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Research on Multi-Step Active Disassembly Method of Products Based on ADSM

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1. Introduction

This chapter discusses the principles of multi-step active disassembly, proposes the method of products multi-step active disassembly and divides the step of product parts according to the step division principle of multi-step active disassembly products. In addition, this chapter also proposes step division process of multi-step active disassembly products and determines parts in each step according to the process. Materials which have the same trigger medium and different trigger strength are used as active disassembly material, ensuring that trigger strength (such as temperature, magnetic field strength, etc) of active disassembly device which is in different disassembly step forms gradient. Trigger strength of active disassembly device increases along with the disassembly step from low to high. The joints which are in the same disassembly step use the active disassembly devices which have the same trigger strength. In different disassembly steps, install active disassembly parts according to the gradient. Lastly, disassemble the products by sending it to the different work areas.

2. Active disassembly

As the concept of circular economy and sustainable development is gradually extended, the requirement of recycling of the life cycle terminal electronic products after they are discarded becomes increasingly stringent. At present, electronic products are disassembled by means of manual disassembly or mechanical crushing. But the efficient of manual disassembly is very low and mechanical crushing will damage reusable parts or components. To solve these problems, the concept of active disassembly is proposed. The product is disassembled when it is heated to a specific temperature by using active disassembly device instead of traditional connecting device.

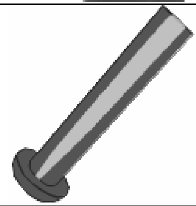
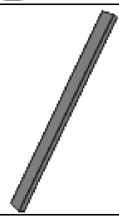
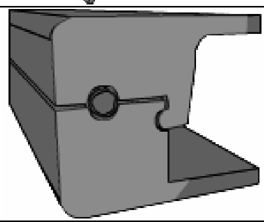
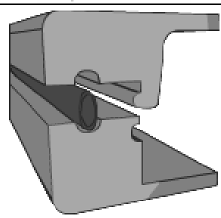
2.1 The concept of active disassembly

Active Disassembly uses active disassembly device instead of traditional device like the snap -fit, rivet and thread connection. Active disassembly device deforms when it is in certain external trigger conditions. At last, the parts of products are disassembled. This technique mainly uses the properties of shape memory materials. It is also known as active disassembly using smart materials (Chiodo et al., 1998, 1999, 2002; Suga & Hosada, 2000).

2.2 The characteristics of active disassembly device

ADSM (Active Disassembly using Smart Materials) uses the principle of SMA (Shape Memory Alloy) or SMP (Shape Memory Polymer) that they can automatically return to its original shape under certain circumstances to make active disassembly devices using SMA or SMP, such as smart driver and active separation snap-fit. Active disassembly device is placed to the products during the stage of the design and assembly of the products. These products are placed on the trigger conditions of active disassembly device, such as temperature, when they are recycled. The products will be disassembled by these active disassembly devices. So ADSM makes disassembly and recycling of products very convenient.

The deformation force of SMA is very large when SMA return to its original shape. So SMA can be used to make active disassembly device which provides driving force, such as coil spring, splint pin, ribbon, cotter pin, rivet, tube and so on. The deformation force of SMP is very low, but its deformation is 400%, so SMP can be used to make active disassembly device, such as screw, snap-fit, rivet, washer, zipper snap-fit and so on. Table 1 shows several typical active disassembly devices (Chiodo et al).

Active disassembly device	Before trigger	After trigger
SMA coil spring		
SMA rivet		
SMA ribbon		
SMA tube		

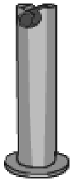
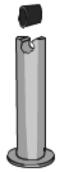
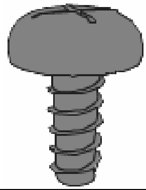
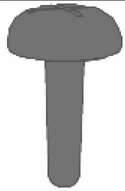
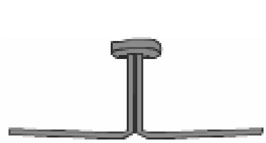
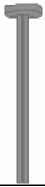
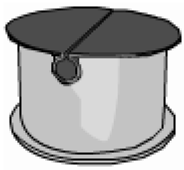
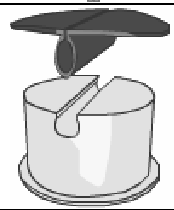
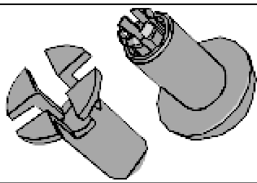
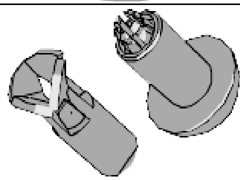
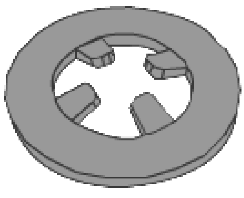
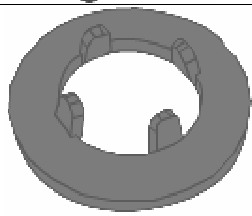
SMA splint pin		
SMP screw		
SMP cotter pin		
SMP Snap Fastener 1		
SMP Snap Fastener 2		
SMP Snap Fastener3		
SMP clamping washer		

