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Green Design of a Descaling Machine for Remanufacturing Cleaning Based on QFDE

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***Abstract*—The importance of the reuse of steel plates is highlighted, because of the intensifying pressure of recession and natural resource shortages. The surface rust of steel plates is removed by a remanufacturing cleaning process so that they can be reused, which in turn reduces steel waste and saves costs. However, the remanufacturing cleaning process has disadvantages such as high-labor intensity, high-energy consumption, and high pollution. Therefore, it is necessary to design a descaling machine for remanufacturing cleaning with high efficiency, low pollution, and good cleaning and rust removal effect. Firstly, quality function deployment for the environment (QFDE) is used to obtain the functional characteristics that the designer needs to focus on, and a better structural scheme is obtained by constructing the functional structure expansion solution domain. The design of a descaling machine is a win-win for both customers and manufacturers.**

Keywords—remanufacturing; quality function deployment for the environment (QFDE); descaling machines

I. INTRODUCTION

Remanufacturing has come into being to alleviate the pressure caused by resource scarcity and environmental pollution [1]. It can repair or upgrade wasted mechanical equipment so that its quality and environmental protection performance are not lower than new products [2]. The price of remanufactured products is not higher than 50% of that of new products, and remanufacturing can save energy by 60% and reduce pollutant emissions by more than 80% [3],[4].

The research on remanufacturing-oriented product design mainly focuses on remanufacturing design methods, remanufacturing evaluation, remanufacturing impact factor identification, and so on. For research in remanufacturing design methods [5][6][7], Wang et al. [8] proposed a multi-objective optimal redesign method and redesigned wasted mechanical equipment with multi-objective optimization. Similarly, Huang et al. [9] proposed a remanufacturing solution design method based on the reconstruction of incomplete information of old parts. Haziri et al. [10] proposed a framework for remanufacturing design based on the information feedback from remanufacturing design. These methods can help researchers study the remanufacturing design of products. At the same time, the remanufacturing evaluation of mechanical equipment has also been emphasized [11],[12]. Ong et al. [13],[14] quantitatively evaluated disassembly and recyclability in remanufacturing evaluation. Research on remanufacturing evaluation of mechanical equipment can help researchers reduce unnecessary remanufacturing designs for used mechanical equipment. In addition, some researchers have conducted research on remanufacturing impact factor identification of mechanical equipment [15][16]. Shi et al. [17] explored the basic elements of the remanufacturing evaluation of mechanical equipment. Zwolinski et al. [18] conducted a cluster analysis of successfully remanufactured products based on remanufacturing product profiles (RPP).

The aforementioned studies provide a useful reference for the green design of descaling machines for remanufacturing cleaning. A descaling machine for remanufacturing cleaning used for cleaning and derusting in the remanufacturing process. It is a significant equipment in the remanufacturing process. With the emphasis on remanufacturing, the demand for descaling machines for remanufacturing cleaning has gradually increased, but people have not paid attention to its green features. Based on this, this paper proposes the green design of descaling machines for remanufacturing cleaning. The green design of descaling machines for remanufacturing cleaning can reduce environmental pollution from the source of manufacturing and use, and is conducive to reducing the cost of enterprises. It adopts the QFDE method. Firstly, it adopts the construction of HOQ to obtain the demand importance, and then obtains the importance of functional characteristics. Finnally, the functional analysis is used to get the structural scheme.

II. METHODS

A. QFDE for remanufacturing-oriented mechanical equipment

QFDE is a green design method that can well integrate the user's requirements and environmental needs for consideration [19]. The workflow of QFDE is shown in Fig. 1.

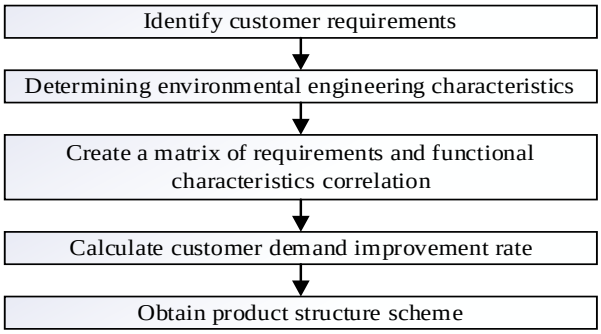


Fig. 1. QFDE-based product design flow char

B. Requirement-function mapping for remanufacturing-oriented mechanical equipment design

QFDE can use HOQ to create requirement and engineering characteristic correlation matrix [20], as shown in Fig. 2.

