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Design of a Method for Disassembly Works on Recycle Products

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Abstract. This study proposes a new framework for designing disassembly methods. In recent years, environmental problems have become global issues. Recycling of used products or resources is recognized as a matter of significance since it may help reduce the risk of exhausting natural resources. Considering possible exhaustion of limited natural resources in the near future, reuse of products would gain more environmental significance. As yet, it relies hugely on manual disassembly, which labor cost places burden on the total recycling cost. The purpose of this study is to propose a methodology designing for manual disassembly works, and a creation method of a jig. By focusing on parts' connection and attachment relationship, parts are categorized in 5 categories (parent part, joint key part, attaching key part, child part, and independent part) according to the features that parts possess, and 3 kinds of connection relationships (parent part-joint key part connection, parent part-independent part connection and child part-child part connection) are clarified. Connection relationship and attachment relationship charts have also been created, and utilizing them, disassembly orders are settled, and a disassembly jig is devised. The proposed methodology is also applied to a real product and its work time is improved 42% form 31 to 13 seconds.

Keywords: Recycle, Disassembly Work, Disassembly Jig, Connection Relationship, Attachment Relationship

1. INTRODUCTION

In recent years, environmental problems have become global issues, and accordingly, recycling of used products or resources is recognized as a matter of significance since it may help reduce the risk of exhausting natural resources. The term 'recycling' here includes both 'recycling' in which products are crushed into resources without any prior separation based on the materials in a lower level of recycling, and 'reuse' of product in which products are disassembled into parts or components for the purpose of building new products using these parts or components. Considering possible exhaustion of limited natural resources in the near future, the latter would gain more environmental significance. As yet, it relies hugely on manual disassembly, which labor cost places burden on the total recycling cost. In order to economize the process and increase productivity, more work needs to be done.

Regarding assembly works, a number of researches have been done and presented (Yamagiwa, 1997) (Shinoda, 2004). As for disassembly works, several types of studies, such as studies on product designing and assessment methodology for rather easily-disassembled products (Onoda, 2004), on disassembly orders in view of total disassembly time (Yamamichi, 1996), on jigs to re-

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move the connecting parts (Rebefka, 2001) have been presented. However, there has not yet been any proposal on the designing methodology for disassembly works focusing on the connection or attachment relationship between parts.

This study thus proposes designing methodology for smooth and feasible disassembly works by focusing on connection/attachment relationship between parts of a product, and also necessary functions that a disassembly jig thereby should possess, in hopes of promoting productivity of recycling processes. This study also aims to verify the validity using examples from real products, by actually applying the proposed designing methodology and using the disassembly jig created exclusively for the products.

2. DEVISING METHODOLOGY FOR DISASSEMBLY WORKS

2.1 A Target Unit

In order to function as a product, each part is composed of appropriate material and has a different figure. To devise designing methodology for a disassembly work, an example product, which can be assembled/disassembled in one-way linear movement, is modeled as shown in Figure 1. Connection/attachment relations are the key to the modeling, and each part is simplified and modeled in rectangular shape.

The Target unit consists of 5 different parts, namely, parent part (PP; 0), joint key part (JP; 1), attaching key part (AP; 5), child part (CP; 3, 4), and independent part (IP; 2). 3 kinds of connections are observed in the model, which are parent part-joint key part connection (P-J; 0&1), parent part-independent part connection (P-I; 0&2) and child part-child part connection (C-C; 3&4).

"Connection" here refers to the status in which parts are joined together and are not easily unfastened. "Attachment" means parts are touching different parts wholly or partially.

A parent part functions either as basis of a unit or as holder of other parts. A joint key part connects to the parent part and has no other part positioned above it, although there are several parts between a joint key part and a parent part. An attaching key part is located on the bottom of a product and multiple parts are attached to it. A child part touches a parent, a joint key, or an attaching key part, but has no bond or connection with any of them. An independent part is solely connected or attached to the parent part, and has no connection/attachment with other parts.

2.2 Methodology Designing for Disassembly Works

Disassembly methods designed in this study aims to break down relationships between parts by first clarifying connection relationships between major parts and subsequently eliminating attachment relationships. This approach let multiple parts involved disassembled at one time, and thus reduces the number of steps involved in a whole disassembly process. In a "disassembled" status, a target part has no connection or attachment with any other parts. Using the target units illustrated in Figure 1, designing method for disassembly works and the creation of a jig to be used will be described next.