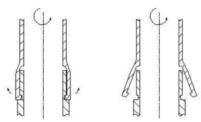
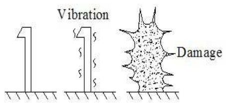
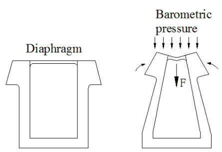
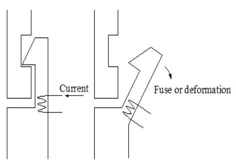
Table 1. Typical active disassembly devices (Chiodo et al,)

The most common two broad categories of active disassembly devices in Table 1 are snap-fit and screw. Screw type is generally made of shape memory polymer. The threads disappear or soften after screw is triggered by heat. So SMP screw loses its connecting function. The advantages of SMP screw are that the structure is simple and the cost is low. SMP screw is usually used in places where connection strength are not high. The connection strength of snap-fit is very high. But its disadvantages are complicated structure and high cost. SMP snap-fit is usually used in places where connection strength is high or where special requirements are needed appropriate active disassembly device will be chosen according to the needs of products device when designing products.

When a product is designed using active disassembly device, the initial device should be designed by traditional method at first. Then the material will be chosen according to initial device and the environmental conditions and the active disassembly device will be designed. After that the active disassembly device will be arranged in the suitable place to achieve the active disassembly. At last the device and façade should be optimized.

2.3 Trigger methods of typical active disassembly device

Trigger ways of active disassembly device as shown in Table 2 (Willems, 2005).

Trigger ways	Figure	Work instructions	Requirements	principle
Centrifugal force		Use centrifugal force to make snap-fit release	Axisymmetric device	special device
Vibration		Fasteners collapse in a particular vibration frequency	Device with default/ modify characteristic frequency	Special device or material
Barometric pressure		Increase air pressure make fasteners deform so that connection failures	Closed cavities filled with air	Special device
Current		The internal resistance wire in connector melt the plastic around when it is energized and make connec- -tion failure	Bury the resistance wire during the manufacture of connectors	Special material

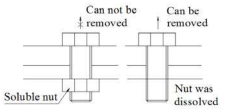
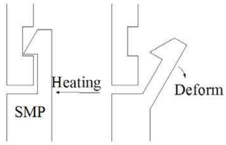
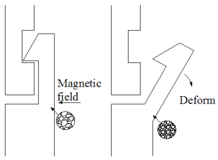
Dissolve		Fasteners which are made of soluble materials are dissolved away during disassembly	Suitable soluble materials	Special material
Heating		Deformation at elevated temperatures of shape memory materials / composites of two materials (such as bimetal)	Shape memory material or two bistable composite material	Special material
Magnetic field		Magnetoresis- -tive materials deform under the magnetic field trigger	Magnetoresistive particular material with Special shape	Special material

Table 2. Trigger ways of active disassembly devices (Willems, 2005).

The general trigger way of active disassembly device is heating.There are five main heating trigger methods to stimulate active disassembly device: air convection heating such as air bath, immersion heating such as water bath heating, microwave heating, far infrared heating and induction heating. Five methods have advantages and disadvantages separately, as shown in Table 3 (Li, 2008).

Aimed at the active disassembly device, 5 heating ways are normal used. Water bath or air bath heats the whole product, which may damage the components and parts that have bad heat resistance, besides heat is dispersed as a result of costing more energy, and it takes a long time for heat to transmit from the surface to the inside. So the trigger time is uncontrollable and the disassembly efficiency reduces. To avoid the problems mentioned above, the active disassembly device triggered by electric heating has been studied deeply. This active disassembly device can be classified into 3 steps as follows:

The active disassembly drive parts made from SMA can be electrified directly to generate applicable force after deformation by electric heating to achieve the separation between components and parts. The trigger time can be controlled by the electric power of active disassembly drive parts (Z. Liu et al., 2011).

The snap-fit made from SMP can be electrified through the electric heater band glued at root of SMP snap-fit or heating wire in the root. When electric heater band or heating wire is electrified, the electric heat generates the enough deformation to make the connection lost its effect. The trigger time of SMP snap-fit can be controlled by the electric power of electric heater band or heating wire (Z. Liu et al., 2011).

Heating method	Advantage	Disadvantage	Scope
Air convection heating	Clean and pollution-free, simple equipment	Heating efficiency is low, the internal heating effect of the product is bad	Smaller products
Immersion heating	High heating efficiency, simple equipment	Erosion or pollution of components	Suitable for parts of products no longer reuse
Microwave heating	High heating efficiency, no affecting for the volume	Unable to inspire the SMP, may damage or even burnt parts	Suitable for SMA active dis-assembly device
Far infrared heating	Low energy consumption, heating uniformity	The internal heating effect of the product is bad	Suitable for smaller products
Induction heating	High heating efficiency, uniform heating	Energy consumption, unable to inspire the SMP, electronic devices cannot be reused	Suitable for electronics products no longer reuse

Table 3. Advantages and disadvantages of 5 heating methods and their applications (Li, 2008).

The snap-fit made from the same metrical above can be electrified through the electric heater band glued at root of it. When electrified, the root of the SMP snap-fit will be fused by electric heating to achieve the separation between snap-fit and slot, so that the connection of components and parts will lose effectiveness to achieve the active disassembly. The fused time can be controlled by the electric power of heating wire (Z. Liu et al., 2011).

