

Research on Disassembly Sequence Planning Method for Maintenance

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Abstract—Some parts of mechanical products often need to be replaced or repaired for maintenance. The complexity of the internal structure of machine makes the disassembly sequence planning the focus of researches. A three-dimensional disassembly sequence planning method is put forward in this paper based on the interference relationship of parts and components of complex machine. In this method, the hierarchical disassembly model of complex structure of machine was built based on group technology to express the mechanical products using parts and components after removability analysis. The three-dimensional nested combinatorial interference matrix was designed based on traditional interference matrix on several dimensions and the nested structure of matrix to express the disassembly relationship corresponding to the hierarchical model. The disassembly difficulty factor was introduced to determine the optimal disassembly sequence. An example was used to verify the rationality and effectiveness of the method. The method provided a new perspective of disassembly sequence planning and can be easily applied in engineering.

Keywords-disassembly;sequence;planning;matrix;mechanical;

I. INTRODUCTION

Failure happens inevitably for mechanical products while using, which requires some parts of mechanical products to be replaced or repaired for maintenance. Research on disassembly sequence planning for maintenance is helpful to figure how quickly and efficiently the specified parts can be removed while the parts involved are as few as possible, in order to improve maintenance efficiency and speed up the maintenance process. Researches have been done on the planning method based on interference matrix [1]-[4]. The hierarchical or modular planning methods [5]-[10] and the sequence optimization methods [11]-[12] have also been studied.

To optimize the disassembly sequence, a disassembly sequence planning method for the maintenance is proposed. A mechanical product was firstly divided to build the hierarchical disassembly model based on group technology, and an improved three-dimensional nested block interference matrix was used to express the disassembly relationship. Finally, the disassembly difficulty factor was introduced to determine the optimal disassembly sequence.

Compared with previous studies, this method can expand disassembly directions, reduce the number of

interference matrix, and, to some extent, avoid combinatorial explosion of disassembly of complex mechanical products. At the same time, due to the introduction of disassembly difficulty factor, a new method for disassembly sequence optimization would be put forward.

II. THE NESTED COMBINATORIAL MODEL FOR DISASSEMBLY

In order to avoid combinatorial explosion and by the principles of mechanical disassembly, the parts, components and assemblies in the composition of a complex mechanical product were grouped according to the disassembly relationship based on the idea of group technology after removability analysis.

The two principles of grouping complex products were:

- The parts that can be removed separately should be numbered individually;
- The components, assemblies, or a group of parts that can be removed separately should be numbered as an individual, to be removed as a part in the disassembly.

According to these principles, a mechanical product would be broken down into parts and components, and the components may also be nested with other components. Thus, the nested combinatorial model of a mechanical product for disassembly can be constructed with parts and components nested.

Suppose the total of parts and components in a mechanical product is n . The hierarchical nested combinatorial model for disassembly could be composed as shown in Fig. 1, in which components and parts can be equally obtained in one same layer.

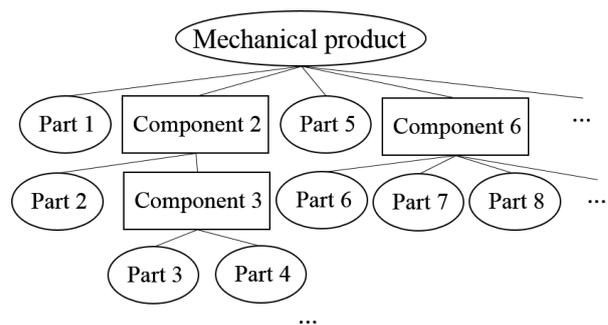


Figure 1. The hierarchical nested combinatorial model

III. THE THREE-DIMENSIONAL DISASSEMBLY RELATIONSHIP MATRIX

The traditional interference matrix method uses one matrix to show the interference relationship of parts and components in one direction, so that 6 matrices are required to indicate 6 directions such as $\pm X, \pm Y, \pm Z$. Because of this, the disassembly sequence planning based on traditional interference matrix demands to deal with several matrices, and the sequences generated also need to be furtherly optimized. During this optimization, the disassembly difficulty cannot be quantified for there are only “1” and “0” used in the interference matrices.

A new expression of interference matrix, noted as the disassembly relationship matrix, was designed to solve these problems. The two-dimensional interference matrix was improved to three-dimension to bare the interference relationship on three directions. Meanwhile, the disassembly difficulty factor of parts and components was introduced in the interference matrix instead of the original composition of just “1” and “0”, which made it possible to generate an optimal disassembly sequence and the optimal disassembly directions for every part in the sequence simply depending on the matrix itself. Definition of the disassembly relationship matrix is introduced.

Definition 2.1: $\mathbf{R} = (r_{ijk}) (i, j = 1, 2, \dots, n; k = 0, 1, 2, 3)$

is defined as the disassembly relationship matrix.

Where k stands for three disassembly directions.