2.2.1 Creation of Connection Relationship Chart and Establishment of Disassembly Order

A connection relationship chart illustrates connection relationships between parts involved in a unit as shown in Figure 2. Linkage in the chart disappears when connection relationship is lost. In order to disassemble a unit smoothly, connection relationship should be removed first to make sure a unit consists of attachment relationship only. To realize that, connection relations must be clarified and classified, reflecting the relations to the connection relationship chart, and then the disassembly orders should be established.

Generation of a connection relationship chart is explained as follows.

(1) Clarify connection relationships between parts in a target unit, and classify the relationships in 3 categories as below.

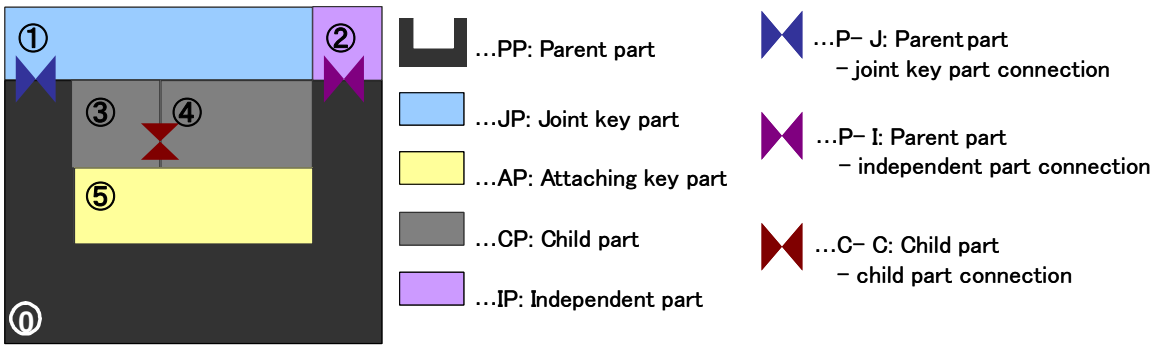

Figure 1. A Target Unit.

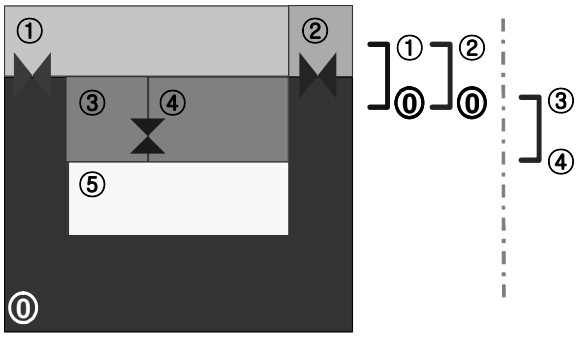

Figure 2. Connection relationship chart.

Connection 1: parent part-joint key part connection (P-J)
Connection 2: parent part-independent part connection (P-I)
Connection 3: child part-child part connection (C-C)

(2) Draw U-shaped connection linkage line and put part numbers on the right side.
(3) Classify the identified connection relationships in 2 groups-connection 1, 2 as one group and 3 another-and draw a dotted line between groups. Note that connection 3 should be described on the right.

Using the connection relationship chart above, effective ways and orders to break down connection relations will be now devised. Here parts' stability influenced by connection relationship should not be overlooked. To remove connection relationship in a unit, naturally it takes force; if parts are not in a stable manner, the force does not reach the parts appropriately and takes extra time to disassemble the unit. Disassembly orders thus must be devised on the ground that it does not affect the stability of parts.

Taking above into account, connection relationships should be removed, following the order: connection 3, 1, 2. Stability will be maintained as long as connection 1 and 2 are sustained. Considering stability matter, it is best to remove connection relationship categorized as connection 3 first. Connection 1 should be removed after that, since it integrates other parts and functions as a basis, and breaking it down will consequently affect stability of the whole unit. Connection 2 should be removed last, since breaking it down will make it difficult to remove connection 3 and 1, due to the parts' instability caused by connection 2 removal.

