Optimal Design of Remanufacturing Process for Injection Molding Machine Parts

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Abstract. The remanufacturing process of an injection molding machine is a key link that affects the remanufacturing process of an injection molding machine. Uncertainties such as damage form and degree of damage will increase the difficulty of remanufacturing repair process technology and process parameter selection. To this end, this article is based on the failure characteristics of injection molding machine parts, first establishes the failure feature fault tree extraction model of used parts, and uses damage to describe the failure characteristics such as wear, fracture and corrosion. This paper establishes a mathematical model of damage, and then uses Fuzzy comprehensive evaluation method is used to establish a quantitative scoring table for the failure characteristics of waste parts of injection molding machines. Afterwards, a directed graph is used to indicate the priority relationship between the failure feature processing elements, and finally the genetic-neural network algorithm is used to optimize the remanufacturing process route in combination with the remanufacturing time and cost to realize the optimized design of the remanufacturing process of the injection molding machine parts.

Keywords. Remanufacturing; failure characteristics; genetic-neural network machine.

1. Introduction

In 2020, President Xi Jinping promised at the United Nations General Assembly that carbon dioxide emissions will peak by 2030 and strive to achieve carbon neutrality by 2060 [1]. Achieving carbon neutrality in the middle of this century is a solemn commitment of our country to the environment of the earth. China’s economic development model will also inevitably change from a pursuit of high GDP at the expense of the environment to a greener, more efficient and reasonable economic development model.

China’s injection molding machine industry is developing rapidly. Among them, the annual output of Haitian in Ningbo in the Yangtze River Delta area accounts for more than 50% of the total annual output of domestic injection molding machines and one third of the world's injection molding machines. In 2019, the global output of injection molding machines reached 146,047 units, and the output of China’s injection molding machines ranked first in the world, reaching 95,560 units, accounting for 65% of the market share [2]. China is the world’s largest manufacturer of injection molding machines and the country with the largest number of injections molding machines in the world. In recent years, the development of remanufacturing of injection molding machines has been relatively rapid. Companies such as Ningbo Zhuorui Machinery, Anhui Liming Machinery, and Ningbo Lituo Machinery located in the Yangtze River Delta are all actively engaged in the remanufacturing business of injection molding machines. Among them, Anhui Liming Machinery plans to build an annual production capacity of 500 injection molding machines. Ningbo Lituo Machinery undertook the on-site remanufacturing project of the clamping mechanism of Haitian 2800T, 2400T and other large equipment from Ningbo Inoue...
Huaxiang, Century Huatong and other companies. In 2015, the sales had reached more than 7 million yuan.

Uncertainty in the structure, failure mode and failure degree of scrap parts leads to the complexity of remanufacturing process selection. The quality and efficiency of remanufacturing can be improved by improving the reasonable choice of remanufacturing process plan [3]. Du [4] proposed a reliability allocation method for remanufacturing machine tools based on neural networks and remanufacturing factors. The remanufacturing factors were determined based on multi-layer fuzzy evaluation, and the reliability was allocated from the subsystem level to the component level. Xiang [5] proposed a method to introduce the L-M algorithm into the training process of BP neural network, and established a BP neural network model for remanufacturing process plan decision-making. This article starts with the failure characteristics of the injection molding machine parts, establishes the damage model, combines the experience of the technicians, establishes the injection molding machine parts remanufacturing process route, and finally combines the remanufacturing time and cost to optimize the remanufacturing process route through the genetic-neural network algorithm. Realize the optimized design of the remanufacturing process route, and finally combines the remanufacturing process route. Therefore, studying the optimization method of remanufacturing process route is of great significance for enterprises to implement remanufacturing.

2. Uncertainty And Influence Analysis of Remanufacturing Process
Due to the uncertainty of the failure characteristics and failure degree of the remanufactured blanks, the remanufacturing process route presents individualized differences. For example, the uncertainty of the damage form and degree will increase the selection of remanufacturing repair process technology and process parameters.

Remanufacturing process route design [6]. The remanufacturing process is shown in figure 1. Due to the uncertainty of the failure characteristics, damage degree and quality status of the used parts, the remanufacturing process route has strong randomness, and the remanufacturing process relies on experience to a certain extent. For example, when the screw of the injection molding machine is lightly worn, high-speed arc spraying is used, and when the wear is severe, surfacing welding is used. Therefore, the remanufacturing process is naturally different for different failure degrees of injection molding machine parts.

![Figure 1. Process flow of remanufacturing injection molding machine.](image-url)
It is difficult to determine the remanufacturing process parameters. The traditional manufacturing process route design is based on the known information of the product, and the process route of the same batch of parts is the same, but the quality level of scrap parts after retirement is different, so the process parameters of different parts are also different. Moreover, the selection of process parameters needs to be based on relevant domain knowledge and actual processing, which greatly affects the performance of the remanufacturing system.