2.4 Application object of ADSM method

ADSM method is primarily applied to the following types of electrical and electronic products:

1. The products which need non-destructive disassembly, because components can be reused or pollute the environment after they are damaged, such as PC, LCD display, LCD TV and so on.
2. The products which are small and whose manual disassembly are extremely inconvenient, such as remotes, mobile phone, MP3, MP4 and so on.
3. The products which have complicated device or many components cause that the efficiency of manual disassembly is very low, such as precision instruments.
4. The products which have large output, serious shortage of recycling capacity and whose disassembly efficiency need to increase significantly.

The products which are not suitable for ADSM method are as follows.

1. The products which only recycle materials instead of recycling parts and recycle through overall fragmentation instead of disassembly, such as refrigerator.
2. The products which are mainly composed of metallic materials and have requirements of high structural strength, such as Air conditioner outdoor unit.

For example, based on the design theory and method of ADSM, some remote controls are redesigned to put the active disassembly device in. The active disassembly experiments of redesigned remotes show that the cost of life circle reduces while the disassembly property is obviously enhanced. The disassembly efficiency is 300 times enhanced with no pollution and damage for the environment. So the active disassembly devices are suitable for large-scale industrial production (G. Liu et al., 2008), as shown in the Fig.1.

Fig. 1. The active disassembly efficiency of the shells of remote controls (G. Liu et al., 2008).

For medium-sized electronic products such as monitors, television sets, the results are unsatisfactory. Because these products are larger and the time for heat transmitting to the internal active disassembly device of product is longer. As a result, heating time has to be extended. It is difficult to achieve complete dismantling through one trigger. Efficiency of disassembly is very low and components with poor heat-resistant are damaged. Because medium-sized electronic products have a lot of components, all completely disassembled parts are mixed together and create difficulties for subsequent sorting. So it increases the workload of sorting parts. In a word, it is important to research on the method of products multi-step active disassembly deeply and achieve step active disassembly of products components.

3. The multi-step active disassembly of products

The multi-step active disassembly methods mainly aim at the condition that the distance between the internal active disassembly devices and the shells of products is so far that it is difficult to be disassembled by single-step active disassembly. On the other hand, the parts from single-step active disassembly are mixed up. That goes against the follow-up material recycling, so disassembly efficiency is low. By using the multi-step active disassembly, the products can be divided into multi-step for disassembling. In each step, one or several kinds of components will be disassembled from the products, which can save time of disassembly and be benefit to the follow-up material sorting, and it reduces the cost of products disassembly. Therefore, it can realize the automation of product recovery and assembly line work.

3.1 The conception of the multi-step active disassembly products

According to the properties of the shape memory materials, when different kinds of material are in the effect of certain trigger medium(such as infrared ray heating, microwave heating, water bath, etc), the trigger strength they need is not the same. Thus products can be designed in different kinds of trigger medium or increasing trigger strength in proper order in the same trigger medium. When these recycled products are sent to different disassembling areas, one or several kinds of components are disassembled in each step, until the products are completely disassembled, in order to achieve the purpose of grading disassembly. This method is called multi-step active disassembly (Zhao et al., 2011a)

When it is disconnected between the internal active disassembly devices and the housings of products, multi-step active disassembly can save the disassembling time and improve the disassembling efficiency observably. For some products that have complex device or large volume, the trigger speed of the internal active disassembly devices is low, which leads to the decrease of the efficiency of entire disassembly. In this case, different kinds of active disassembly devices with different trigger strength can be used in the stage of products design to achieve the active disassembly of components and parts.

3.2 The principle and method to achieve multi-step active disassembly products

According to the principle of multi-step active disassembly, there are two kinds of methods or their combination to achieve multi-step active disassembly (Zhao et al., 2011a).

1. Different trigger media: In different disassembling steps, active disassembly devices belong to the connection location use different trigger media. While in the same disassembling step, active disassembly devices belong to the connection location use the same trigger medium. The active disassembly device in different disassembling steps is triggered by different excitation ways, and multi-step active disassembly can be achieved.

For example, the method of air heating can be used to trigger SMP snap-fit to achieve the separation of the components and parts. And the field effect can be used to trigger SMA driver parts to achieve the separation. In this way the purpose of multi-step active disassembly can be achieved.

2. Same trigger medium, but the trigger strength increases in gradient way: Using shape memory materials with same trigger medium but different trigger strength as the active

disassembly devices in the design phase of products, it makes trigger strength(such as temperature, magnetic field strength) of active disassembly devices in different disassembling steps form a gradient. According to the disassembling step from low to high principle, the trigger strength of active disassembly device appears a gradient rise. In the same disassembling step, the trigger strength of active disassembly device is the same. Install the active disassembly devices in different disassembling step according to the gradient, and then send the products to each step of working area to complete the disassembly.

For example, by physical cross-linking irradiation, PVC can obtain property of shape memory, when the irradiation dose is 100kGy, the trigger temperature is 65°C, but the irradiation dose of the shape memory alloy is 75°C. Therefore, we can disassemble adapting piece made of shape memory polymer materials in 65 temperature field, and disassemble adapting piece made of shape memory alloy in 75 temperature field, in order to achieve the purpose of multi-step active disassembly.

According to the property of PVC, if the irradiation dose is 100kGy, the trigger temperature of PVC is 65°C, and if the irradiation dose is 4kGy, the trigger temperature of it is 80°C. So in the design phase of products, active disassembly devices with different trigger temperature can be used in different disassembling step of the products, in order to achieve the purpose of multi-step active disassembly.

