Research on Remanufacturing Technology and its Basic Process Flow

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Abstract: Remanufacturing technology is a new green manufacturing technology that restores the geometric dimensions or comprehensive performance of damaged parts. Regarding remanufacturing technology, this article specifically elaborates on the concept, connotation, and advantages of remanufacturing, product remanufacturability, remanufacturing technology, and the impact of remanufacturing on the economy, and reviews and summarizes the main research situation at home and abroad. It also introduces the types of remanufacturing processes and their practical applications in various industries, and puts forward suggestions for the development of remanufacturing technology.

Keywords: Remanufacturing Technology; Remanufacturability; Economy

1. Introduction

Environmental protection and sustainable development are increasingly receiving attention from governments around the world, and the Chinese government also regards sustainable development as a strategic national policy. Legislation related to environmental protection and sustainable development has also emerged, and under this pressure, the disposal strategy after the end of product life becomes particularly important. At present, the main treatment methods after the end of product life are 3R (Cycle, Reuse, and Remanufacturing), which includes recycling, reuse, and remanufacturing. Undoubtedly, the most beneficial aspect for environmental protection and sustainable development is product remanufacturing, because during remanufacturing, the geometric shape of the product will remain unchanged, and the geometric shape of each component will not change. Parts and products maintain the same function, so that the added value in the product and parts can be preserved.

Research on remanufacturing in foreign countries can be traced back to the 1970s, and many scholars have conducted extensive research. The research on manufacturing in our country started in the late 1990s under the initiative and promotion of Academician Xu Bin. Academician Xu Bin and relevant experts and scholars also conducted some research. In summary, research on remanufacturing mainly focuses on the following aspects: (1) the concept, connotation, and advantages of remanufacturing; (2) Product remanufacturability; (3) Remanufacturing technology; (4) The impact of remanufacturing on the economy. This article will review and summarize the main research on the above four aspects both domestically and internationally, and point out the direction and prospects for the development of remanufacturing in the future.

2. The Concept, Connotation, and Advantages of Remanufacturing

2.1 Concept

Robert Lund conducted significant research in various aspects of remanufacturing in the late 1970s and early 1980s, and was a pioneer in this field. His definition of remanufacturing is: waste products are completely dismantled, parts are cleaned, inspected, refurbished, and necessary updated, then reassembled and tested, and product performance is restored to its original state. Academician Xu Bin is a

pioneer in the field of remanufacturing in China. His definition of remanufacturing is: remanufacturing is guided by the design and management of the entire product life cycle, with the goal of high-quality, efficient, energy-saving, material conservation, and environmental protection, and advanced technology and industrial production as means. It is a series of technical measures and engineering activities for repairing and transforming waste products. It utilizes existing components from scrapped equipment, adopts modern production methods, high-tech surface engineering technology, and other processing techniques to restore the size, shape, and performance of the components, forming remanufactured products.

2.2 Connotation

Remanufacturing is the horizontal manufacturing of parts, where the geometric shape and function of the parts remain unchanged. Academician Xu Bin pointed out that remanufacturing is green manufacturing and belongs to the category of advanced manufacturing technology. Remanufacturing is not only about extending the lifespan and restoring functionality of products, but also about upgrading with the development and progress of technology.

Remanufacturing is the integration of 3R,. 3R refers to REDUCE, REUSE, RECYCLE. REDUCE is to reduce material and energy consumption; Reuse refers to reusing as much as possible; RECYCLE refers to the recycling at the material level when it cannot be reused. And remanufacturing is the combination and integration of the three. It is the use of old components or parts to manufacture new products or devices. Remanufacturing is the process of using waste product components as raw materials, repairing and reusing them, and turning waste into treasure. The scrapping of a product refers to the end of its lifespan. The lifespan of a product can be divided into material lifespan, technical lifespan, and economic lifespan. Material lifespan refers to the time it takes for a product to be used until it is physically scrapped. The material life of a product is determined by factors such as physical wear and tear, metal corrosion, material aging, and mechanical damage. A considerable portion of the components of products that are scrapped due to the end of their material lifespan can be used directly or through remanufacturing and processing. The technical lifespan refers to the time it takes for a product to be used until it is eliminated due to technological backwardness. The speed of technological development determines the technical lifespan of products. Timely renovation and upgrading can extend the technical lifespan of the product. Economic lifespan refers to the time it takes for a product to experience a decrease in economic benefits from its initial use to continued use. The deterioration of a product (caused by increasing maintenance costs, fuel and power costs, production costs, and downtime losses during use) determines its economic lifespan. In product technology and economics, there are multiple methods to calculate the economic lifespan of a product: optimal service life. The object of remanufacturing - "waste products" is broad. It can be a device, system, facility, or its components, including both hardware and software.

Proper maintenance and repair of products can extend their material lifespan. Remanufacturing is different from repair. Product maintenance is a measure taken to maintain its normal operation.