2.2.2 Creation of Attachment Relationship Chart and Establishment of Disassembly Order

An attachment relationship chart illustrates attachment of parts, and positional relationship between parts, as proposed by Dr. Shinoda *et al*. (Shinoda, 2004). This study uses an improved version of the attachment relationship chart and proposes both a designing methodology for disassembly works and creation method of the jigs to be used in the works. When all connection relationships are removed from a unit, it is framed solely with vertical and horizontal attachment relationships. Figure 3 shows designing method for an attachment relationship chart.

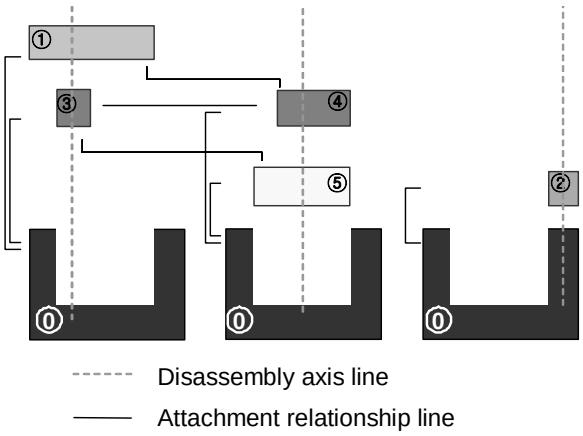

Figure 3. Attachment relationship chart.

(1) Select and decide a parent part.
As previously mentioned, a parent part functions as a basis of a unit and fastens other parts on them. A parent part must be selected accordingly.

(2) Draw disassembly axis lines.
Disassembly axis lines start either from the center of fixing part of a parent part or the center of the attaching part. Disassembly axis lines are shown in dotted lines. Number of disassembly axis lines is equivalent to the number of figures of the parent part shown on the charts. In the targeted unit, to match 3 disassembly axis lines, 3 figures of the parent part are placed.

(3) Draw vertical attachment relationship lines.
Vertical attachment relationship lines must be expressed collectively for each disassembly axis line. Each part is shown alongside the axis individually. Attachment relationships between individual parts are represented by U-shaped solid lines.

(4) Draw horizontal attachment relationship lines.
Horizontal lines are drawn across multiple axis lines to represent attachment with parts on different disassembly axis lines. Positional relationships are expressed with upward/downward ends of lines, and if a part is placed on the tip of upward end of a line, it means that the part comes above the other. If a part is on the tip of downward end of a line, the part is placed below the other. If a line possesses no upward/downward ends, two parts are attached side by side on the upright position.

