

# **Make-up Fabrication of Big or Complex Parts Using the SLA Process**

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## **ABSTRACT**

Rapid prototyping is a highly flexible manufacturing technology which can produce big or complex parts without any special fixtures and tools. But it is often a costly and time consuming process to produce big and complex parts. To solve this problem, this paper proposes the make-up fabrication process. The process cuts the CAD models of big or complex parts into several small components, optimizes the building orientation and the layout of the multiple objects and then uses the SLA process to build. The paper discusses the basic process, the discretion rules of the CAD models and the optimization of the layout of multiple objects in the simultaneous building.

## **Introduction**

Rapid prototyping has brought new thoughts into the manufacturing engineering. It is a highly flexible manufacturing technology which can produce complex parts without any special fixtures and tools. By using discretion-accumulation shaping principle[1], rapid prototyping technology is totally different from traditional forcing (e.g. moulding or forming) and removing (e.g. milling or turning) manufacturing processes. The process has the following characteristics:

- Manufacturability is independent of the complexity of the parts;
- Manufacturing cost is independent of the batch of the parts.

This means that when changing the shapes, batches, and processing requirements of the parts, there is no need to re-design and re-manufacture the special tools. By modifying the CAD models and adjusting the process parameters, the new parts can be built quickly.

Although the history of rapid prototyping is short, the development of this technology is very fast. According to the present status of the rapid prototyping techniques, there are still many aspects to be improved. For example, most RP machines cannot build big parts, the processing accuracy cannot meet the industrial requirements, the processing time is very long, and the

processing cost is still very high. To solve these problems, this paper proposes the make-up fabrication process. Make-up fabrication process [2] means that cut the CAD models of the big or complex parts into several simpler or smaller components according to their geometrical features before building the part, optimize the building orientation, generate support structures, optimize the space layout, and then build the physical models by the traditional RP processes.

## **The Basic Steps and Advantages of the Make-up Fabrication**

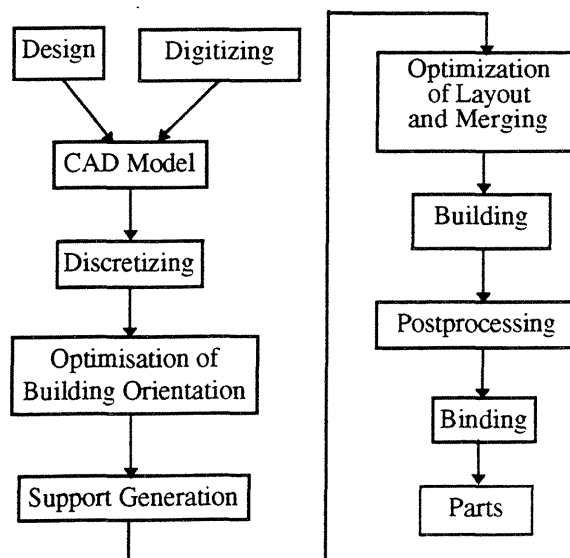
From the application point of view, it is feasible to build big or complex parts using the make-up method with this technique. The basic steps are shown in Figure 1. The following briefly describes this process.

### ***Construction of the CAD model***

The construction of the CAD model can be achieved using a CAD software or by reverse engineering using digitizing methods. This procedure is not different from the routine design; it provides a data model for further processing.

### ***Discretion of the big or complex parts***

Discretion means to cut the complex or big parts into several simpler and smaller pieces for convenient building in the fabrication process. For the maximum use of the SLA technique, the cutting principles of the CAD models are to simplify the complex or big parts into simpler and smaller ones that can be easily handled. This can be done according to the geometric feature and characteristics. The discretized parts should utilize planar surfaces as much as possible. The number of cutting surfaces can be one, two, three or even more.



**Fig 1** The make-up fabrication process

### ***Optimization of the building orientation***

Building orientation can greatly affect the final processing accuracy of the parts. It is very

important to choose an optimal orientation for part building. Factors must be considered in this step including accuracy, building time, and support generation, etc. After these factors are examined, the final orientation is determined for the building process.

### ***Support generation***

After the optimal orientation has been chosen, the support will be generated for the subsequent operations. Because of the simplification of discrete, the support structure can be more easily constructed. This step can be achieved by the existing RP software.