2.3 Advantages

Lund and Denny (1977) explored the benefits and issues of extending the product lifecycle, as well as the factors that affect the product lifecycle. They believe that the advantages of remanufacturing include generating employment opportunities, having higher value than recycling, and providing a pathway and source for the replacement of parts and components. Overby (1980) pointed out that the benefits of remanufacturing include material savings, energy conservation, job creation, reduction of pollution and waste, and so on. Lund (1983) emphasized that remanufacturing means recycling at the level of parts and components, thus preserving the value added to the parts. Haynsworth and Lyons (1987) argue that remanufacturing means reuse at the part level, thus avoiding the use of many material processing and manufacturing resources. Its advantages can be summarized as follows:

(1) Good environmental protection and energy efficiency, reducing pollution and landfilling, retaining added value in parts such as energy

consumption and labor, reducing material and energy consumption, in line with sustainable development strategies.
(2) Good economic and social benefits. Remanufacturing can increase income and is also a labor-intensive industry that can increase employment opportunities.
(3) Created an optional product for consumers and enriched the product market.

3. Product Remanufacturability

Not all products are suitable for remanufacturing, as remanufacturing has a certain scope of application. The evaluation of the remanufacturability of a product should be based on the criteria for remanufacturability and the disassemblability of the product.

3.1 Criteria for Judging the Remanufacturability of Products

Lund (1998) summarized the following 7 criteria for determining the remanufacturability of 75 different types of remanufactured products through their understanding and research:
(1) The functionality of the product has been lost;
(2) Having mature technology for recovery products;
(3) The product has been standardized and the parts are interchangeable;
(4) Renewable added value is relatively high;
(5) Compared to its added value, the cost of obtaining "raw materials" is relatively low;
(6) The technology of the product is relatively stable;
(7) Customers know where to purchase remanufactured products.
These guidelines need to be supplemented, expanded, and modified. Article (1) should be revised as follows: The product has already reached the end of its lifespan, that is, whether due to the loss of function due to the end of its material lifespan, the end of its economic lifespan, the elimination due to technological progress, or the expiration of its service period. (7) It should be added that customers understand and recognize remanufactured products.

3.2 Product Detachability

The decomposition and disassembly of products are important links in remanufacturing. The feasibility of decomposition and disassembly in terms of technology and economy directly affects the feasibility of remanufacturing. At present, there is not much literature in this area. The evaluation of product disassembly mainly includes: (1) defining disassembly; (2) Determine the parameters for evaluating disassemblability; (3) Quantify various parameters based on certain algorithms and rules; (4) Obtain the disassembly index (which is a function of parameters).
The author defines disassembly as the ease, economy, and environmental friendliness of disassembly. Mainly including the following aspects:
Does disassembly require external force;
- The simplicity of dismantling the mechanism;

Do tools need to be used for disassembly;
- Are there identical or similar components that are reused;

The difficulty level of identifying disassembly points;
The simplicity of product structure design;
Whether toxic materials are used in the product.

3.3 Remanufacturability

Remanufacturability refers to having a certain degree of disassembly and economy while meeting the criteria for remanufacturability. As mentioned earlier, the concept of detachablity has been briefly introduced. Economy mainly refers to the comparison with direct recycling. There is currently no mature method for comprehensively evaluating the remanufacturability of products.

3.4 Suitable for Remanufactured Products

Lund conducted in-depth research and investigation on remanufacturing enterprises and products in the United States, involving nearly 70 types of products such as automobiles, compressors, appliances, machinery, furniture, valves, etc. At present, there are only two true remanufacturing enterprises in China, both of which are automotive engines and their technologies are imported from abroad. It is also very important to conduct research and analysis on products, and establish a database of remanufactured products based on foreign research results. It can serve as an important reference for determining remanufacturability.

4. Remanufacturing Technology

4.1 Process Flow of Remanufacturing

Remanufacturing generally involves processes such as disassembly, cleaning, inspection, sorting, refurbishment, restoration, maintenance, and assembly.

4.2 Organization and Management of Remanufacturing

Remanufacturing is manufacturing, but it is different from traditional manufacturing in terms of production organization, management, and planning. It mainly has the following characteristics:

(1)The uncertainty of the return of (raw materials) in terms of time and quality;

The necessity of balancing return and demand;

The returned product needs to be disassembled and disassembled;

- Inaccuracy of materials;
- Need for reverse logistics network;

The complexity of material matching limitations;

The randomness of material and height variations in processing, recovery, repair time, etc.

These characteristics affect some aspects of remanufacturing organization and management, as shown in Table 1.

The impact of these characteristics on remanufacturing management cannot be viewed in isolation, but rather as a whole. It is a remanufacturing production planning and control system, where the interrelationships between its decision points, as well as the process and information flow, can be seen. Due to the characteristics of remanufacturing, it has a significant impact on the decision-making and management of each node. Therefore, there are many issues worth studying in the management and organization of remanufacturing, which will be discussed later.