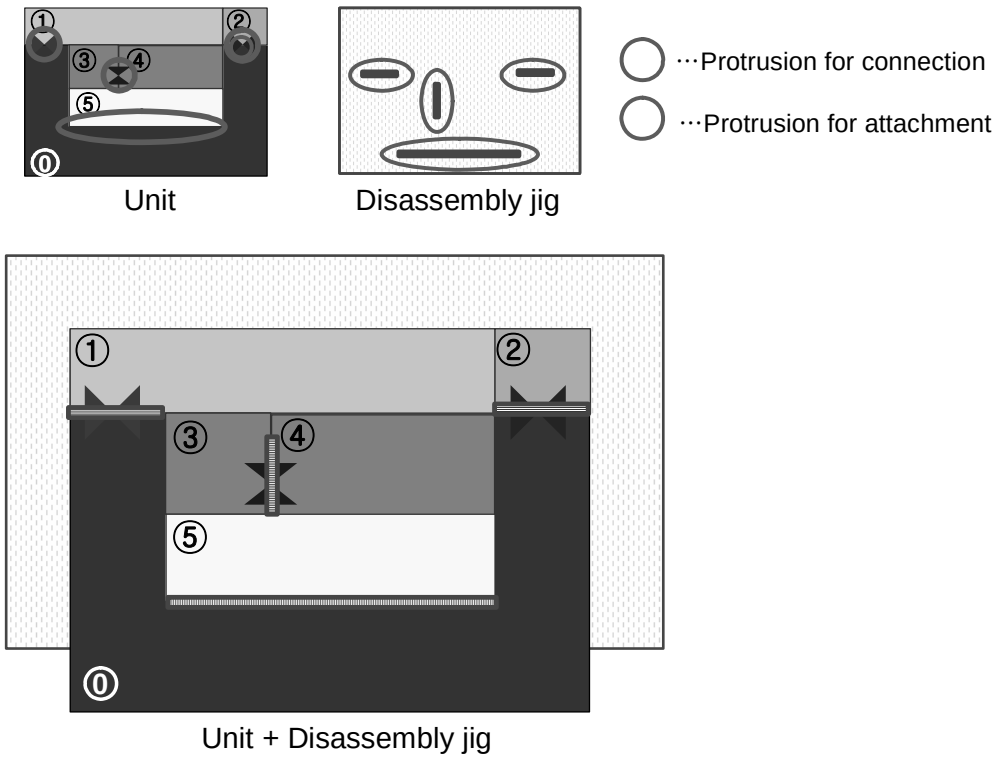

Figure 4. A Target unit and a disassembly jig.

Next, the discussion is on disassembly method. The method should minimize the number of steps involved in a disassembly work by focusing on the attachment relationships between parts. When parts exist on the same disassembly axis line, disassembly of the lowest-positioned part on the line enables disassembly of all the other parts on the same axis. Double or concurrent disassemblies, disassembly of parts on the different disassembly axes, may be planned utilizing the horizontal attachment relationship lines.

When all connection relationships are removed from a target unit; naturally it consists of attachment relationship only, and by unfastening an attaching key part which also functions as an independent part, concurrent disassembly–disassembly of multiple parts utilizing the nature of attachment relationship-may also be made possible. Concurrent disassembly thus can reduce the number of steps in a work effectively, although strength or area of attachment may matter in some cases when utilizing horizontal attachment relationships.

2.3 Designing a Disassembly Jig

The authors have succeeded in creating a disassembly jig exclusively designed for the disassembly work described here, considering parts' functions, connection and attachment relationships as mentioned previously. Figure 4 illustrates the jig, and the basic work it does is to remove connection and attachment relationship by applying its protrusions to the parts' gaps of the unit. First, in order to leave the unit with attachment relationship only, connection relationships should be removed using the jig's protrusions. Connections must be removed orderly, so the first ones should be child part-child part connections (connection 3). Once all child part-child part connections are removed, joint key parts, which fasten multiple parts, and the parent part connection (connection 1) can be removed. After all the connections are removed, attaching key parts can be taken apart. Independent part connections (connection 2) and child part connections (connection 3) can often be removed automatically by removing the parent part relating connection (connection 1), so examining connection/attachment relationship is vital for the task. If removing an independent part connection (connection 2) also means removing attachment relationship the part has, then the protrusion takes the part apart not only in terms of its attachment but also its connection. Thus connection relationship removal results in attachment relationship removal occurring at the same time and parts will be disassembled. Following the described mechanism above, it will be possible to disassemble all the parts involved in the target unit.

Here it should be noted that the position of the protrusions must be carefully decided. The protrusions intending to remove attachment relationships must work after the connection relationships are removed; when designing, attachment relating protrusions should be positioned lower than connection relating protrusions, so there is a sufficient time lag.

3. APPLICATION TO A REAL PRODUCT

Here the study covers application of the methodology to a real product. Figure 5 shows a built-in of a single-use camera, a target product here, which consists of 11 parts as a whole.

The target product has 2 kinds of connections. First one is applied for the snap-fit hook. The connection here is strong and can not be removed with bare hands. In addition, it can not be simply removed by applying force in one direction. The second connection is the slide. Connection strength is fairly low, and can be removed without much trouble by applying force in one direction.

The connection relationship chart for the target product is shown in Figure 5, and utilizing it, disassembly order was devised. Figure 6 shows the generated attachment relationship chart of the target product, and the disassembly order was finalized. A jig for disassembly was designed subsequently, and shown in Figure 7. The jig consists of the face jig and the back jig, and was made by wood and metal. The target product is put between them, forced and pulled upward to be disassembled. The 3 protrusions were set to remove connections, and to disassemble the product in a single movement, 5 more protrusions for attachment were added.