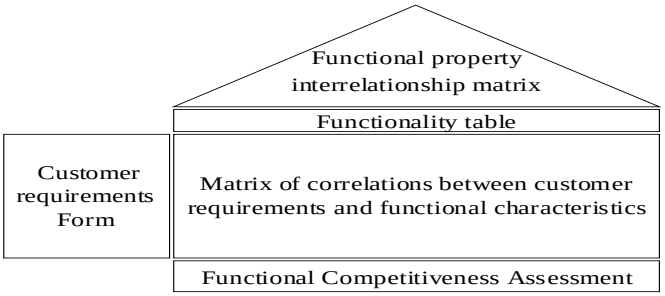


Fig. 2. HOQ for remanufactured mechanical equipment

(1) Composition of HOQ

1) Identify customer requirements, which is obtained using the hierarchical analysis method [21]. The voice of the customer (VOC) is:

$$\omega^T = \{\omega_1, \omega_2, \cdots, \omega_i, \cdots, \omega_m\} \tag{1}$$

2) The matrix of correlations between customer requirements and functional characteristics is expressed as matrix A:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix} \tag{2}$$

3) The importance of functional characteristics is:

$$V = \omega^T A = \{\upsilon_1, \upsilon_2, \cdots, \upsilon_n\} \tag{3}$$

(2) Mapping of feature parameters

Fig. 3 shows the mapping relationship from design parameters to remanufacturing characteristics and then to remanufacturing process association.

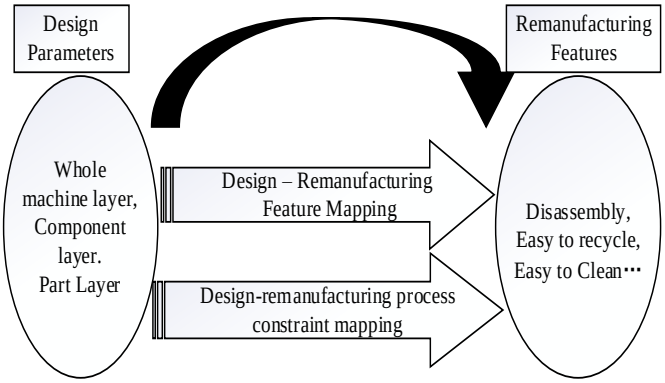


Fig. 3. Characteristic -parameter mapping model

III. CASE STUDY

A. Customr Requirements

Step 1. HOQ for building a descaling machine for remanufacturing cleaning is shown in Fig. 4， and the customer requirements and functional characteristics in the figure are represented by codes as shown in TABLE 1 [22]. The intersection between customer requirements and functional characteristics is the relationship strength, which is expressed in numbers. “9” shows the relationship is strong, “3” shows it is relatively strong, and “1” shows weak relation. And “-3” shows a negative correlation, “-9” shows a strong negative correlation.

Step 2. According to the data in Fig. 4, the correlation matrix A between customer requirements and functional characteristics is:

$$A = \begin{bmatrix} 9 & 0 & 0 & \cdots & 0 \\ 0 & 0 & 3 & \cdots & 0 \\ 3 & 0 & 0 & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}_{12\times 19} \tag{4}$$

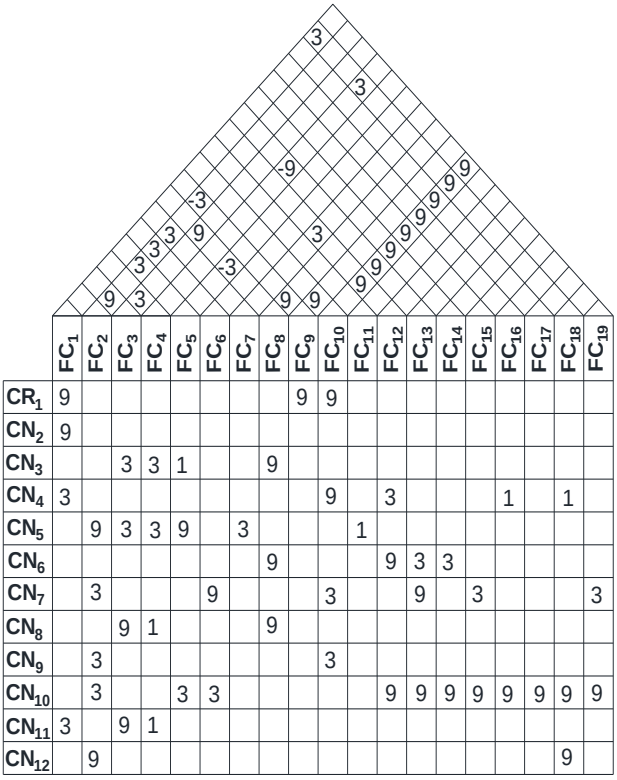
Step 3. To obtain the importance of functional characteristics, a matrix for determining the importance of customer requirements is constructed, as shown in TABLE 2. The scoring criteria of the judgment matrix are divided into 1-9. If the ratio of the scoring criteria is greater in the numerator than in the denominator, then the characteristics of the corresponding row are more important than those of the column; and vice versa.