Using temperature as the trigger medium of the active disassembly devices of products, connection location in products is divided into different disassembling steps according to the position and the heat transfer performance of materials around the products. The inner or worse heat transfer performance of materials around, the higher of the disassembling step. Active disassembly devices located in the same disassembling step has the same trigger temperature. The trigger temperature of the active disassembly device appears gradient rise according to the disassembling steps from low to high. The temperature difference between the trigger temperature of adjacent disassembling step shouldn't be less than 5°C.

Check the strength and the deformability of the shape memory materials in the choice of materials, and then choose the trigger temperature. Generally speaking, the trigger temperature is higher than the temperature the product is normally used, but it shouldn't be too high to damage the parts which don't have high temperature resistant during disassembly. In a general way, the SMP materials whose trigger temperature is between 60°C and 150°C are selected. The SMP materials' trigger temperature by irradiation modification is related to their molecular crosslinking degree, the molecular crosslinking degree increases with the radiation dose, until reach a steady value.

The shape memory performance of the SMP mainly depends on its material type and the molecular crosslinking degree. The shape memory performance of the commonly used polymer material PVC which goes through irradiation modification is the best; the mechanical strength and corrosion resistance ability of PVC are also well, it is appropriate for being used as material of active disassembly devices. For the same polymer material, the bigger of the radiation dose, in other words, the greater of the molecular crosslinking degree, the lower of the trigger temperature. In the same disassembling step, the connect parts use active disassembly devices with the same trigger temperature. On the contrary, in different disassembly steps, the connect parts use active disassembly devices with different trigger temperature, which can achieve the purpose of multi-step active disassembly.

Another way to trigger the active disassembly device by temperature is through the heating wire method (Z.Liu et al, 2011), by using the controllability of the trigger time, the multi-step active disassembly products can be achieved. Considering the disassembly sequence of active disassembly parts in each step in the design phase of products, electric heating elements with different power are chosen according to the trigger time, then the fully automatic disassembly of products can be achieved. Electric heating elements with different power are arranged in connection of active disassembly devices, and the time that the active disassembly devices are triggered is controlled by adjusting the power of the electric heating elements. In the same disassembling step, the power of electric heating elements which is needed in active disassembly device that belongs to the connect parts is the same, on the contrary, in different steps, it forms a certain power gradient, which can achieve the purpose of multi-step active disassembly by using the difference of the power between each trigger level.

4. The design of multi-step active disassembly products

The key of multi-step active disassembly design is to classify the products into several disassembly steps, and to set the trigger intension of active disassembly device in connections in every step. The trigger intension of active disassembly device in different disassembly steps is different, while that in the same disassembly step is the same. The components and parts in every disassembly step should be set by the gradient, and disassembled in the work area of every step.

4.1 The principle of division of multi-step active disassembly products

The principle of division of multi-step active disassembly products is shown in the Fig.2.

The purpose of multi-step active disassembly is to save time. It is conducive to recycle the materials if the components and parts with the same or compatible materials are disassembled in the same step. When classify the steps of multi-step active disassembly products, the below principles should be followed (Z. Liu et al., 2010; Zhao et al., 2011a).

1. The principle of disassembly

There are some differences between disassembling properties of multi-step active disassembly and the traditional disassembling properties. The later only consider the restraint relationship among all the parts, as shown in Fig.3. Part 1 is chosen as the basic part (the part will be disassembled last), and the disassembly property of every part from direction (+X, +Y, +Z, -X, -Y, -Z) can be determined by the method of interference-freedom matrix (Wang et al., 2005a, 2005b, 2006).

$$\begin{aligned} DAW(2)=&(F_{1,2,1}, F_{2,2,1}, F_{3,2,1}, F_{4,2,1}, F_{5,2,1}, F_{6,2,1}) \wedge (F_{1,2,3}, F_{2,2,3}, F_{3,2,3}, F_{4,2,3}, F_{5,2,3}, F_{6,2,3}) \\ &\wedge (F_{1,2,4}, F_{2,2,4}, F_{3,2,4}, F_{4,2,4}, F_{5,2,4}, F_{6,2,4}) \\ =&(1,1,1,1,1,0) \wedge (0,1,1,1,1,0) \wedge (0,1,1,1,1,1)= (0,1,1,1,1,0) \end{aligned} \quad (1)$$

