Review on remanufacturability evaluation of retired products

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Abstract. The uncertainty of recycling waste products affects the remanufacturing of products. Therefore, whether waste products can be remanufactured has become a key issue. Remanufacturability evaluation is an important part of the remanufacturing process of waste products, which directly determines the service safety and reliability of remanufactured products. Based on the research and review of a large number of literatures, this paper studies the current research hotspots and main research achievements of remanufacturing evaluation, and summarizes the existing achievements from the aspects of evaluation objects, evaluation directions and evaluation methods. Through research, it is found that most of the remanufacturability currently selects economic, technical, environmental and other evaluation grades, constructs corresponding evaluation index system, assigns weight to each index, and finally obtains evaluation conclusions through hierarchical analysis and entropy method.

Keywords: Remanufacturing; Remanufacturability evaluation; Evaluation method.

1. Introduction

With the concept of carbon peak and carbon neutrality in China and the deployment requirements of related tasks, accelerating the pace of low-carbon emissions is conducive to guiding green technology innovation and improving the global competitiveness of industry and economy. As a national emerging strategic industry, remanufacturing is an advanced form of resource regeneration, an important direction for the transformation and upgrading of manufacturing industry, and an important carrier for promoting green development, circular development, low-carbon development, and ecological civilization construction. It is a development mode that takes into account economic development and green transformation. After more than 20 years of development, the remanufacturing industry has been booming in the fields of auto parts, construction machinery, coal mining machinery, metallurgical equipment, aviation equipment, machine tools and other fields.

Remanufacturing refers to the general term of a series of technical measures and engineering activities to repair and transform waste products with the whole life cycle theory of products as the guidance, the performance improvement of waste products as the goal, the high quality, high efficiency, energy saving, material saving and environmental protection as the criteria, and the advanced technology and industrial production as the means [1]. Remanufacturing is a kind of circular economy model and concept, through remanufacturing, the retired waste products can reach or exceed the same quality and performance as the original new products, with good economic benefits, environmental benefits and social benefits. Figure 1 is a schematic diagram of the life cycle process of the remanufactured product. The goal of remanufacturing is to maximize the use of waste products and increase the recycling proportion of waste parts. The remanufacturing of waste

products mainly includes three modes: reuse, remanufacturing and recycling. Among them, reuse means that some parts of waste products can be used directly. Remanufacturing means that some parts of waste products need to be reused after remanufacturing. Recycling refers to the parts of waste products that can no longer be used directly for resource treatment.