When $i \neq j, k \neq 0, r_{ijk}$ is the interference relationship for removable part or component j to i on direction k , $r_{ijk} = 0$ means no mutual interference, $r_{ijk} = 1$ means the existing of mutual interference; when r_{ijk} is invalid, it will be set to NULL, in a model of n parts and components, there are always $n^n - (3A_n^2 + n)$ elements should be NULL.

Definition 2.2: The disassembly difficulty factor indicates the disassembly difficulty of each part in the product.

In the disassembly relationship matrix, when $i=j$ and $k=0$, r_{ijk} stands for the disassembly difficulty factor of the part or component i , $r_{ijk} \in (0, 1)$. Larger number means the disassembly is harder.

The disassembly relationship matrix can be nested, that is, the main diagonal elements of the matrix can be a sub-matrix to represent the inside disassembly relationship of a component. The disassembly relationship and level relationship expressed by the matrix was corresponding to the hierarchical nested combinatorial model in Fig .1. The level in Fig .1 was corresponding to the nested level in disassembly relationship matrix. The parts in the figure corresponded to the main diagonal elements of the matrix, and the components corresponded to the sub-matrices on the main diagonal of the matrix. To

extinguish parts and components, a flag was added to the disassembly difficulty factor with “ R ” for the components and “ r ” for the parts. For example, the disassembly difficulty factor flagged with “ R ” meant that it’s corresponding to a sub-matrix of disassembly relationship on its position.

The disassembly relationship matrix \mathbf{R} corresponding to the Fig .1 is shown in Fig .2. There are three dimensions in this disassembly relationship matrix. However, matrices on other directions can also be established according to the demand of disassembly, such as \mathbf{R}^{45} for three oblique 45° directions etc.

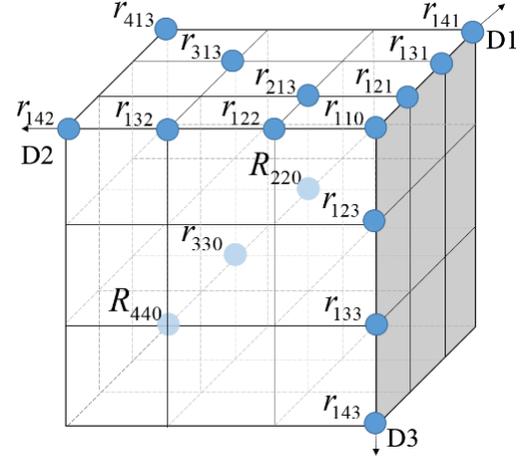


Figure 2. The disassembly relationship matrix

Definition 2.3: The disassembly sequence tree T is defined to record the disassembly sequence generated.

IV. THE OPTIMAL DISASSEMBLY SEQUENCE PLANNING METHOD BASED ON THE DISASSEMBLY RELATIONSHIP MATRIX

A. The generation of disassembly sequence tree

Setting some certain part as the target part of removing, there can be several sequences by which the target part can be removed in different orders. After building the hierarchical nested combinatorial model and the disassembly relationship matrix, all the possible disassembly sequences can be selected and documented as the disassembly sequence tree in following algorithm.

- 1) Given the disassembly target part p^* , note the current target as p ;
- 2) Search the location of p^* . If p^* is in a component P , then initialize $P = p^*$; if p^* is not in any component, then initialize $P = p^*$;
- 3) Iterate the value of $r_{pj k} (j = 1, 2, \dots; k = 1, 2, 3)$ through matrix \mathbf{R} (in all trips, the NULL elements shall be ignored). If:

- a) there are all $r_{pj1} = 0$, or all $r_{pj2} = 0$, or all $r_{pj3} = 0$, then list p in the disassembly sequence tree T , if:

$p = p^*$, then terminate the search;

$p = P$, then set $\mathbf{R} = \mathbf{R}_{pp0}$, reset target $p = p^*$, return to Step 3;

Otherwise, remove all r_{pjk} and r_{ipk} , return to Step 2;

b) there are all $r_{pjk} = 1$, then terminate the search;

Otherwise, for all elements q which makes $r_{pqk} = 1$ when $j = q$, set $p = q$, and return to Step 2.

Thus, the disassembly sequence tree T can be generated recording all the possible disassembly sequences and the disassembly direction of each part and component.

B. The generation of optimal disassembly sequence

The disassembly sequence tree T contains all the possible disassembly sequences. The optimal disassembly sequence can be generated in following algorithm.

1) Divide the disassembly sequence tree T into disassembly sequences $\{t\}$, and the total number of sequences is m ;

2) The optimal disassembly sequence is generated as:

$$\min \left(\underbrace{\dots, \sum_m r_{t0}, \dots}_{m} \right)$$

V. THE APPLICATION EXAMPLE

The valve in Fig .3 was used as an example to verify the method above. The disassembly target was part 4, the steel ball.

Parts of the valve in Fig .3 are 1.bar; 2.plug; 3.valve body; 4.steel ball; 5.spring; 6.joint; 7.cock. The parts in valve can be removed from right or left, and the valve body could be removed from its location from upper direction if needed. Therefore, the three disassembly directions chosen were $+X, -X, +Y$ as shown in Fig .3.