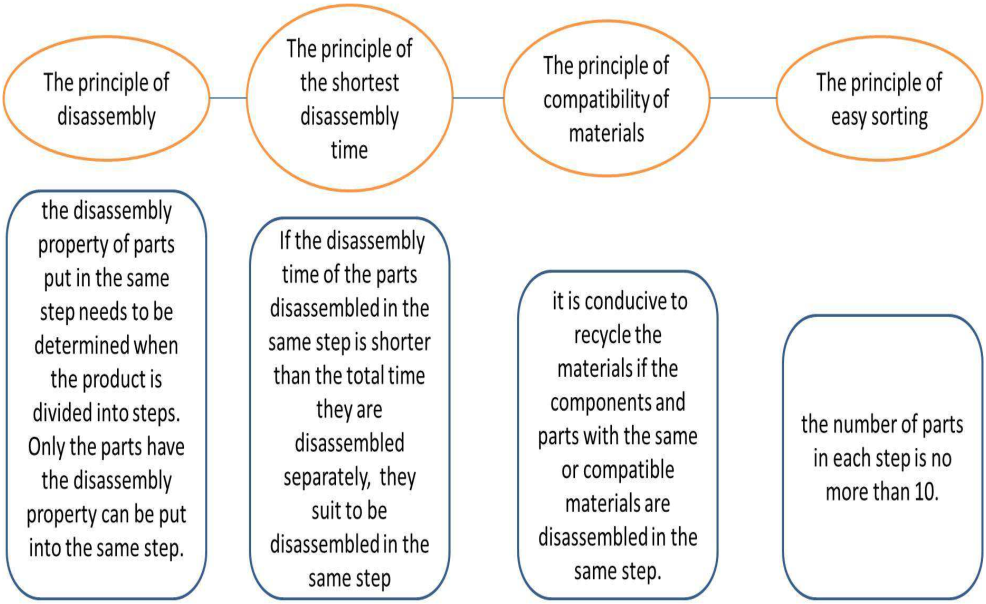
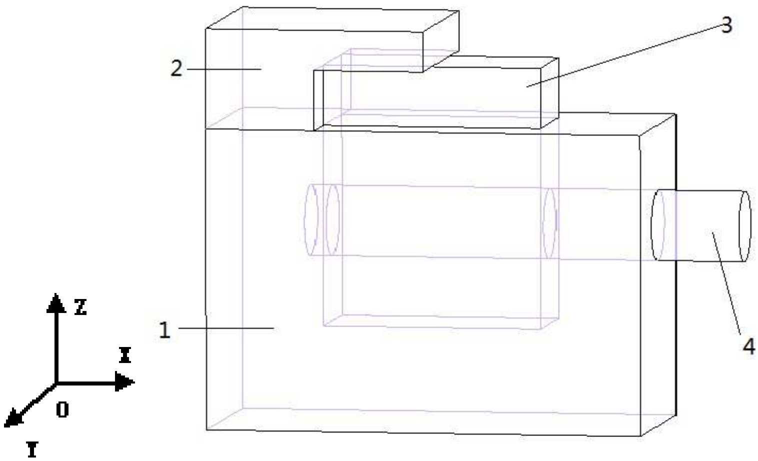


Fig. 2. The principle of division of multi-step active disassembly products



1. the foundation 2. top cover 3. the carriage 4. pin

Fig. 3. The model and its frame diagram (Zhao et al, 2011a)

$$DAW(2)=(F_{1,3,1}, F_{2,3,1}, F_{3,3,1}, F_{4,3,1}, F_{5,3,1}, F_{6,3,1}) \wedge (F_{1,3,2}, F_{2,3,2}, F_{3,3,2}, F_{4,3,2}, F_{5,3,2}, F_{6,3,2}) \wedge (F_{1,3,4}, F_{2,3,4}, F_{3,3,4}, F_{4,3,4}, F_{5,3,4}, F_{6,3,4}) = (0,0,1,0,0,0) \wedge (1,1,0,0,1,1) \wedge (0,0,0,1,0,0) = (0,0,0,0,0,0) \quad (2)$$

$$DAW(3)=(F_{1,4,1}, F_{2,4,1}, F_{3,4,1}, F_{4,4,1}, F_{5,4,1}, F_{6,4,1}) \wedge (F_{1,4,2}, F_{2,4,2}, F_{3,4,2}, F_{4,4,2}, F_{5,4,2}, F_{6,4,2}) \wedge (F_{1,4,3}, F_{2,4,3}, F_{3,4,3}, F_{4,4,3}, F_{5,4,3}, F_{6,4,3}) =(1,0,0,0,0,0) \wedge (1,1,0,1,1,1) \wedge (1,0,0,0,0,0)= (1,0,0,0,0,0) \quad (3)$$

Where, DAW denotes the disassembly property. For example, DAW(1) denotes the disassembly property of part 1.

By the calculation, we can see that the part 2 can be disassembled from the direction +Y，+Z，-X，-Y. The part 3 cannot be disassembled. Part 4 can be disassembled from the direction +X. That is, the part 2 and part 4 have the disassembly property, while the part 3 hasn't. So the part 3 can only be disassembled after disassembling part 2 and part 4 by the traditional disassembly method. However, whether the part can be disassembled or not needs to consider other parts probably in the same step when multi-step active disassembly divides steps. For instance, when the disassembly property of the part 3 is checked, the parts probably disassembled with it in the same step will be considered first. When the part 3 is arranged in independent disassembly step, by the interference-freedom matrix, the part 3 is calculated to have not the disassembly property because the parts 2 and 4 have interference for it. If the part 2, 3 and 4 is disassembled in the same disassembly step, the interference that the part 2 and 4 is to the part 3 should be wiped off when the disassembly property of the part 3 is calculated with the method of the interference-freedom matrix. Thus we can calculate that the part 3 has the disassembly property by the interference-freedom matrix. So the parts 2, 3 and 4 can be disassembled in the same step. In the same way, if the parts 2 and 3 are disassembled in the same step, the interference the part 2 is to the part 3 should be wiped off when the disassembly property of the part 3 is calculated with the method of the interference-freedom matrix. By the interference-freedom matrix, we can calculate that the part 3 has not the disassembly property because of the interference the part 4 to the part 3. So, the part 2 and 3 cannot be disassembled in the same step.

In summary, the disassembly property of parts put in the same disassembly step needs to be determined when the product is divided into disassembly steps. Only the parts which have the disassembly property can be put into the same disassembly step.