### ***Layout optimization and merging***

After all the necessary supports have been generated, the components of the parts must be merged to form a single model file. In such case, the effective use of the building space is very important. The layout of the components should consider 2D and 3D cases to achieve a good use of the building space.

### ***Slicing and building***

In this stage, 3D models will be sliced into 2D cross-sectional contours for building. For most SLA processes, the slicing thickness is constant. In the make-up fabrication process, the constant thickness is applicable. The time-saving of using variable slicing is not obvious to this process. The building process can be the same as the existing SLA process.

### ***Post-process***

Post-process includes the removal of the support structures, surface finishing, position and gluing, and the post cure processes. Because of the simplicity of the supports, the post-process (cut the supports off, then position and glue all the components into a complete one) is simpler. Besides the position and gluing, the post-process is quite similar to the traditional SLA process.

### ***Advantages***

The make-up process has more advantages than that of the traditional rapid prototyping processes. Generally speaking, it has three main advantages:

- Improve the processing accuracy. Because all components of big or complex part are built by their own optimization orientation, every part can achieve its highest accuracy.
- Simplify the generation and removing of the support structures. Because there are no hang-up and other slope surfaces, all the support structures can be based on the bottom planes. These will simplify the generation and removing of the support structures.
- Reduce the building time. Because the height of fabrication is reduced, the total building time will be greatly reduced.

## **Geometrical Discretion of the CAD Models**

The geometrical discretion is the key procedure in the make-up fabrication process. The results of the discretion will directly affect the processing time and accuracy. The general principle of the

discretion of the CAD models is to cut the models based on geometrical features. It is known that most CAD softwares are feature-based modeling systems. In the make-up fabrication process, the discretion is also based on features, but the process is reversed. The make-up fabrication is also called feature-based manufacturing process [3]. The following discusses the basic rules to discretize the CAD models:

1. Cutting the cantilever structures. In the SLA process, cantilever structures directly affect the processing accuracy, building time and stability. But the cantilever structures are very common in the actual parts. Cutting the cantilever structures from the CAD models will greatly improve the processing accuracy (the cantilever structures are composed of horizontal cylindrical surfaces or other lower-slope surfaces), shorten the building time (for long or big parts, discrete components will greatly reduce the building height), and increase the stability in processing (when one part is cut into several pieces, the center of gravity will be lowered).

The cutting pattern will be dependent on the geometrical features, processing requirements, possible building orientation and user's experience. The cantilever structures can be cut by a plane or a regular surface.

2. For the rotational parts, the cutting strategy is to cut the part in several segments equally. This discretion will improve the building efficiency without affecting the surface accuracy. For example, the tibia bone, often used in medical applications, is a thin and long bone. If the bone is built in a horizontal direction, the generation of the support is difficult and the surface finish is poor. When it is built in a vertical direction, the building time will be much longer. When using geometrical discretion methods, the long and thin bone can be cut into several pieces. Building the components in a vertical direction, the generation of the support structures will be simpler, the building time is shorter and the processing accuracy also becomes better.

3. For free form and cylindrical surfaces, if the result of orientation optimization is not satisfactory, the geometrical discretion could be used to cut the solid with the free form or cylindrical surfaces. For example, when the angle between the normal vector of the surface or the axis of the cylinder with the building direction is greater than  $30^{\circ}$ , the surface or cylinder should be cut off to form a new building unit. The cutting boundary should adopt the original boundary as much as possible. The cutting plane should be a plane so as not to generate new surfaces.

4. For the parts with a down-slope surface, the parts should be discretized. Generally speaking, the down-slope surface needs complex support structure. This means that the generation and removing of the support structure will be more difficult. Besides, this building case also leads to a bad surface finish. Hence, this kind of features should be discretized and then built separately.

5. For the slope plane, it should be discretized. The result should make it possible to realize the slope plane either parallel or perpendicular to the building direction.

