by applying a volume decomposition method called alternating sum of volumes with partitioning. Kailash et al. [1] addressed an interesting method based on a process centered approach. The method consists of three steps: 1) obtaining the machining removal volumes by conducting a 3D Boolean difference operation between the stock and the final part model; 2) identifying machined faces from the removal volumes; and 3) grouping the machined faces into clusters, where each cluster can be produced by a single machining operation. In designing the procedure, they carefully considered the attributes of the machining of casting components, which were not covered by previous works assuming a cube-shaped stock. Although the procedure proposed by Kailash et al. is suitable for machining feature extraction of casting and forging components, there is a computational difficulty in conducting a 3D Boolean difference operation. If the component model is simple, the 3D Boolean difference operation can be conducted without difficulty. Figure 2 shows the machining volume computation of a connecting rod having a relatively simple shape. Let's consider the more complicated parts shown in Figure 3. Even for commercial CAD systems, it is extremely difficult to conduct a 3D Boolean operation for such complicated models consisting of thousands of faces. Because of this problem, Kailash et al.'s method may not be suitable for handling parts with complicated shapes.

The objective of this paper is to develop a practical procedure for machining feature extraction of casting and forging components. To avoid the computational difficulty, noted above, the proposed procedure employs 2D geometric algorithms instead of costly 3D algorithms, such as a 3D Boolean difference operation, which is expensive and unstable for complicated models.

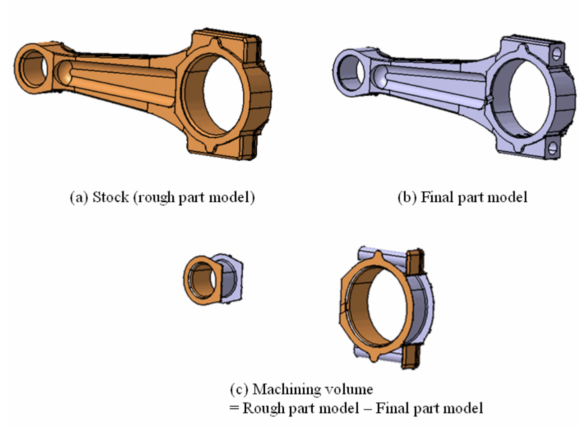

Fig. 2. Machining volumes of a connecting rod

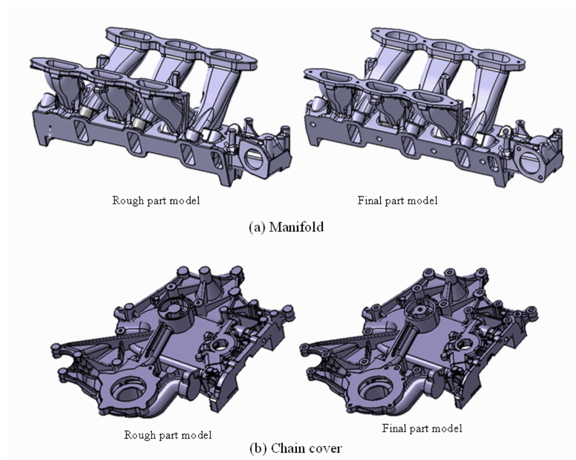

Fig. 3. Components with complicated shapes

The remainder of this paper is organized as follows: Section 2 addresses the approach of this paper to machining feature extraction; Section 3 provides a detailed description of identifying machined areas from a final part model; and, finally, concluding remarks are presented in Section 4.

2. APPROACH TO EXTRACT MACHINING FEATURES

One of the important issues in handling features is their representation. In the literature [15-18], there are generally two approaches in representing features, the superficial approach and the volume approach. While the superficial approach defines features as sets of faces having topological relationships, the volume approach uses volumes to represent features. For the machining features of casting and forging components, the superficial approach may use the machined areas from a final part model (Figure 4(c)), and the volume approach uses the machined volumes from a rough part model (Figure 4(d)). If a large amount of material should be removed from the rough part model, the material removal volumes have significant meaning in process planning. In this case, the volume approach would be more desirable to represent machining features, because process engineers need to carefully consider the amount of material removal volumes to determine how many and what kinds of machining operations should be applied to the stock. As shown in Figure 4(c), if the volume difference between the rough part model and the final part model is relatively small and even, the machined areas from the final part model provide better information for process planning than the material removal volumes. The machining of casting and forging components falls into this category. Consequently, this paper employs the superficial approach and focuses on finding the machined areas from a final part model.