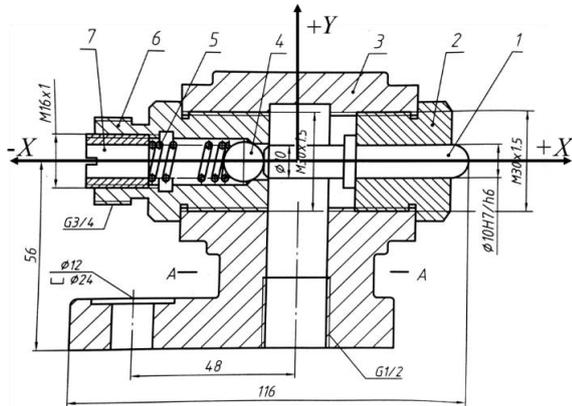


Figure 3. The structure of Valve

The steel ball (part 4) needed to be removed for maintenance, hereinafter it was set as the disassembly target. While the steel ball was stuck by the spring and the cock inside of the joint, the part 4, 5, 6 and 7 could compose a component, here noted as component 4.

The bar, plug and component 4 were located independently inside of the valve body, so that the valve was divided into part 1, part 2, part 3 and component 4.

The nested combinatorial model of this valve is shown in Fig .4.

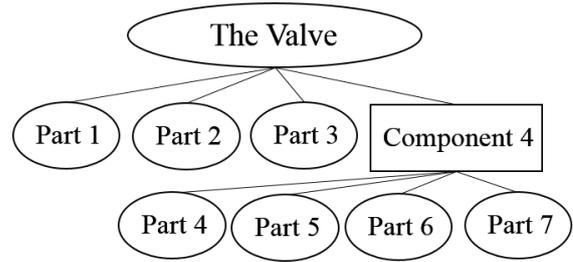
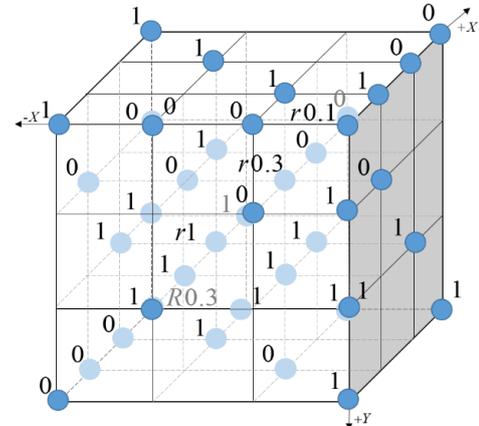


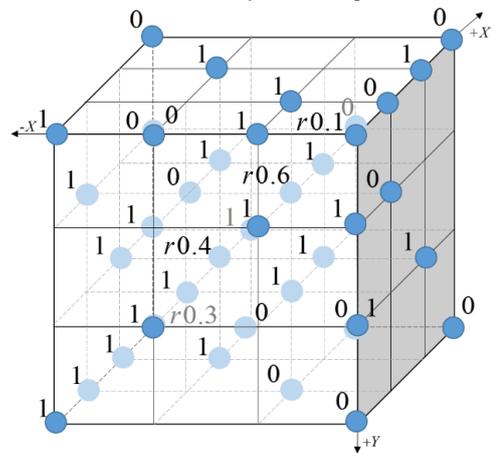
Figure 4. The nested combinatorial model of the valve

Corresponding to the model in Fig .4, the main disassembly relationship matrix \mathbf{R} and sub-matrix of disassembly relationship \mathbf{R}_{440} are written as in Fig .5.

The part 3 in matrix \mathbf{R} was the fixed chassis, and the part 6 in sub-matrix \mathbf{R}_{440} was the fixed part in disassembly process. Both of them were irremovable. When the fixed parts or components during disassembly process are contained, the columns on three dimensions shall be set to 1. So r_{3jk} and r_{i3k} in matrix \mathbf{R} , as well as $r_{6,jk}$ and r_{i6k} in matrix \mathbf{R}_{440} were all set to 1.



(1) Main disassembly relationship matrix \mathbf{R}



(2) Sub-matrix of disassembly relationship \mathbf{R}_{440}

Figure 5. Disassembly relationship matrix of the valve

The disassembly target part 4 was in sub-matrix of disassembly relationship R_{440} .

After iterating through the matrices, the optimal disassembly sequence and the disassembly direction of each part or component was generated as: component 4($-X$)-part 7($-X$)-part 5($-X$)-part 4($-X$). The disassembly difficulty factor of the optimal sequence is 1.3.

VI. CONCLUSIONS

Paper presented a disassembly sequence planning method. The hierarchical disassembly module was built for a complex mechanical product. Then the three-dimensional nested combinatorial interference matrix was designed to express the disassembly relationship corresponding to the model. The disassembly difficulty factor was introduced, and the optimal disassembly sequence was generated at last. An example was given to prove the method is reasonable and effective.

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