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Research on design management based on green remanufacturing engineering

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Abstract

With the popularization of the concept of "Product Multi-lifecycle" and "Extended Producer Responsibility", many manufacturers put the concept of green remanufacturing engineering into practice and begin to think about how to do the design management based on green remanufacturing engineering. This paper firstly analyses the concept of the remanufacturability, then explores the design content for new products' remanufacturability, and builds up the evaluation model of a used product's remanufacturability, in which the remanufacturability index of a used product is the product of the technological index and the economical index.

keywords: green remanufacturing engineering; design management; remanufacturability; evaluation model

1. Inroduction

At present, the whole world is facing the serious threat of the shortage of resources and environmental pollution, while a lot of recyclable and remanufacturable end-of-life products are abandoned, or are just recycled in low level, such as turnning them into new raw materials again by smashing or melting them. This resulted in the irrational use of resources and make the situation of the environmental pollution worse.

There are various product recovery means, including recycling, reconditioning and green remanufacturing (or "remanufacturing"). Material recycling is one of the most popular traditional ways to deal with the used products, which means to turn the used products into new raw materials again by smashing or melting them. Comparing with material recycling, product remanufacturing is a more profitable product disposition means, both ecologically and economically, as the reprocessing and manufacturing expenditures (time, energy, cost, etc) are avoided. Remanufacturing is defined as the practice of dissembling, cleaning, refurbishing, replacing parts (as necessary) and reassembling a product, the product may be returned to service with a reasonably high degree of confidence that it will endure (at least) another full life-cycle. According to the statistics, comparing to the new products, the remanufacturing products can save 60% of the energy, 70% of the materials, and 50% of the cost. So, this new measure becomes more and more popular in the whole world.

With the popularization of the concept of "Product Multi-lifecycle" and "Extended Producer Responsibility", More and more manufacturers begin to put the concept of green remanufacturing into practice, and begin to think about how to do the product design management based on green remanufacturing engineering. In the process of

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carrying out the green remanufacturing, they gradually realize that it will be much better to consider the later requirements of remanufacturing as early as in the new products' design stage[1]. This product design concept can dramatically improve the efficiency of remanufacturing and better achieve the strategy of resources sustainable development.

2. Design for New Products' Remanufacturability

Product design based on remanufacturing is a a great design concept transition and innovation from the traditional "passive solve the problems" to "take the initiative to prevent problems", which can greatly save resources and energy of the whole world and bring enormous economic benefits as well as social benefits. This concept focuses on considering the later requirements of remanufacturing as early as in the new products' design stage, namely to improve new products' remanufacturability.

2.1. Concept of remanufacturability

Remanufacturability is an attribute of a product, which can be used to describe the product's possibility and ability to be remanufactured when it reaches it life expiration. The evaluation of a product's remanufacturability is a comprehensive consideration of various factors, such as can the end-of-life product reach or even surpass the quality and performance of the original new product after remanufactured, the cost of remanufacturing, the price of remanufactured products, and so on.

The evaluation result of a product's remanufacturability is different on different stages, mainly including the stage of a new product (a new product's remanufacturability) and the stage of a used product before being remanufactured (a used product's remanufacturability). The influencing factors of a new product's remanufacturability usually include material property, the situation of its connection, the condition of its structure, and so on. The influencing factors of a new product's remanufacturability are showed in table 1.

2.2. Design content for new products' remanufacturability

The following aspects of contents Should be considered when design for a new product's remanufacturability.

2.2.1. Devoting much attention to the rationality of the material

Whether the end-of-life product can be reused or remanufactured, it depends largely on the physical capabilities and work performance of its material, including the material's durability, corrosion resistance and fatigue life,etc.

Therefore, firstly, the manufacturers should choose materials of high functionality and performance, which helps to reduce product's damage and environment pollution and improve the material's remanufacturability as well.Secondly, the manufacturers should choose as few materials' types as possible, which helps to save the cost and improve the efficiency of the used products materials' classify and storage.Thirdly, the manufacturers should choose as more environment friendly material as possible, which helps to reduce the environment pollution to the minimum. Take the plastics usually used on the cars, for example. There are two kinds of plastics: one is thermoplastic plastic, the other is thermosetting plastic. The former can be melted like wax, which is easy and convenient to be recycled and reused.

2.2.2. Design for easy load

Remanufacturing logistics includes two links: one is recycling link, which means sending the used products to the remanufacturing firm; the other is selling link, which means sending the remanufactured products to the customers. Obviously the transfer cost is in a bigger scale. So strengthening the convenience of products' transport and handling will be helpful to reduce the whole remanufacturing cost.

2.2.3. Design for disassembling and reassembling

Design for remanufacturing also means the parts should be easily disassembled or reassembled. So the quantity of the product's connectors, the type of the product's connectors and the quantity of the product's parts are all key contents.