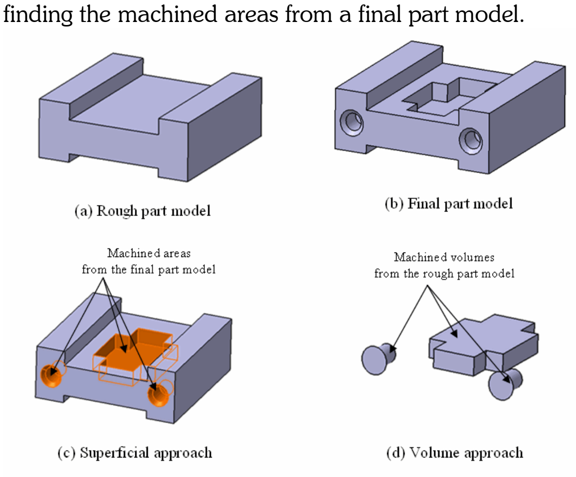

Fig. 4. Two ways of machining feature representation

For casting and forging components, the general approach of machining feature extraction consists of two steps; 1) identifying machined areas from a final part model, and 2) grouping the machined areas into clusters, where each cluster corresponds to a machining feature. The first step has computational issues (efficiency, robustness), and the second step can be considered as a pattern matching problem. It is the first step that distinguishes this problem from a general machining feature extraction problem starting from a cube-shaped stock. Although there are quite a few available solutions [1, 3, 5-10] for the second step, the first step has seen relatively little attention. For the first step, it is necessary to compare two solid models, a final part model and the corresponding rough part model. For a comparison of two solids, the most intuitive approach would be to conduct a 3D Boolean difference operation. However, this has a serious computational difficulty for complicated models for the following reasons: 1) a final part model and its rough part model are very similar (Figure 3) and contain many identical faces which might cause problematic degeneracy cases for a 3D Boolean difference operation, and 2) a 3D Boolean difference operation is computationally very expensive which means it will require excessive computational costs to conduct the operation for complicated models consisting of thousands of faces. To avoid these computational difficulties, a new algorithm is developed and described in the next section. The algorithm finds machined areas from a final part model by using 2D geometric algorithms instead of a 3D Boolean operation.

3. MACHINED AREA IDENTIFICATION

To develop an efficient algorithm for identifying machined areas, it is necessary to carefully observe the inherent attributes of the problem involving two solid models, a rough part model and a final part model. There are two important attributes which distinguish this problem from general solid comparison problems; 1) a rough part model always encloses the corresponding final part model, and 2) a rough part model and the final part model are very similar and have many identical faces, as shown in Figure 3. These attributes provide the possibility of developing a more efficient algorithm than the general algorithms, such as a 3D Boolean difference operation. By utilizing the first attribute of the problem, we can easily determine whether a point on a final part model belongs to a machined area. Because a rough part model always contains the final part model, any points on the final part model need to be machined if they do not exist on the skin of the corresponding rough part model. We will expand this aspect to develop an algorithm for identifying machined areas from a final part model. The following are several term definitions that are used throughout the paper.

Definition 1 (R-areas): Portions of the skin of a rough part model is *R-areas* if they do not exist on the skin of the final part model (See Figure 5(c)).

Definition 2 (C-areas): Portions of the skin of a final part model is *C-areas* if they also exist on the skin of the rough part model (See Figure 5(d)).

Definition 3 (F-areas): Portions of the skin of a final part model is *F-areas* if they do not exist on the skin of the rough part model (See Figure 5(e)).

By definition, *F-areas* are the same as machined areas, because any portion of a final model needs to be machined if it does not exist on the skin of the rough part model. One interesting point here is that the sum of *R-areas* and *F-areas* bounds the machined volumes. In other words, it is possible to identify machined areas and machined volumes as well by using *F-areas* and *R-areas*. Then the question is how to compute those areas in an efficient way.