3. Model for Extracting Failure Features of Used Parts and Components Based on Fault Tree

3.1. Fault Tree Establishment

The establishment of the fault tree is a key step to determine the completeness of the failure feature extraction of waste parts in the later period. The perfection of the extraction model will also indirectly affect the rationality of the remanufacturing process route [7]. The following figure 2 shows the establishment process of the fault tree. First, it is necessary to accurately analyze the load properties, environmental media and materials of the waste parts, determine the fault boundary conditions and failure probability, and finally establish the fault tree.

![Figure 2. The process of establishing a fault tree.](image)

The fault tree is composed of bottom events through some logical relations. Therefore, the mathematical model of the fault tree can be represented by a structure function, which can make qualitative analysis and quantitative calculation more convenient. Suppose the bottom event state variable is $X_i$, and the top event state variable is $\phi(X)$, both of which are represented by 0 or 1, and the definition is as follows [6]:

$$X_i = \begin{cases} 1 & \text{When the bottom event does not occur (component failure)} \\ 0 & \text{When the bottom event does not occur (the parts are normal)} \end{cases}$$

$$\phi(X) = \begin{cases} 1 & \text{When the top event occurs (system failure)} \\ 0 & \text{When the top event does not occur (system normal)} \end{cases}$$

Since the system does not want a fault state, that is $\phi(X) = 1$, at this time, since the top event is caused by the bottom event, the bottom event fails, that is $X_i = 1$. Obviously, the top event state is directly determined by the bottom event state, and the fault tree structure function can be expressed as:

$$\phi(X) = \phi(X_1, \ldots, X_n)$$

3.2. Failure Feature Extraction Model

As parts and components are affected by factors such as material performance, structural design, processing and assembly, and working conditions during service, Lead to decommissioned parts with multiple failure characteristics such as wear, fracture and corrosion. However, the repair process that may be selected for different failure characteristics is also different. For example, when the damage of the failure area is small, it can be repaired by grinding and electroplating, but when the damage of the failure area is large, it needs to be repaired through processes such as grinding, cold welding and grinding. Therefore, the extraction and accurate quantitative analysis of the failure characteristics of waste parts are important basis for designing a reasonable remanufacturing process route.
4. Damage Model and Quantitative Analysis of Failure Characteristics

4.1. Establishment of Failure Characteristic Damage Model
In order to more accurately express the failure degree of used parts and components, the damage amount is used to describe the failure characteristics such as wear, fracture and corrosion, and the corresponding damage amount model is established [8].

Assuming that wear occurs on a metal surface with low hardness, and the real contact area of the contact surface is the maximum cross-sectional area of the asperity, the calculation formula for the number of contact points can be expressed as:

\[ n_j = \frac{F_n}{\pi r_a^3 \sigma_y} \]  

where \( n_j \) is the number of contact points between the contact surfaces; \( F_n \) is the normal load; \( r_a \) is the average radius of the asperity; \( \sigma_y \) is the yield stress of the worn material.

The crack feature model of the scrap parts is mainly registered with the original CAD model. Through the Boolean subtraction operation of the two, the 3D model of the crack of the scrap parts is obtained. The volume of the model is calculated by the software, which is the volume damage of the crack.

Corrosion characteristic damage model

\[ W_{yh} = L_s \left[ \frac{A_o \exp(-Q/RT_s)}{v/\sqrt{2\pi p_o \sigma_o}} \right] \frac{F_n}{SH_n} \]  

\( L_s \) is the sliding distance; \( F_n \) is the normal load; \( RH \) is the material hardness; \( p_o \) is the oxide film density; \( L_s \) is the sliding distance of contact; \( v \) is the sliding speed; \( A_o \) is the Arrhenius constant; \( Q \) is the activation energy of the oxidation reaction; \( R \) is the molar gas constant; \( T_s \) is the sliding interface thermodynamic temperature; \( h \) is the critical thickness of the oxide film.

4.2. Quantitative Analysis of Failure Characteristics
The quantification of the failure characteristics of waste parts is a process of using the fuzzy comprehensive evaluation method [9], taking the calculated failure characteristic volume damage amount as input, and obtaining the quantified value of the failure characteristic by inputting the membership function. The input membership function describes the mapping relationship from the damage amount to the quantized value of the failure feature, and is generally triangular or trapezoidal. The quantified value of the failure characteristics of used parts obtained by fuzzification is a binary combination:

\[ A_i = \{ A_i(x_i) \} = \{ x_i, \zeta(x_i) \mid x_i \in X, \zeta(x_i) \in [0,1] \} \]  

Among them, \( x_i \) represents the fuzzy level of the failure feature, \( \zeta(x_i) \) represents the degree of truth under the corresponding fuzzy level, and each fuzzy level language set corresponds \( A_i(x_i) \) to an input membership function \( f_i(x_i) \). In this way, a quantitative scoring table for the failure characteristics of waste parts of injection molding machines is established.

5. Remanufacturing Process Route Reduction Model Based on Directed Graph
Technicians formulate a repair plan for the failure characteristics of injection molding machine parts based on information such as damage amount and machining allowance. However, there are often multiple failure features on a waste part. In order to quickly select the optimal process route, establish a repair plan for the waste part. Process constraint directed graph.