Take the type of the product's connectors, for example. There are many kinds of connectors: such as demountable connectors, movable connectors, semipermanent fastener and permanent fastener. Usually, demountable connectors, movable connectors and semipermanent fastener can be easily disassembled, while permanent joint can hardly be taken apart without destroying the product. So to improve the remanufacturability of the product, demountable connectors and movable connectors should be chosen as more as possible. For example, comparing with traditional welding joint, plug-in connectors and buckle tie-in are much better.

Moreover, module design method and standardized design method are very helpful to improve products' remanufacturability[2].

Table 1 the Influencing factors of a new product's remanufacturability

The influencing factors	Explanation
Material's durability, corrosion resistance and fatigue life	The better the material's attribute is, the less of the used product's parts will be changed.
Can the product or its parts be easily cleaned or not	This will influence the cost and efficiency of the process of cleaning.
Can the product or its parts be easily renewed or not	This will influence the cost and efficiency of the process of renewing.
The quantity of the product's connectors	The less of the connectors there are, the easier the product will be taken apart and be reassembled.
The type of the product's connectors	Demountable connectors, movable connectors and semipermanent fastener can be easily disassembled, while permanent joint can hardly be taken apart without destroying the product. Moreover, it will influence the cost and efficiency of the process of disassembling.
The quantity of the product's parts	The more of the product's parts there are, the lower of the efficiency of the cleaning, disassembling and reassembling will be.
The shape of the product's parts	The more strange the shape of the product's parts are, the lower of the efficiency of the cleaning, disassembling and reassembling will be.
The degree of the product's or its parts' standardization	The higher of the product's or its parts' standardization, the easier it will be to disassemble and reassemble the product.

2.2.4. Design for classification

To improve the efficiency of remanufacturing, the manufacturers should pay more attention to design for classification. Module design method, standardized design method and reducing the types of the materials are all good ways to achieve this target.

2.2.5. Design for cleaning

As cleaning process is the necessary process of remanufacturing, designing for cleaning is very important. In order to reduce the damage to the products during the process of cleaning, easy- cleaning material and smooth surface should be chosen in the new product design stage.

2.2.6. Design for repairing and upgrading

Green remanufacturing engineering include two types of activities. One is taking the end-of-life products as the blanks, and recovering products' performance by using remanufacturing technology. Usually the remanufactured products' performance can reach or even surpass the performance of new products. The other is working on outdated products, and improving products' performance to meet the requirement of the times. Therefore, design for repairing and upgrading is very necessary and module design and standardized design method are also good ways to achieve this target[3].

3. Evaluation of a Used Product's Remanufacturability

After a used product is sent to the remanufacturing firm, the first step is to evaluate its remanufacturability, which is the premise to decide is it worthy to remanufacture the product.

3.1. Influent factors of a used product's remanufacturability

There are more influencing factors of a used product's remanufacturability. A used product's remanufacturability is not only influenced by its remanufacturability designed in its new product stage, but also influenced by the condition of the used product, the technology of the remanufacturing, and so on. The influent factors of a used product's remanufacturability are showed in table 2.

Table 2 the Influencing factors of a used product's remanufacturability

The influencing factors	Explanation
The technological feasibility of remanufacturing	It is possible on the aspect of technology to recovery the used product to reach or even surpass the performance of the new product.
The economical feasibility of remanufacturing	It is possible on the aspect of economics to remanufacture the used product, which means that the input-output yield is over zero.
The environmental feasibility of remanufacturing	The remanufactured product is more environmental friendly than the original product.
Product's service ability	The remanufactured product has rational service ability, which means it will not go out of date very soon.

3.2. Evaluating model of a used product's remanufacturability

The evaluating model of a used product's remanufacturability include two models-technological model and economical model.

3.2.1. Technological model

Technological model mainly aims to evaluate the technological feasibility of a used product's remanufacturing and selects 4 evaluation indexes-connection performance, standardization level, materials performance and accessibility.

3.2.1.1. connection performance index

The quantity and types of the product's connectors will influence the cost and efficiency of the process of remanufacturing.

$$\mu_f = \frac{1}{\sum_{i=1}^{L} s_i n_i k} \tag{1}$$

In which μ_f means connection performance index of the product; s_i , the evaluation of the connector of number i ; n_i , the quantity of the connector of number i ; k , the modified coefficient index of the quantity of the connectors; L , the quantity of the types of the connectors.

The data range of s_i is 1-9, which can be evaluated by the type of the connectors. If the connector is more difficult to be taken apart, the score is higher. The data range of k is 1/40～1/60.

3.2.1.2. standardization level index

The higher the parts' standardization level are, the easier it will be to disassemble or reassemble the product.

$$\mu_{st} = n_{st} / n \tag{2}$$

In which μ_{st} indicates standardization level index of the product; n_{st}, the quantity of the standard parts of the product; n, the quantity of all the parts of the product.