2. The principle of the shortest disassembly time

In order to reduce disassembly cost and raise disassembly efficiency, the disassembly time is expected to be as short as possible. Therefore, when classify the steps of product, ensure the disassembly time of the parts as they are disassembled in the same disassembly step is shorter than the time needed when they are disassembled separately. When two parts are disassembled in the same step, it will cost extra time for heat to pass to the other parts after one of them reaches the trigger temperature. Thus make the disassembly time of the parts disassembled in the same step longer than the total time they are disassembled separately. For example, when battery and battery compartment cover of cellphone are heated to disassemble in the same step, active disassembly of the battery compartment cover reaches the trigger temperature first, and then it will cost a period of time to pass heat from battery compartment cover to the battery. Thus make the disassembly time of the parts disassembled in the same step longer than the total time they are disassembled separately. So, the number of work area and the cost can be reduced for making the number of parts disassembled in the same step as more as possible. If the disassembly time(t_1) of the parts disassembled in the same step is shorter than the total time(t_2) they are disassembled separately, they suit to be disassembled in the same step. For example, when a product will be multi-step active disassembled by the way of air heating, the total time they are disassembled separately is t_1=25s, while the disassembly time of the parts disassembled in the same step is t_2=20s. $t_2<t_1$, so, the two parts are suited to be disassembled in the same step.

3. The principle of compatibility of materials

The manufacturing of every electronic product needs different materials because of functional requirements. Some of the parts have high value can be recycled or reused after manufacturing, but the materials of some parts are maybe harmful to the environment. These components and parts should not be disassembled together (Guo et al., 2005). When classify the steps of product, it is conducive to recycle the materials if the components and parts with the same or compatible materials are disassembled in the same step.

The components and parts which are hard to separate should be manufactured using the same or compatible material to increase the recycling rate. The compatibility of materials has two meanings: the one is the compatibility that two or more materials exist to fulfill the function and have no interference between each other during the using process of materials; the other is the materials can be recycled together, such as Polycarbonate and ABS used in the computer can be recycled together and obtain another material PC/ABS copolymers. The compatibility of ordinary engineering plastics is shown in Table 3-1 (Qi & Xu, 2007).

	PE	PVC	PS	PC	PP	PA	POM	SAN	ABS
PE	√	×	×	×	√	×	×	×	×
PVC	×	√	×	×	×	×	×	√	√
PS	×	×	√	×	×	×	×	×	×
PC	×	O	×	√	×	×	×	√	√
PP	O	×	×	×	√	×	×	×	×
PA	×	×	O	×	×	√	×	×	×
POM	×	×	×	×	×	×	√	×	×

notes：√ good compatibility, O normal compatibility, ×bad compatibility.

Table 4. the compatibility of ordinary engineering plastics (Qi & Xu, 2007)

4. The principle of easy sorting

The parts disassembled in each step need to be sorted. It is more convenient to sort the parts if each step contains fewer parts. Choose the sort of the electronic and electrical components in circuit board as an example. The number of the electronic and electrical components in circuit board is about 277, and they are connected to the circuit board by the surface mount technology and through hole technology. They have different disassembly methods. If all of electronic and electrical components are disassembled together, it is hard to sort each of them. But if a few of them are disassembled once, it will be easy to sort. Thus it will save the sorting time and raise the sorting efficiency. One provision here is that the number of parts in each step is not more than 10.

There is little or no consideration of the principles of classifying steps during the design stage of products. Therefore, when determining the steps of active disassembly products, first of all, it needs to meet the principle of disassembly and the principle of the shortest disassembly time, and then meet the principle of compatibility of materials and the principle of easy sorting as much as possible. In addition, the parts which are prone to be damaged at the high temperature should be disassembled at first. And the parts need different trigger media should be disassembled in different steps, which also requires the designers to adopt the same trigger medium to parts in the same step when classify the steps of products. Thus put designers forward a higher request, which requires them to consider the disassembly and recycle problems after products are abandoned when design the products. This is also the basic requirement of the Green design concept based on the life cycle of products.

4.2 The process of division of multi-step active disassembly products

According to the principles of division of multi-step active disassembly, a flow chart about the process of division of multi-step active disassembly products is worked out, as shown in Fig.4 (Zhao et al, 2011a). At first, number the parts of a product from outside to inside. The more inside the part is, the greater the number is. Then according to the process in Fig.4, finish dividing the steps of multi-step active disassembly.

Where i values between 1 and n, n denotes the quantity of the parts. When dividing the disassembly steps of a product by the flow chart, it needs to make the quantity of the parts in each step meet the principle of easy sorting, which will be conducive to sort materials afterward.

When the parts contained in each step of a product is determined, the disassembly of each step is allowed. In order to achieve the multi-step active disassembly products, shape memory materials with different trigger strength are used in product design, which makes the trigger strength(such as temperature, magnetic field, etc.) form a gradient. Then install the active disassembly parts in each step according to the gradient. Finally the products will be disassembled in the work area of each step.

According to the flow chart of division of multi-step active disassembly, the steps of a product can be divided based on the following procedures (Zhao, 2011b):

Procedure 1: create the product model and analyze the connection way of the product.

Product model is the foundation and premise of disassembly research, which makes the disassembly process be simulated on computer. Industrial design software provides adequate possibility and convenience for creating product model. After the product is designed, the connection way of each part of a product needs to be analyzed.