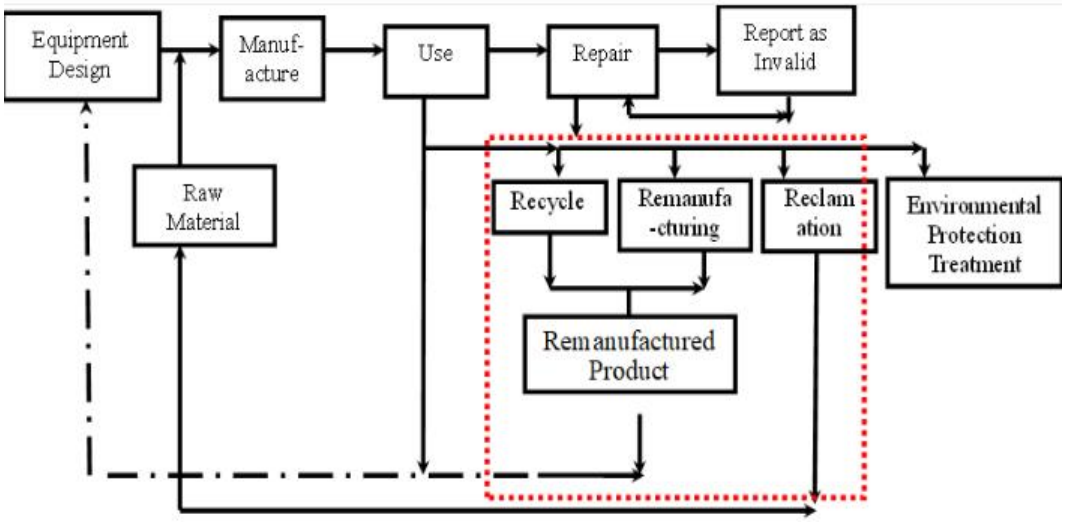

Fig. 1 Schematic diagram of the life cycle process of remanufactured products

Remanufacturing evaluation refers to the ability to make the serviceability of the remanufactured object meet the expected requirements under specified conditions, taking into account technical, economic, environmental and other factors under the influence of advanced remanufacturing technology, which is the key to determining its remanufacturing value, determining the remanufacturing method, and carrying out the remanufacturing design. It is also related to the service safety and reliability of remanufactured products. Figure 2 shows the whole process of remanufacturing. From the old parts to the birth of remanufactured products, it needs to go through dismantling, cleaning, testing, remanufacturability evaluation, processing, testing and other steps, among which remanufacturability evaluation is the key process in the remanufacturing process, and remanufacturability evaluation should be carried out first before the remanufacturing process. Remanufacturability evaluation not only determines whether waste products can be remanufactured, but also determines the formulation of remanufacturing strategy, and in turn can guide remanufacturability design in the initial design of new products.

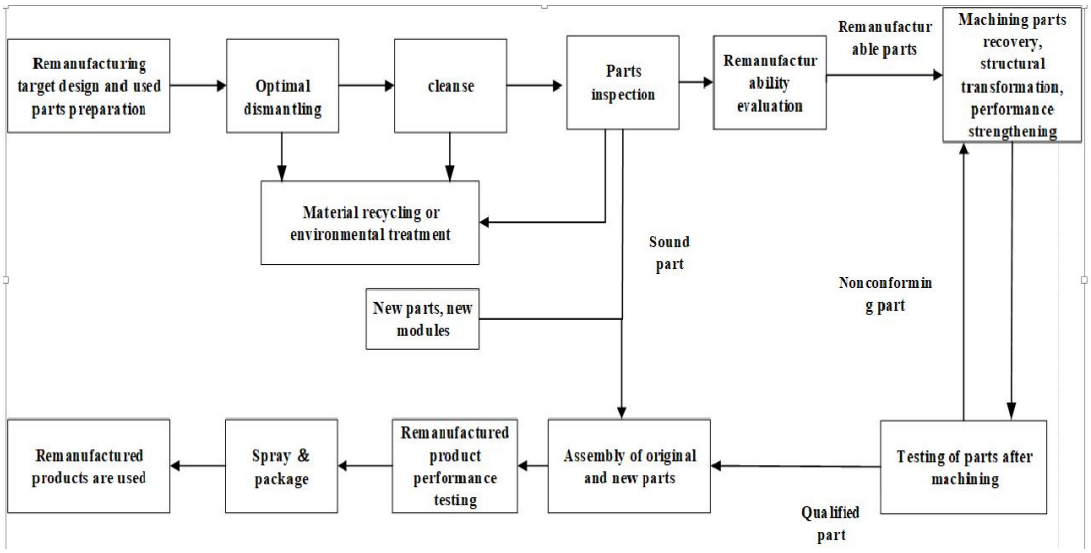

Fig. 2 Schematic diagram of the life cycle process of remanufactured products

Remanufacturability evaluation is one of the key technologies in the process of remanufacturing of mechanical products, which should run through the whole life cycle of the product. It is mainly reflected in the remanufacturability evaluation of the design stage, the remanufacturability evaluation of the used parts, and the performance evaluation of the remanufactured parts. The remanufacturability evaluation discussed in this paper is mainly to discuss the remanufacturability evaluation of used parts. Due to the special position of remanufacturability evaluation in the process of remanufacturing, there are many researches on remanufacturability evaluation. This paper reviews the papers on remanufacturability evaluation from 2005 to 2021, analyzes the current hot issues and achievements of remanufacturability evaluation research.