3.2.1.3. materials performance index

The materials performance index can be described by 3 indexes-material's durability, corrosion resistance and fatigue life.

material's durability index

The material's durability index can usually be obtained by compare the testing material's durability with the standard material's durability.

$$\mu_w = W_s / W_e \tag{3}$$

In which μ_w indicates the material's durability index of the material; W_s, the durability rate of the standard material; W_e, the durability rate of the testing material.

corrosion resistance index

The corrosion resistance index of the material is evaluated according to the Corrosion Resistance Evaluation Standard of China, which is judged by material's corrosion speed (table 3).

Table 3 the Corrosion Resistance Evaluation Standard of China

Grade	Corrosion speed/（$mm \times a^{-1}$）	Corrosion Evaluation
1	<0.05	Excellent
2	0.05-0.5	Good
3	0.5-1.5	Still can be used though there is some corrosion.
4	>1.5	Cannot be used at all because the corrosion is very serious.

After the linear processing, the corrosion resistance index can be describe as following:

$$\mu_c = 1 - 2.67c \tag{4}$$

In which μ_c indicates the corrosion resistance index of the material; c, the corrosion speed of the material.

fatigue life index

The fatigue life index of the material can be described by using S-N fatigue curve. This paper takes the fatigue degree when the fatigue life is $N = 10^8$ as the standard.

$$\mu_s = \sigma_{-1} / \sigma \tag{5}$$

In which μ_s means the fatigue life index of the material; σ_s, the fatigue degree of the standard material; σ_{-1}, the fatigue degree of the tasting material.

the total index of materials performance

The weight distribution of 3 indexes-material's durability, corrosion resistance and fatigue life, is showed in table 4.

Table 4 the weight distribution of 3 indexes

	material's durability	corrosion resistance	fatigue life	weight	The approximation of weight
material's durability	1	2	1/2	0.249	0.25
corrosion resistance	1/2	1	1/4	0.124	0.15
fatigue life	4	4	1	0.62	0.6

$$\mu_m = 0.25\mu_w + 0.15\mu_c + 0.6\mu_s \tag{6}$$

In which μ_m indicates the total index of one material's performance; μ_w, material's durability index of the material; μ_c, corrosion resistance index of the material; μ_s, fatigue life index of the material.

μ_m means the total index of one material's performance, so the total index of all materials' performance of a product is showed as following:

$$\mu_{pm} = \frac{\sum_{i=1}^{n} \mu_{mi}}{n} \tag{7}$$

In which μ_{pm} means the total index of all materials' performance of a product; μ_{mi}, the total index of material's performance of Part i; n, the quantity of the parts of the product.

3.2.1.4. accessibility index

The accessibility index just be measured in a rough way in this paper. It's mainly decided according to the normal experience.

$$\mu_a = n_a / n \tag{8}$$

In which μ_a means the accessibility index of the part; n_a, the quantity of the parts whose accessibility is good; n, the quantity of the parts.

3.2.1.5. the technological index of the product

$$\mu_T = w_f \mu_f + w_{st}\mu_{st} + w_{pm}\mu_{pm} + w_a \mu_a \tag{9}$$

In which μ_T indicates the technological index of the product; μ, each index; w, the weight of each index.

The weight distribution of 4 indexes-connection performance, standardization level, materials performance and accessibility, is showed in table 5.

Table 5 the weight distribution of 4 indexes

	index	weight
connection performance	μ_f	20
standardization level	μ_{st}	5
materials performance	μ_{pm}	70
accessibility	μ_a	5

Then,

$$\mu_T = 0.2\mu_f + 0.05\mu_{st} + 0.7\mu_{pm} + 0.05\mu_a \tag{10}$$

3.2.2. Economical model

The economical index stands for the economical feasibility, which can only be 0 or 1.

$$u_E = F(x) = \begin{cases} 0 & x < 0 \\ 1 & x \geq 0 \end{cases} \tag{11}$$

$x = \frac{C_a}{C} - 1$, $C_a = \sum_i (1-\lambda) p_i m_i$ means the added value of the used products. p_i stands for the price of the remanufactured Part i. m_i means the quantity of the Part i. λ stands for the material's proportion in the part.

$C = \sum_1^7 p_j c_j + C_g$

is the cost. C_g means the cost to obtain the used products, while C_j stands for the cost to disassemble, clean, check, repair and reassemble the product. p_j is the corresponding probability.

Lastly, the remanufacturability index of a used product is the product of the technological index and the economical index. So, the evaluating model of a used product's remanufacturability can be described as following:

$$\mu_R = \mu_T \mu_E \tag{12}$$

4. Conclusions

With the popularization of the concept of "Product Multi-lifecycle" and "Extended Producer Responsibility", more and more manufacturers begin to put the concept of green remanufacturing into practice and gradually realize that it will be much better to consider the later requirements of remanufacturing as early as in the new products' design stage.

The evaluation result of a product's remanufacturability is different on different stages, mainly including the stage of a new product (a new product's remanufacturability) and the stage of a used product before being remanufactured (a used product's remanufacturability). This paper explores the design content for new products' remanufacturability, and builds up the evaluation model of a used product's remanufacturability, in which the remanufacturability index of a used product is the product of the technological index and the economical index.

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