The priority relationship between the failure feature processing elements is reflected in the order of execution. The optimization of the remanufacturing process route is a process of constraining the failure
feature processing element set one by one, so that the failure feature repair plan is in a certain order and the objective function value is optimal. A directed graph is a data structure composed of vertex sets and arc sets, it can clearly indicate the priority relationship between the failure feature processing elements. For the directed graph of the repair process of waste parts, it represents the finite non-empty set of the repair process that needs to be used in the remanufacturing process, and is the finite set of relations between the vertices of the processing elements [10].

6. Optimization of Remanufacturing Process Route Based on Genetic-Neural Network Algorithm

Based on the volume damage and failure characteristics of the injection molding machine parts, combined with the remanufacturing time and cost of the injection molding machine, a solution method based on the genetic-neural network algorithm optimization model is proposed.

![Diagram](image)

**Figure 3.** Optimization model of remanufacturing process route based on genetic-neural network.
The remanufacturing process route optimization model based on genetic-neural network is shown in figure 3. First, an initial population of size N is randomly generated according to the way of individual coding, and each individual represents a network structure and the corresponding initial parameters of the structure.

First, through the establishment of the neural network in the initial state, the given sample data is used as the input layer of the network, the network is trained and the input error is calculated. After the training is completed, the total error of the network is used as the fitness function of the genetic algorithm, and the fitness function value of each individual is calculated, and then the current population is genetically operated according to the selection, crossover, and mutation genetic operation methods to produce a new generation of population Individuals, when inherited to the maximum evolutionary algebra, output the optimal solution [11].

7. Conclusion
In order to achieve China’s goal of carbon neutrality by 2060, China will certainly implement remanufacturing projects. Remanufacturing is conducive to the formation of a circular economy model of “resource products, waste products, and remanufactured products”, making full use of resources and protecting the ecological environment. Compared with traditional manufacturing mode, remanufacturing has more uncertainties, which makes the remanufacturing process route more complicated. This article starts with the failure characteristics of injection molding machine parts, and establishes the failure feature model of waste parts in the way of fault tree. In order to express the failure degree of waste parts more accurately, the damage amount is used to describe the failure characteristics such as wear, fracture and corrosion. The mathematical model of the damage amount, and then the fuzzy comprehensive evaluation method is used to establish a quantitative score table for the failure characteristics of the waste parts of the injection molding machine. Establishing a preliminary remanufacturing process route through the directed graph, and then optimizing the remanufacturing process route through the genetic-neural network algorithm, which can optimize the design of the remanufacturing process route of injection molding machine parts. Certainly.

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References
[1] President Xi Jinping of Xinhuanet delivers an important speech at the general debate of the 75th UN General Assembly http://www.qstheory.cn/yaowen/2020-09/22/c_1126527766.htm.2020-9-22.
[2] 2021-2027 Global and Chinese Injection Molding Machinery Market Research and Feasibility Study Report (Guangzhou Chenyu Information Consulting) 2021-06-30.
[3] Cui X, Zhang X F and Xue J F 2019 Remanufacturing process optimization method for crankshaft based on failure modes Mechanical and Electrical Engineering 36 (09) 938-943.
[4] Du Y B, Wu G O and Xu L 2021 Remanufacturing machine tool reliability allocation method based on neural network and remanufacturing factor Computer Integrated Manufacturing System 27 (04) 1052-1061.
[5] Xiang P and Qin W 2017 Remanufacturing process plan selection research combination based on improved BP neural network Machine Tool and Automatic Manufacturing Technology (11) 130-133.
[6] Fu Y 2020 Design of remanufacturing process scheme for die casting machine Research on Optimization of Remanufacturing Process Route of Horizontal Cold Chamber Die Casting Machine (Shenyang University of Technology) Chapter 4 pp 15-23.

[7] Fu Y Yang L and Cui J 2020 Research on the optimization of the remanufacturing process route of the big bars of the XT260 horizontal cold chamber die casting machine Heavy Machine (04) 77-81.

[8] Jiang Y 2019 Optimization framework for remanufacturing process routes of used parts and components based on failure characteristics Research on Optimization of Remanufacturing Process Route of Waste Parts Based on Failure Features (Wuhan University of Science and Technology) Chapter 2 pp 9-17.

[9] Wu J Z, Wang M and Yuan M 2016 Evaluation method and application of remanufacturability of electromechanical products based on fuzzy extension analytic hierarchy process Modular Machine Tool and Automated Processing Technology (09) 153-156.

[10] Liu Q H 2018 Link prediction of directed network based on genetic algorithm Research on link prediction on directed graphs[D] (Yangzhou University) Chapter 4 pp 27-34.

[11] Qi X and Zhang X 2021 Predictive modeling based on genetic algorithm to optimize BP neural network Intelligent Computers and Applications 11(05) 160-162+169.