2. Research status of remanufacturability evaluation

Through literature analysis, most scholars will consider technology, economy and environment when evaluating remanufacturing. In fact, after the present stage of green reengineering, the impact on the environment and the saving of resources are the focus of scholars. Since remanufacturing is mostly used in civilian product equipment, the economy of remanufacturing is the focus of attention of enterprises, and the ability to obtain economic benefits plays a decisive role in whether to remanufacture. Zhang Guoqing et al. [2] analyzed the remanufacturing process from the perspective of technology and economy, calculated the remanufacturability index of products, and applied it to the remanufacturability evaluation of automobile engines. In addition, scholars add different indicators to remanufacturing evaluation according to the concerns of remanufacturing. For example, Shi Bowen [3] evaluated the remanufacturability of products from four aspects: technology, environment, economy and timeliness, and calculated the evaluation model and evaluation index by considering the weights of various factors. Hu Yanfeng et al. [4] used fuzzy mathematics theory to evaluate remanufacturability from three aspects: technology, economy and serviceability. Jiang Zhipeng[5] used analytic hierarchy process (AHP) to evaluate the remanufacturability of automotive generators from three aspects: technical feasibility, resource feasibility and performance feasibility. Wang Qingfeng et al. [6] studied the problem of serviceable remanufacturing, and conducted a comprehensive evaluation of serviceable remanufacturing from six aspects, including technology, environment, resource, serviceability and overall harmony, using the method of cause analysis. Wang Yuling et al. [7] studied the remanufacturing of used parts in the product design stage and after service respectively from the perspective of the whole life cycle of the product, and built a remanufacturing model of the whole life cycle. When analyzing the remanufacturing evaluation of used parts, the remanufacturing design characteristics, material properties, recycling value, manufacturability, economic index and environmental index are considered comprehensively. Cui Xiang et al. [8] constructed a hierarchical model of remanufacturability from various factors such as failure characteristics, scrap characteristics and recycling decision making for remanufacturability evaluation. Wang Yanan [9] used structural entropy weight method to evaluate remanufacturability from five aspects: recyclability, technology, economy, resource environment and risk. Hu Yanfeng et al. [10] evaluated the remanufacturability of centrifugal pumps considering the whole process of their re-service. The evaluation process is shown in the figure3.

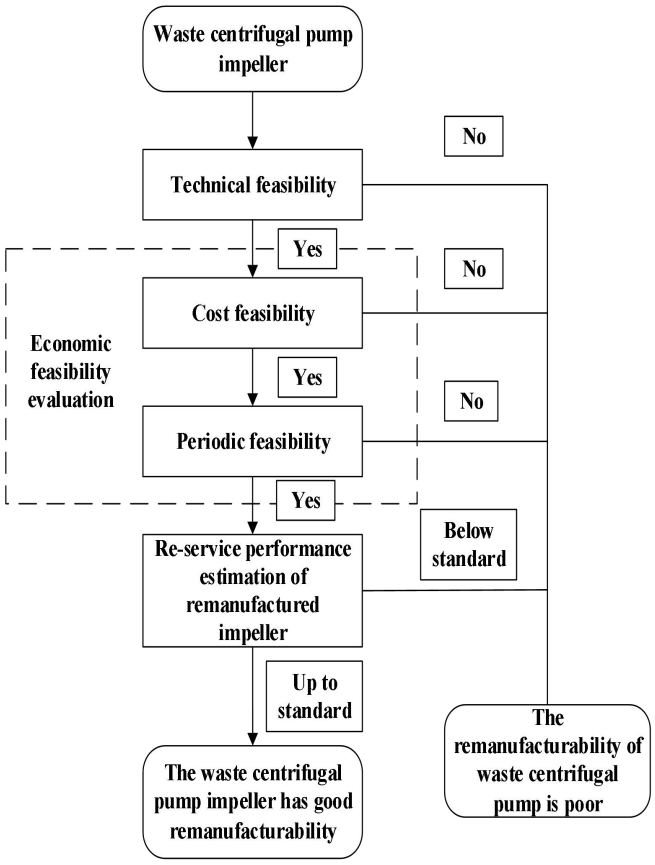

Fig. 3 Remanufacturability evaluation flow chart

To sum up, the evaluation of remanufacturability first considers its technology and economy, and environmental indicators are also the focus of consideration in the evaluation of remanufacturing. In addition, some scholars have evaluated remanufacturing according to the characteristics of the research object, the service environment of the product and the safety of remanufacturing.

3. Research status of remanufacturability evaluation methods

At present, most remanufacturability evaluation methods include the following steps: first, to determine the impact of product remanufacturability evaluation indicators; Second, analyze the indicators, analyze the lower indicators, form the rating index system; Third, determine the weight factor of the index; Fourthly, the index is quantified with weight factor to form dimensionless measurement value of product remanufacturability. Fifth, calculate the remanufacturability evaluation value. The evaluation process is shown in the figure4.For remanufacturability evaluation methods, analytic hierarchy process (AHP), entropy method and fuzzy method are often selected, as shown in Table 1.