At an actual disassembly factory, formerly, it used to take 31 seconds to disassemble the target product by manual. After introducing the disassembly method and the jig proposed in this study, the work took only 13 seconds by manual and 42% disassembly time could be improved. The key to this improved efficiency in disassembly work was application of the described mechanism; remove connection relationship first, leave the unit with attachment relationship only, and finally disassemble attaching key parts and independent parts. Also the jig contributed to the speed-up, since it enabled one-shot disassembly by taking attaching key parts and independent parts apart at the same time. The authors estimate it would be possible to shorten the disassembly time furthermore, down to 5 seconds to disassemble the whole unit, by improving the accuracy of jigs, by using solid material more suitable for the work for example.

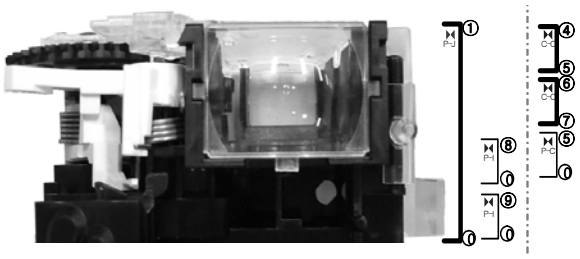

Figure 5. A Target product and connection relationship chart.

4. CONCLUSIONS

In this study, the authors have proposed a new framework for designing disassembly methods, focusing on parts' connection and attachment relationship, and categorized parts in 5 categories according to the features that parts possess, and clarified 3 kinds of connection relationships. Connection relationship and attachment relationship charts have also been created, and utilizing them,

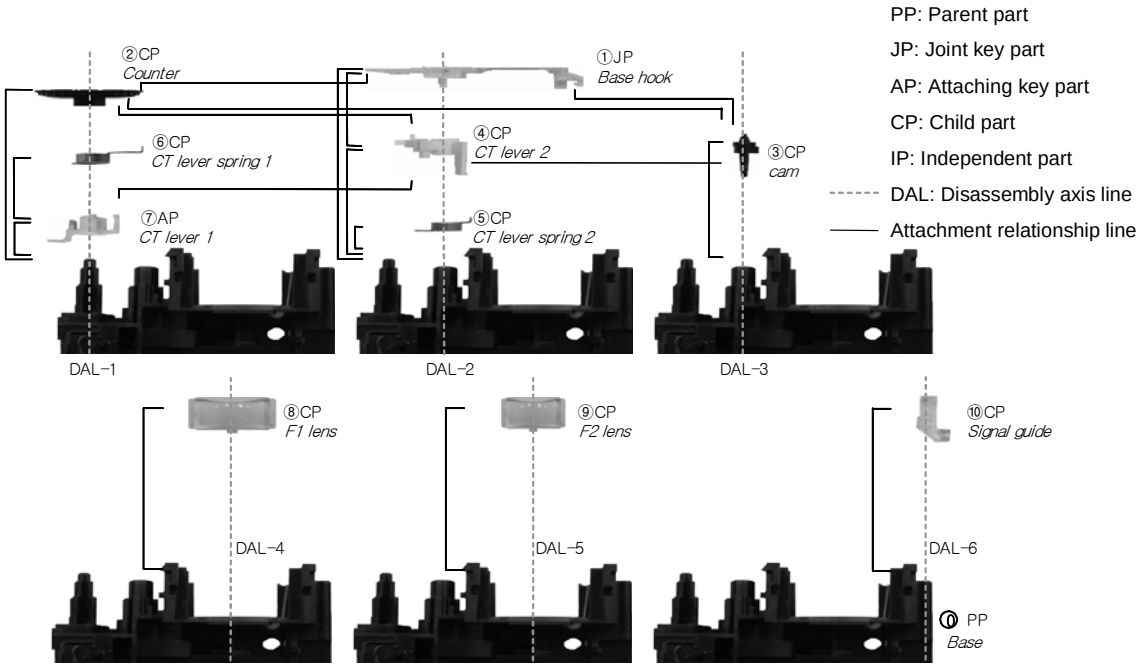

Figure 6. A Target product and attachment relationship chart.