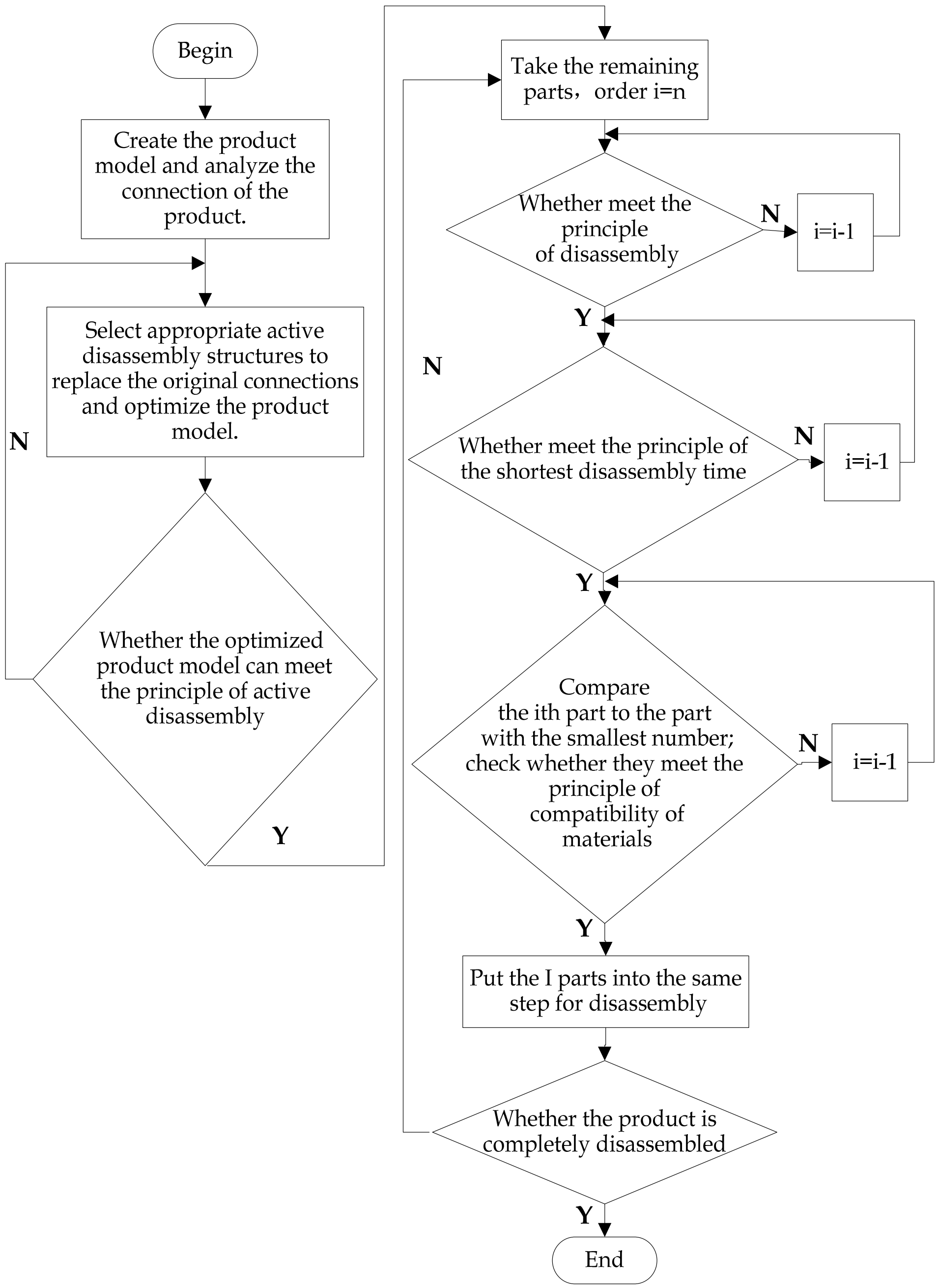


Fig. 4. The flow chart about the process of division of multi-step active disassembly (Zhao, 2011b)

Procedure 2: Select appropriate active disassembly devices to replace the original connections and optimize the product model.

When active disassembly product is designed, the original configuration should be designed based on traditional method, then select appropriate active disassembly devices and arrange them in the appropriate location to achieve active disassembly. Finally, optimize the configuration and appearance of active disassembly product.

Procedure 3: Check whether the optimized product model can meet the principle of active disassembly. If satisfied, transfer to step 4, otherwise, return to step 2.

Procedure 4: For the multi-step active disassembly products, take the remaining parts, and order i=n, then enter the next procedure.

Procedure 5: Check whether the i parts meet the principle of disassembly, if satisfied, transfer to procedure 6, otherwise, order i=i-1, that is, get rid of the component most inside, and continue to check until the principle of disassembly is satisfied.

Procedure 6: Check whether the i parts meet the principle of the shortest disassembly time, if satisfied, transfer to procedure 7, otherwise, order i=i-1, that is, get rid of the most inside component, and continue to check until the principle of the shortest disassembly time is satisfied.

Procedure 7: Compare part i to the part with the smallest number. Check whether they meet the principle of compatibility of materials. If satisfied, transfer to procedure 8, otherwise, order i=i-1, that is, get rid of the most inside component, and continue to check until the principle of disassembly is satisfied.

Procedure 8: Put the parts which have been checked through procedure 5, 6 and 7 into the same step for disassembly, then enter procedure 9. G1, G2… denotes the steps.

Procedure 9: Check whether the product is completely disassembled. If the parts are completely disassembled, end the procedure. Otherwise, transfer to procedure 5. Cycle this procedure until the product is completely disassembled.