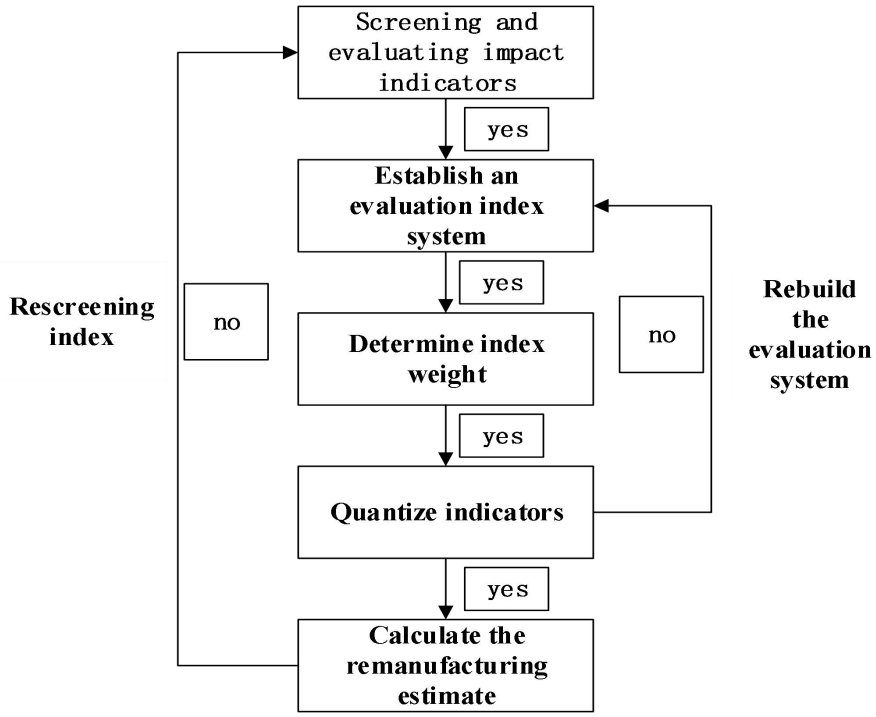

Fig. 4 Remanufacturability evaluation flow chart

Table 1.Statistical table of remanufacturing evaluation methods

Author	Evaluation Method	Author	Evaluation Method
Liu Mingsheng[11]	Fuzzy mathematical method	Wang Jingjing[16]	Fuzzy Analytic Hierarchy Process
Du Yanbin[12]	Entropy weight method	Rong Tao [17]	Analytic Hierarchy Process
Yang Qi[13]	entropy weight analytic hierarchy process	Xiang Qin [18]	Fuzzy Extension Analytic Hierarchy Process
Jiang Xinxin[14]	Fuzzy method	Xiang Hong[19]	Analytic Hierarchy Process
Fan Jian[15]	Fuzzy Analytic Hierarchy Process	Du Li [20]	FuzzyJudgment Mathematics

Addition to these three methods, some scholars have also used some other evaluation methods. For example, Pan Quan et al. [21] built the reliability model of the structural arm with two-parameter Weibull distribution according to the actual use data of the structural arm of the concrete pump truck, and scientifically evaluated the remanufacturability of the structural arm combined with the remaining life. According to the logical relationship between residual fatigue life and remanufacturability, Wang Jinlong [22] obtained the remanufacturability critical threshold and remanufacturability judgment index, and proposed a remanufacturability evaluation method based on fatigue damage. Based on green remanufacturing, Cheng Xianfu et al. [23] built a fuzzy mapping relationship between failure mode and recycling from the relationship between component remanufacturing structure decision and failure mode, formed a transfer network model between the two, and evaluated the closeness of the correlation between zero parts according to material compatibility, service life, recycling mode and remanufacturing processability. Building remanufacturable integrated associations of components; Xie Haijun [24] comprehensively used