## The Optimization of the Building Orientation

The optimization of the building orientation is a very important procedure to obtain high processing quality and efficiency. It will greatly affect the processing accuracy, time and stability and support generation. There are many literatures [4~6] devoted to this topic. For example, Cheng [4], et al., developed the building orientation algorithm based on the multi-objective optimization in which the processing accuracy is used as the primary objective and the building time as the secondary objective. Seth and Dutta [5] investigated this problem using the generation of the support structures. Frank and Fadel [6] tried to solve this problem using the expert-system-based selection for the preferred build direction. Because of the complexity of the orientation, it is hard to optimize the building orientation considering all factors. In this paper, a new method which considers the processing accuracy and building time simultaneously will be used (by using discretion method, the support structures will become quite simple, and the stability can also be greatly enhanced).

Suppose the objective function of the orientation optimization to attain the best possible accuracy is defined as [4]:

$$Q = \vec{N}_i \vec{\xi} \quad (i = 1, 2, \dots, m) \quad (1)$$

or

$$Q_i = \sum_{j=1}^n N_{ij} \xi_j \quad (-1 \leq \xi_j \leq 1) \quad (2)$$

where:

$Q_i$  = the objective value of the  $i$ th orientation of the built part;

$\xi = (\xi_1, \xi_2, \dots, \xi_n)$  the weighting vector consisting of the weights assigned to each surface type;

$N_{ij} = (N_{i1}, N_{i2}, \dots, N_{in})$  the input vector consisting of the numbers associated with the surface types for the respective orientation;

$i$  = the  $i$ th orientation of the part;

$j$  = the  $j$ th type of the surface of the part in an orientation;

$n$  = the possible number of surface types in an orientation; and

$m$  = the possible number of orientations for building the part.

By using the above functions, the objective values of all possible building orientations can be calculated.

For the objective function of the building time, it can be calculated by the following equation:

$$R_i = n_i t_w + \sum_{j=1}^{n_i} \frac{A_{ij}}{u} \quad (3)$$

where:

$R_i$  = the objective value of the  $i$ th orientation of the building time;

$n_i$  = the slicing number of the  $i$ th orientation;  
 $t_w$  = the waiting time between the layer building;  
 $u$  = the scanning area of the laser beam in the unit time; and  
 $A_{ij}$  = the area to be scanned on the  $j$ th cross-section under the  $i$ th building orientation.

Hence, when considering the above two factors simultaneously, the final objective function of the optimization of the building orientation is given by:

$$P_i = \frac{Q_i}{R_i} \quad (4)$$

In this equation,  $Q_i$  is the objective value of the processing accuracy in the  $i$ th orientation,  $R_i$  is the objective value of the processing time in the  $i$ th orientation.  $P_i$  is the objective value, the ratio of the processing accuracy to the processing time and it is similar to the ratio of the performance to price. The bigger the  $P_i$  is, the better the processing quality will be. Thus the maximum objective value of the optimal building orientation should be:

$$P_{max} = \max \{ P_i \} \quad (i = 1, 2, \dots, m) \quad (5)$$

where  $m$  is the number of the candidate orientations.

### **The Optimization of the Layout of Multiple Parts in Simultaneous Building**

For the make-up fabrication process, after the parts are discretized into several components, it is natural to consider the layout of the multiple parts in the simultaneous building. If the parts are randomly placed on the building platform, the processing efficiency, cost and time will not be optimized. For the best use of the building space, reducing the building time and improving the building efficiency, optimizing the layout is necessary. For the simple and few discrete components, the layout can be easily determined by experienced users. But for complex and big components, the optimal layout will be difficult to determine intuitively.

For the layout optimization, it is assumed that the user has oriented the part for the desired build, using the multi-objective progressive optimization method [4] or an expert system [6]. Then the layout can be divided into two categories: one is the 2D layout, the other is the 3D layout [7]. The main objectives in the 2D layout are the better usage of the building platform and the close packing of the parts. The objectives of the 3D layout focus on maximizing the number of parts and the volume of the vat that is utilized. The detailed algorithms about multiple part placement can be referred to literature [7].

### **Case Study**

Figure 2 gives the CAD model of an example brake part. With the optimization algorithm of the building orientation, the result is given in Figure 3. From the figure, it is easy to find that although the overall processing accuracy can reach the best result, there are still two cylindrical

surfaces and one slope plane which are not placed in the optimal direction. So the good accuracy cannot achieve. In such case it must be discretized into several pieces so that the building accuracy can be improved. Besides, because of the horizontal placement of the cylinder, one small area contacts with the building platform, the support generation and the stability are also not good. After the building, it is also difficult to remove the support structures from the part.