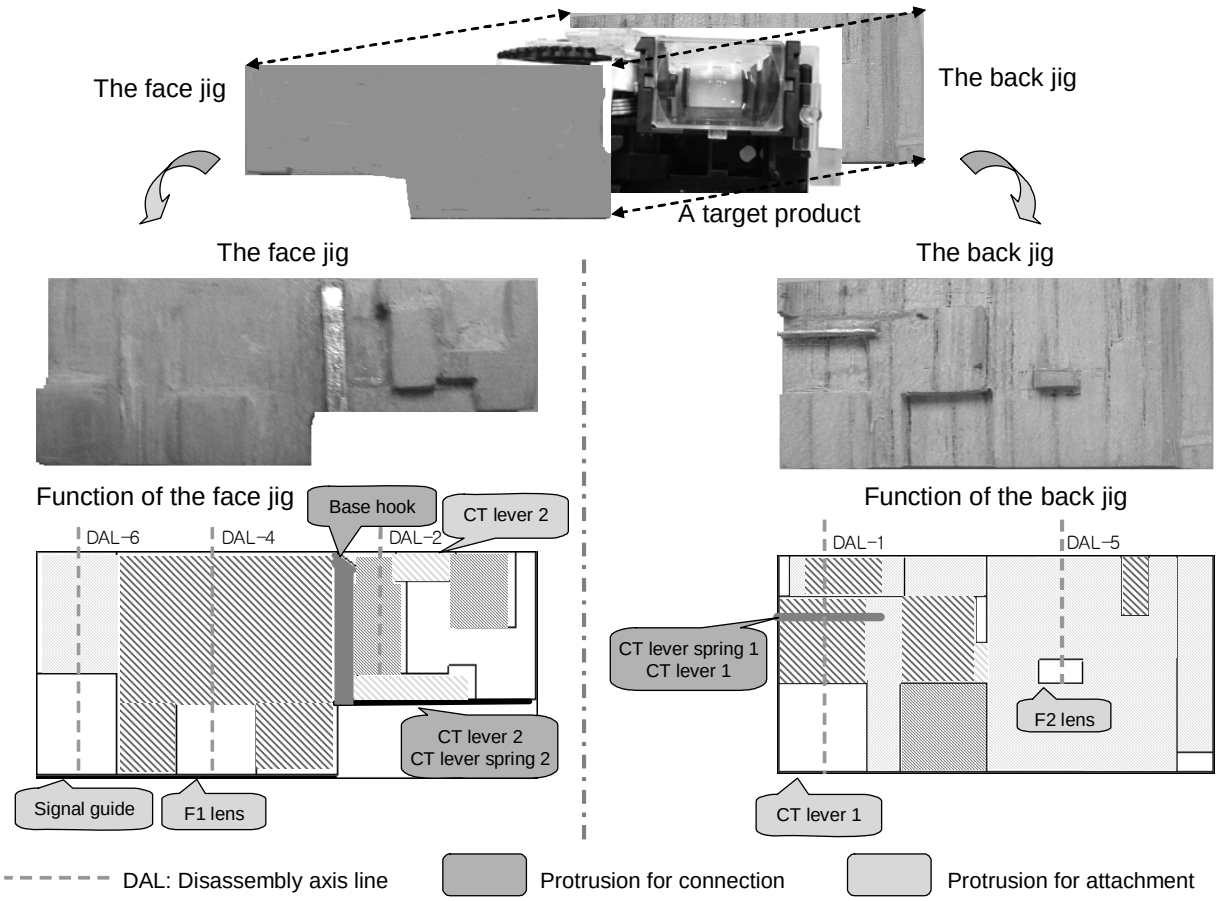

Figure 7. A Disassembly jig for a target product

disassembly orders were settled, and a disassembly jig was devised.

Overall, the study has proposed and presents a methodology designing for manual disassembly works, and a creation method of a jig, considering increasing demands in recycling industry. The study also reports about application of the proposed methodology to a real product, in terms of methodology designing and jig creation for a disassembly work, which proves the effectiveness of the proposed methodology for improving work time.

The methodology was applied only for a simple product which has a single disassembly direction and is connected by snap-fit hooks. So the methodology has limitation of applicable products and should be modified for more complicated products which have many disassembly directions and are connected by screws or E-rings.

The authors intend to work on disassembly methodology designing of a wider and more complicated variety of products, such as the ones including screws or E-rings, further on.

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