information evaluation, detection evaluation and follow-up verification methods to conduct remanufacturability evaluation in three stages: information evaluation stage, acceptability evaluation stage and remanufactured finished product evaluation stage. Pan Shangfeng et al. [25] used the neural network evaluation method to conduct remanufacturability evaluation; Guo Jieqin [26] compared various remanufacturability evaluation methods and selected TOPSIS method based on grey correlation analysis for remanufacturability evaluation. Cui Xiang et al. [27] used extension evaluation to analyze the performance of decommissioned crankshaft, established a remanufacturing quality evaluation model from three aspects of failure, economy and material property, and conducted economic evaluation of design cost and time cost. Zhang Bin et al. [28] quantitatively evaluated various achievements in the remanufacturing process of drilling and production equipment, including the impact of process cost, energy consumption cost and environmental cost on the remanufacturability of parts, and proposed a remanufacturability evaluation strategy based on cost consumption. Shi Ronghua [29] evaluated the accuracy remanufacturability of remanufacturing machine tools based on the multi-body theory accuracy model. Aiming at product configuration and remanufacturing design problems, Zhang Yingying et al. [30] established a nonlinear double-layer programming model, designed nested genetic algorithm and corresponding coding strategy solving model, and adopted double-nested genetic algorithm for solving. Using case reasoning, Jiang Xiaoli et al. [31] focused on the contribution of recent domain algorithms to the remanufacturability evaluation of parts, and improved the evaluation from four perspectives: economy, technology, resources and environment.

4. Summary

Through the analysis of the current research on remanufacturability evaluation in China, the current research status of table evaluation is understood. The existing remanufacturability evaluation methods have certain limitations in practical application, which mainly include three aspects: (1) In terms of the selection of evaluation methods, most scholars currently choose qualitative evaluation methods, and the selected evaluation indicators cannot be described quantitatively. The quantification of weights is based on expert evaluation scores, and the professional skills and professional attributes of the expert group are influenced by various factors, which increase the uncertainty of remanufacturability evaluation. (2) The remanufacturability evaluation measures are relatively vague, which makes it impossible to obtain a clear conclusion; (3) Some studies consider the assessment indicators of technology, economy and environment in the same important level, but do not clarify the primary and secondary relationship of different assessment indicators according to the practical application conditions. Therefore, the existing remanufacturability evaluation methods can not provide effective technical support for the remanufacturing operation of enterprises, and more scientific and objective evaluation methods need to be established to support the remanufacturability evaluation of products.

In addition, the research on remanufacturing upgrade mainly focuses on the remanufacturing upgrade process, flow and management, and there is no relevant research on the systematic analysis and evaluation of remanufacturing evaluation. The performance of the engine upgraded by remanufacturing has been improved, and the evaluation of remanufacturing upgradability should be comprehensively considered.

References

[1] LIU Ling. Research on Residual life Prediction and Remanufacturability Evaluation of retired Machine Tool spindles [D] Xi 'an: Northwestern Polytechnical University, 2019.

[2] ZHANG Guoqing, Jing Xuedong, Pu Gengqiang et al. Remanufacturability evaluation method and model [J] Journal of Shanghai Jiao Tong University, 2005,39(9):1431-1436.

[3] Shi Bowen. Research on Remanufacturability evaluation of centrifugal compressor impeller based on Ultra-high cycle fatigue [D] Dalian: Dalian University of Technology, 2016.

[4] HU Yanfeng, Du Yanbin, Xu Lei, Wang Fan. Remanufacturability evaluation method of centrifugal pump impeller for reservice performance [J] Journal of Chongqing Technology and Business University (Natural Science Edition). 2021,38 (3) : 65-70. (in Chinese)

[5] Jiang Zhipeng. Research on residual life prediction and remanufacturability evaluation of Automotive generators [D] Qingdao: Qingdao University of Technology, 2018.

[6] Wang Qingfeng, Gao Jinji, Yuan Qingbin. Theoretical system of in-service remanufacturing engineering for process equipment [J]. Computer Integrated Manufacturing System.2019, 2446-2455.

[7] WANG Yuling, Kong Yinxiang, Wu Baohua, Chen Jialu. Life Cycle remanufacturability evaluation of mechanical products [J]. Machinery Design and Manufacture, 2012, 266-268.

[8] Cui Xiang, Zhang Xiufen. Extension evaluation Model and method for Remanufacturability of retired Crankshaft [J]. Machine Tool & Hydraulics. 2021,49 (1) : 69-74.

[9] Wang Yanan. Research on comprehensive evaluation of remanufacturability of chiller [D] Tianjin: Tianjin University, 2013.