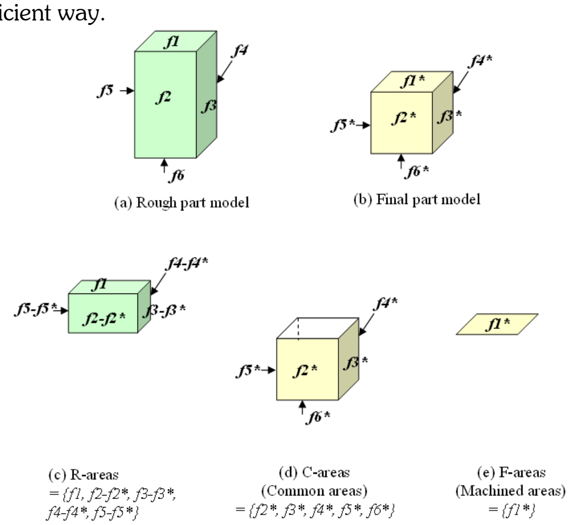

Fig. 5. Definitions of R-areas, C-areas and F-areas

A solid model consists of faces, and a face can be defined as a combination of a parent surface and a trimming curve on the 2D domain. The following algorithm identifies *F-areas* by conducting 2D Boolean difference operations on the domains of parent surfaces.

Identifying F-areas (Machined areas) by conducting 2D Boolean difference operations

// Input: a final part model and a rough part model.
// Output: F-areas (machined areas from the final part model).
Step 1) F-areas = ø;
Step 2) Initialize a set of parent surfaces (PS[i], 1 ≤ i ≤ n) from the final part model;
Step 3) For (i= 1; i ≤ n; i++) { // for each parent surface.
Step 3-1) S_F = a set of faces of the final part model whose parent surface is PS[i];
Step 3-2) S_R = a set of faces of the rough part model whose parent surface is PS[i];
Step 3-3) If (S_F == S_R) continue;
Step 3-4) A_F = trimming areas of S_F on the 2D domain of PS[i];
Step 3-5) A_R = trimming areas of S_R on the 2D domain of PS[i];
Step 3-6) A_B = subtract A_R from A_F;
Step 3-7) Convert A_B into 3D areas and add to F-areas;
}
Step 4) Output F-areas;

To evaluate the efficiency of the algorithm, we need to consider two aspects; 1) the algorithm is based on a 2D Boolean difference operation [11] instead of a general 3D algorithm, and 2) the number of 2D Boolean difference operations would be much smaller than the number of faces because of Step 3-3, which skips the 2D Boolean difference operation if $\boldsymbol{S_F}$ is the same as $\boldsymbol{S_R}$ (Remember the two solid models are very similar and have many identical faces.). The other advantage of the algorithm is that it is not limited to the types of faces as long as they can be expressed as a combination of a trimming curve and a parent surface. The implementation of the algorithm is also intuitive and simple, because it is based on a 2D Boolean difference operation. Figure 6 shows a final part model and its rough part model. Let's assume that ***f1**** and ***f1*** share the same parent surface which is a vertical plane ***PS[1]***. Then Steps 3-4 and 3-5 identify $\boldsymbol{A_F}$ and $\boldsymbol{A_R}$ as shown in Figure 6-(c) and (d). Step 3-6 conducts a 2D Boolean difference operation, subtracting $\boldsymbol{A_R}$ from $\boldsymbol{A_F}$. In this case, $\boldsymbol{A_B}$, which is the result of the 2D Boolean difference operation, is empty because $\boldsymbol{A_R}$ contains $\boldsymbol{A_F}$. This means ***f1**** has no portions to be machined. Figure 7 shows another example. Figures 7-(a) and (b) show two faces, ***f2**** and ***f2***, which belong to the same parent surface ***PS[2]***. Then their trimming areas ($\boldsymbol{A_F}$ and $\boldsymbol{A_R}$) can be identified as shown in Figure 6-(c) and (d). In this case, $\boldsymbol{A_F}$ is bigger than $\boldsymbol{A_R}$ and hence some portions of ***f2**** need to be machined. Figure 7-(e) shows the result of the 2D Boolean difference operation of Step 3-6 ($\boldsymbol{A_B}$). Step 3-7 converts $\boldsymbol{A_B}$ into 3D areas, as shown in Figure 7-(f). In this way, we can very easily identify all machined areas from the final part model. Figure 8 shows the machined areas (***F-areas***) that are identified by the proposed algorithm. A more complicated example of machined area extraction is shown in Figure 9.