All steps of product can be gotten through the above procedures, and the disassembly sequence is G1, G2….. When products are designed, it is convenient to achieve the purpose of multi-step active disassembly when the trigger strength is increasing in each step.

5. Conclusions

1. Aiming to the multi-step active disassembly, the chapter proposes the theory and method of the multi-step active disassembly, and analyzes the principles of multi-step active disassembly of products, then works out the process of classifying the steps of multi-step active disassembly and gives specific procedures of dividing steps according to the flow chart.
2. The theory and method discussed and researched in this chapter has the important academic value to replenish and improve the design method of dismountable products and the design theory system of active disassembly products.

3. The disassembly efficiency of products is greatly improved using the multi-step active disassembly method provided in this chapter. This method is in favor of parts and components sorting after the end-of-life (EOL) products disassembled, which can improve the recovery performance of EOL products and increase utilization rate of resource. To research this method, it is forming the foundation for the active assembly design of products and the industrialized application of this technology.

6. References

Chiodo J. D.,. Billett E. H &. Harrison D. J (1999) Preliminary Investigations of Active Disassembly Using Shape Memory Polymers, Cleaner Electronics Research, Brunel University.

Chiodo J.D (2002). Shape memory alloy actuators for active disassembly using "smart" materials of consumer electronic products. Materials and Design, Vol.23, No.11, (2001 November) pp. 471-478, ISSN 0261-3069

Chiodo, J. D. et al, (1998). Active Disassembly, Journal of Sustainable Design, Refereed Journal

Chiodo, J. D. et al, Available from http://www.activedisassembly.com/

Environmentally Conscious Design and Inverse Manufacturing, Proceedings of Eco Design '99: First International Symposium On pp. 590-596

Guo W, Liu Z, Liu G and so on (2005). Disassembly Sequence Planning Based on Modularization. Journal of Computer Aided Design & Computer Graphics, Vol.17, No.3, (2003 December) pp. 498-504, ISSN 1003-9775

Li X. (2008) Research of Active Disassembly Devices' Design Theory and Methods Based on Smart Materials. Hefei: *School of Mechanical and Auto Engineering, Hefei University of Technology.*

Liu G, Li X, Liu Z, et al. (2008). Research on Detachability of Remotes Based on ADSM. Proceedings of 15th CIRP International Conference on Life Cycle Engineering.

Liu Z, Cheng H, Li X, Zhao L (2011). The Design Method of Active Disassembly Device Using Electro and Heat Stimulation. *Machine Design and Research*, Vol.27, No.3, (2010 December) pp. 12-15, ISSN 1006-2343

Liu Z, Zhao L, Li X, Zhang H (2010) Research on Multi-step Active Disassembly Method of products Based on ADSM. Advanced Materials Research, Vols. 139-141, pp. 1428-1432 ISSN 1662-8985

Qi H, Xu H, 2007. Design theory & means for mechanical and electrical productions facing disassembling & recycling. Modern Manufacturing Engineering, Vol.2007, No.6, (2007 March), pp. 134-138 ISSN 1671-3133

Suga, T & Hosada, N (2000) Active Disassembly and Reversible Interconnection, Proceedings of International Symposium on Electronics and the Environment. IEEE

Wang B, Wang N (2005). Automatic Generation and Optimization of the Disassembly Sequence of Assemblies. Journal of Huaihai Institute of Technology, Vol.14, No.1, (2004 December) pp. 14-17 ISSN 1672-6685

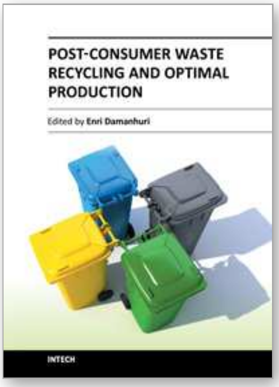
Wang B, WANG N (2005). The Initial Population of the Optimal Disassembling Sequence Generated Automatically. Machine Design and Research, Vol.21, No.2, (2004 July) pp. 59-60, 63 ISSN 1006-2343

Wang B, Wang N (2006). Automatic generation and combinatory optimization of disassembly sequence for mechanical-electric assembly. Journal of Shandong University (Engineering Science), Vol.36 No.2, (2005 January), pp. 52-57 ISSN 1001-9839

Willems B, Design for Active Disassembly (2005) Katholieke University, ISEE

Zhao L (2011) Research on Multi-step Active Disassembly Methods and Design Principle of Products Based on ADSM and Its Environmental Reliability Analysis. Hefei: *School of Mechanical and Auto Engineering, Hefei University of Technology.*

Zhao L, Liu Z, Li X, Zhang H, 2011. Cheng H. Research on Multi-step Active Disassembly Methods and Design Principle of products Based on ADSM[J]. *China Mechanical Engineering*, Vol.22, No.7, (2010 May) pp. 848-852 ISSN 1004-132X



Post-Consumer Waste Recycling and Optimal Production

Edited by Prof. Enri Damanhuri

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This book deals with several aspects of waste material recycling. It is divided into three sections. The first section explains the roles of stakeholders, both informal and formal sectors, in post-consumer waste activities. It also discusses waste collection programs for recycling. The second section discusses the analysis tools for recycling system. The third section focuses on the recycling process and optimal production. I hope that this book will convey both the need and means for recycling and resource conservation activities to a wide readership, at both academician and professional level, and contribute to the creation of a sound material-cycle society.

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