[10] HU Yanfeng, Du Yanbin, Xu Lei, Wang Fan. Remanufacturability evaluation method of centrifugal pump impeller for reservice performance [J] Journal of Chongqing Technology and Business University (Natural Science Edition). 2021,38 (3) : 65-70. (in Chinese)

[11] Liu Mingsheng, Xiang University, Pu Shanshan. Construction and Application of Remanufacturability evaluation Model for Mechanical Parts [J]. Henan Science and Technology.2021,759(25):60-63.

[12] Du Yanbin, Cao Huajun, Liu Fei et al. Comprehensive evaluation of Machine Tool remanufacturing Scheme based on entropy weight and Analytic Hierarchy Process [J] Computer Integrated Manufacturing Systems, 2011,17(1):84-88.

[13] Yang Qi. Research on remanufacturability evaluation of used Machine Tools [D] Xi 'an: Xi 'an Polytechnic University,2018.

[14] Jiang Xinji. Analysis and evaluation of Remanufacturability of automobile Parts based on Automobile Remanufacturing Engineering [D] Xi 'an: Chang 'an University,2011.

[15] Fan Jian. Research on remanufacturability evaluation of coal machine equipment based on product Multi-life cycle [D] Beijing: University of Science and Technology Beijing,2015.

[16] Wang Jingjing. Research on remanufacturability evaluation of Mechanical and electrical products [D] Zhengzhou: Zhengzhou University,2009.

[17] Rong Tao. Remanufacturability evaluation and active remanufacturing time determination of Concrete pump truck boom system [D] Xiangtan: Hunan University of Science and Technology,2009.

[18] Xiang Qin. Research on Decision making of Construction Machinery remanufacturing Scheme based on ECC [D] Xiangtan: Hunan University of Science and Technology,2017.

[19] Turn red. Research and Application on remanufacturability evaluation of waste mechanical and electrical products [D] Xiangtan: Hunan University of Science and Technology,2016.

[20] Du Li. Research on system reliability under cognitive uncertainty [D] Chengdu: University of Electronic Science and Technology of China, 2010.

[21] Pan Quan, Xie Wen, He Shanghong. Remanufacturability evaluation of Structural Arm of Concrete Pump Truck Based on Reliability Modeling [J]. Mechanical Design and Research, 2015,31 (3) : 109-113.

[22] Wang Jinlong. Study on Ultrahigh cycle fatigue life prediction and remanufacturability judgment of blade material FV520B-1 based on fatigue damage [D] Dalian: Dalian University of Technology, 2019.

[23] Cheng Xianfu, Zhou Jian, You Minhua, Li Jun. Modular approach to product remanufacturing based on failure mode transfer network model [J]. Computer Integrated Manufacturing Systems.2020.

[24] Xie Haijun. Exploration of remanufacturability evaluation methods for imported electronic and electrical products [J]. Technological Innovation.2021, 25-32.

[25] Pan Shangfeng, Lu Chao, Peng Yibo. Remanufacturability Evaluation Model of Machine Tool Base Parts Based on Improved BP Neural Network [J]. China Mechanical Engineering, 2016, 27 (20) : 2743-2748.

[26] Guo Jieqin. Research on remanufacturability evaluation of mechanical products based on Grey Correlation degree analysis and TOPSIS [D] Hefei: Hefei University of Technology,2020.

[27] Cui Xiang, Zhang Xiufen, Liu Jia. Remanufacturability level evaluation of retired Crankshaft based on Failability [J]. Machine Design and Research, 2019, 36 (4) : 109-113. (in Chinese)

[28] Zhang Bin, Zhang Zhiwei, Sun Juan, Zhang Wenying. A cost evaluation method for remanufacturability of key components of oil drilling and Production Equipment [J] Journal of Liaoning Shihua University. 21st, 41 (3) : 71-75.

[29] Shi Ronghua. Analysis and Research on accuracy Remanufacturability of used Machine Tools [D] Changzhou: Jiangsu Institute of Technology, 2018.

[30] Zhang Yingying, Xia Yi, Du Gang. Master-slave optimization of product family configuration and remanufacturing design with consideration of upgrading [J]. Computational Integrated Manufacturing Systems.2021,27(7):2053-2064.

[31] Jiang Xiaoli, Jiang Zhigang, Zhang Hua et al. Remanufacturability evaluation model of used parts based on case-based reasoning and its application [J] Modern Manufacturing Engineering,2013,(12):6-9.