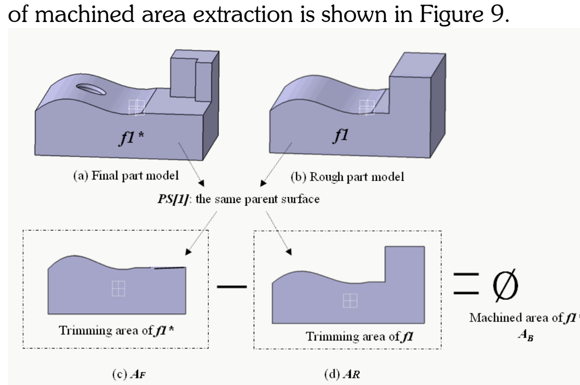

Fig. 6. Machined area extraction from ***fl****

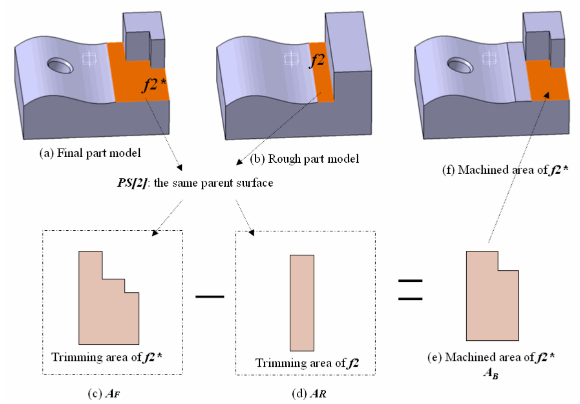

Fig. 7. Machined area extraction from ***f2****

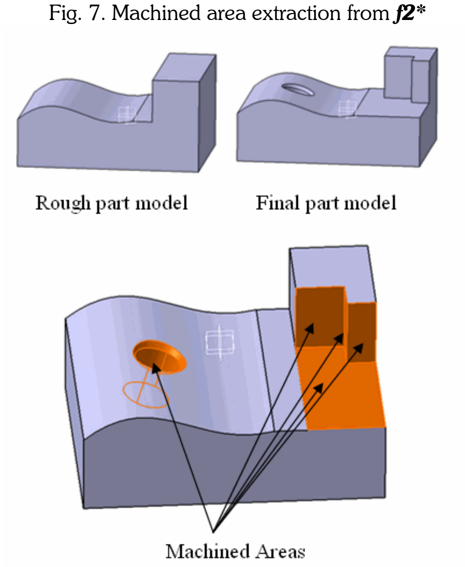

Fig. 8. Extracted machined area

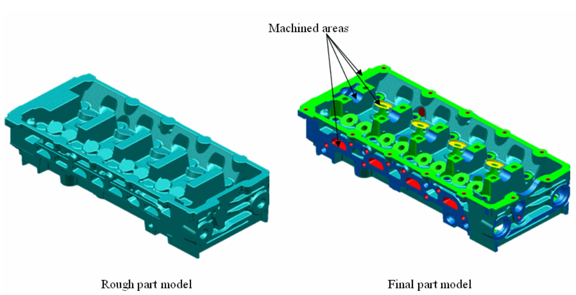

Fig. 9. A complicated example

Even though, the proposed algorithm focuses on the identification of machined areas from a final part model, it also can be easily expanded for identifying machined volumes from a rough part model. As discussed earlier, the sum of *R-areas* and *F-areas* exactly bounds the machined volumes from a rough part model. We can easily change the *F-area* extraction algorithm for identifying *R-areas* by replacing Step 3-6 with '$\boldsymbol{A_B}$ = subtract $\boldsymbol{A_F}$ from $\boldsymbol{A_R}$;'. As a result we can identify the machined volumes from a rough part model by using *F-areas* and *R-areas*.

4. CONCLUSIONS

This paper deals with a procedure for the machining feature extraction of casting and forging components, and the main focus is to identify machined areas from a final part model. In the case of casting and forging components, the input for machining feature extraction includes two solid models, a final part model and the corresponding rough part model. By comparing these two solid models, we need to identify the machined areas from a final part model. To develop an efficient algorithm, this paper makes use of two distinctive attributes of the problem; 1) a rough part model always encloses the corresponding final part model, and 2) a final part model and its rough part model are very similar and have many identical faces. Based on these two attributes, this paper proposes an efficient algorithm identifying machined areas. The algorithm is based on a 2D Boolean difference operation which is cheap and stable compared to 3D algorithms. Even though, the proposed algorithm has been developed for machined area extraction, it can be expanded for identifying machined volumes from a rough part model.

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