Table 1. The impact of remanufacturing characteristics on production planning and control

Characteristic	Production planning and control			
	Prediction	Logistics	Scheduling	Inventory control and management
The uncertainty of the return of (raw materials) in terms of time and quality	▲	▲	▲	▲
The necessity of balancing return and demand				▲
Returning the product requires disassembly and disassembly			▲	▲
Inaccuracy of materials			▲	▲
Need reverse logistics network		▲		▲
The complexity of material matching limitations			▲	
The randomness of processing, recovery, repair time, and other factors related to material and height variations			▲	

5. Research Prospects for Remanufacturing

Remanufacturing is an emerging discipline, and the author has found through research on relevant materials both domestically and internationally that there is currently no systematic research on remanufacturing. Therefore, there is still room for improvement and development in both the disciplinary framework and various aspects involved. The research should mainly focus on product remanufacturability, technical standards for remanufactured products, production management for remanufacturing, relevant laws, and design for remanufacturing.

5.1 Product Remanufacturability

Product remanufacturing is the integration of recycling, reuse, and remanufacturing. Research on remanufacturability is the study of processing strategies after the end of product life. The main constraints of product remanufacturability are economy, disassembly, and technology, and its mathematical model is difficult to establish. So the evaluation system for product remanufacturability should be

based on remanufacturing product databases, knowledge bases, and a human-machine interaction system based on knowledge mining. This raises many questions, such as:
(1) Establish a database of remanufactured products;
(2) Product classification and classification algorithms;
(3) The establishment of a manufacturing knowledge base and knowledge mining algorithms for products;
(4) Dismantling test;
(5) Virtual disassembly;
(6) Optimal disassembly sequence algorithm, etc.

5.2 Technical Standards for Remanufactured Products

For more complex products, remanufacturing is similar to trial production of new products. Before remanufacturing, it is necessary to repeatedly determine relevant technical standards through scheme design, repair of important components, processing technology design, finished product inspection and testing, etc. For example, Shanghai Volkswagen's regenerative engine factory has all introduced German technical standards. Many European countries have already legislated, and manufacturers are responsible for the recovery and handling of product life summaries. China will also do this legislation in the future, including product remanufacturing technology standards.
The formulation of will become a research hotspot in the future, involving the following main issues:
(1) Research on remanufacturing experiments;
(2) Selection of remanufacturing solutions and determination of models;
(3) Remanufacturing process design;
(4) Quality control and management of remanufacturing.

5.3 Production Management of Remanufacturing

The unique characteristics of remanufacturing and its difference from traditional manufacturing make the production management of remanufacturing different from that of traditional manufacturing. The seven characteristics described in 3.2 also raise many problems worth studying. Here are some examples:
(1) A predictive model for the return rate and quantity of waste products;
(2) A product reliability model for better predicting the lifecycle of multi life products;
(3) Inventory control model based on return rate;
(4) Help determine which components need to be regenerated, which need to be repaired, and which models need to be scrapped;
(5) Planning and design of dismantling equipment;
(6) Models and systems for raw material acquisition management and strategies.

5.4 Related Laws

The importance of remanufacturing for environmental protection and sustainable development has exceeded academic attention. Many European countries have already legislated that manufacturers must be responsible for recycling their waste products. Some states in the United States have also introduced laws in this area. It is obvious that these legislation can greatly promote research and development in remanufacturing. The Chinese government should also intensify legislation in this area.

5.5 Design for Remanufacturing

In the design phase of a new product, consideration should be given to remanufacturing the product. Design for remanufacturing involves various aspects of the remanufacturing process, including disassembly, cleaning, classification, inspection, refurbishment, and reassembly.
(1) Dismantling
Disassembly is not simply the opposite of assembly. In the design phase of a product, its disassembly should be considered, and there should be the optimal disassembly sequence. The design criteria include:
● Design partial assembly components for easy disassembly;
● Choose a connection method that is easy to disassemble;
The lifespan of the connector should be the same as the lifespan of the entire product.
(2) Cleaning
More than 90% of the parts in remanufacturing need to be cleaned. The design criteria for easy cleaning include:
● The concave area and cavity have good accessibility;

The markings on the parts should have anti cleaning properties;
The cleaning agents used are environmentally friendly;
The cleaning surface is relatively smooth and wear-resistant;
(3) Classification
After cleaning the parts, they need to be classified for easy production organization, management, inventory, etc. Design criteria that are easy to classify include:
● Parts, especially similar ones, should be easy to classify;
Parts with the same function are either identical or can be clearly distinguished.
(4) Check
Before resuming use, the condition of the parts should be checked or inspected to see if they can be directly reused, repaired, or refurbished. This requires consideration of:
Easy to inspect parts that are prone to wear and corrosion;
Relevant data such as material properties, ultimate loads, tolerances, etc. are known.
(5) Restore
The parts should be easy to install, process, and spray plated; The threaded bushing is easy to replace.
(6) Reassembly
All design criteria for assembly are equally suitable for use in reassembly. Reassembly should be simple, clear, and suitable for large-scale production.

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