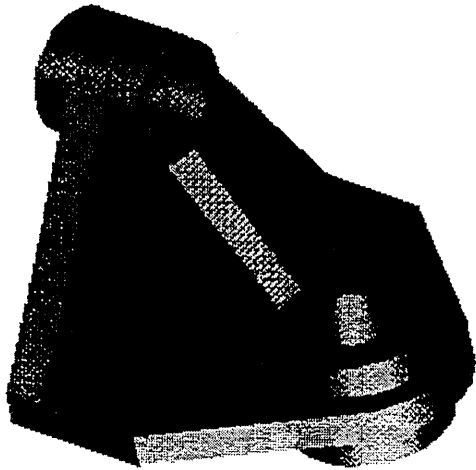


Fig. 2 The CAD model of the brake

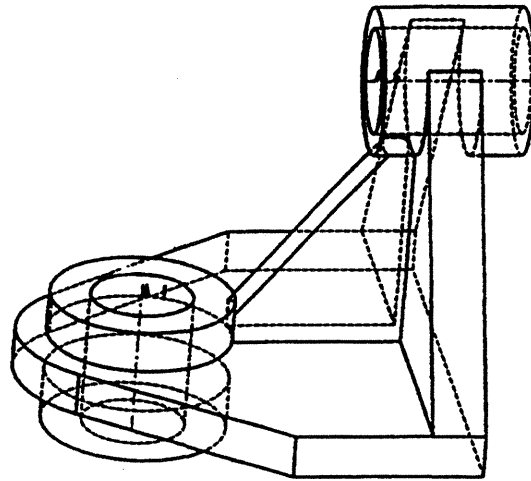


Fig. 3 The optimal building orientation

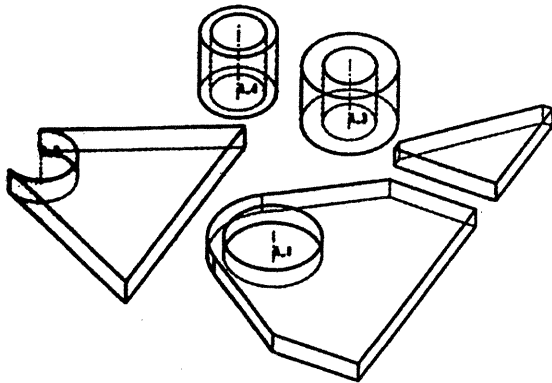


Fig. 4 The discretization result of the CAD model

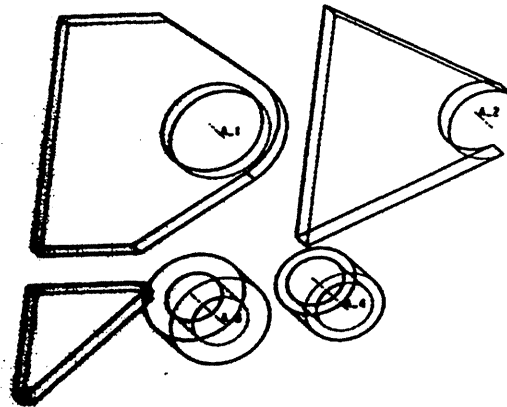


Fig. 5 The optimization of the layout

By using the make-up fabrication process, the problems can be solved. According to its geometrical features, the CAD model can be discretized into five components, as shown in Figure 4. All these components are very simple in geometry and very easy to optimize the building orientation and generate or remove the support structures. Besides, because of the building height is lowered, the building time can also be reduced. Figure 5 gives the final layout of the five components when they are built.

## **Conclusion**

In this paper, the make-up fabrication process has been proposed and discussed. The process discretizes the big or complex parts into small or simple components so as to achieve the better processing accuracy, reduce the building time, simplify the generation of the support structures and enhance the processing stability of the SLA process. The paper presents the cutting rules to an existing CAD model and gives the discussions on the optimizations of the building orientation and the layout when multiple parts are built simultaneously.

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