Step 4. Bring the data from Table 2 into Equation (1) to obtain ω^T:

$$\omega^T = \{0.073, 0.06, 0.03, 0.04, 0.112, 0.097, 0.045, 0.202, 031, 0.012, 0.91\} \tag{5}$$

Based on the known data in Equations (5)-(4), combined with Equation (3), determine the importance of the functional characteristics V:

$$V = \omega^T A = \{1.677, 2.796, 1.911, 0.591, 1.131, 0.903, 0.336, 1.143, 0.657, 1.893, 0.112, 1.272, 1.38, 0.57, 0.549, 0.319, 0.279, 1.138, 0.549\}$$



	FC_1	FC_2	FC_3	FC_4	FC_5	FC_6	FC_7	FC_8	FC_9	FC_{10}	FC_{11}	FC_{12}	FC_{13}	FC_{14}	FC_{15}	FC_{16}	FC_{17}	FC_{18}	FC_{19}
CR_1	9								9	9									
CN_2	9																		
CN_3			3	3	1			9											
CN_4	3									9		3				1		1	
CN_5		9	3	3	9		3				1								
CN_6								9				9	3	3					
CN_7		3				9				3			9		3				3
CN_8			9	1				9											
CN_9		3								3									
CN_{10}		3			3	3						9	9	9	9	9	9	9	9
CN_{11}	3		9	1															
CN_{12}		9																9	

Fig. 4. HOQ for building a descaling machine for remanufacturing cleaning

TABLE 1. Customer requirements and functional characteristics

Customer requirements	**Code**	**Customer requirements**	**Code**
High automation	CN_1	Easily reqair	CN_7
Efficient	CN_2	Low vibration	CN_8
Low noise	CN_3	High safty	CN_9
Affordable	CN_4	Remanufacturable	CN_{10}
High dependability	CN_5	Good derustling	CN_{11}
Little pollution	CN_6	Long operation Life	CN_{12}
Functional characteristics	**Code**	**Functional characteristics**	**Code**
Degree of automation	FC_1	Frictional sub gap	FC_{11}
High reliability	FC_2	Recoverability	FC_{12}
Mechanical vibration	FC_3	Easily disassemble	FC_{13}
Movement Coordination	FC_4	Easily clean	FC_{14}
Abrasion resistance	FC_5	Easily classify	FC_{15}
After-sales treat	FC_6	Easily reprocess	FC_{16}
Corrosion resistance	FC_7	Easily reassemble	FC_{17}
Noise	FC_8	Easily upgrade	FC_{18}
Low energy consumption	FC_9	Easily test	FC_{19}

TABLE 2. Matrix for determining the importance of customer requirements

	CN_1	CN_2	CN_3	CN_4	CN_5	CN_6	CN_7	CN_8	CN_9	CN_{10}	CN_{11}	CN_{12}
CN_1	1	1	3	3/2	3/5	1/2	3/4	3/2	1/3	3/7	3/8	3/4
CN_2	1	1	3	3/2	3/5	1/2	3/4	3/2	1/3	3/7	3/8	3/4
CN_3	1/3	1/3	1	1/2	1/5	1/6	1/4	1/2	1/9	1/7	1/8	1/4
CN_4	2/3	2/3	2	1	2/5	1/3	1/2	1	2/9	2/7	1/4	1/2
CN_5	5/3	5/3	5	5/2	1	5/6	5/4	5/2	5/9	5/7	5/8	5/4
CN_6	2	2	6	3	6/5	1	3/2	3	2/3	6/7	3/4	2/3
CN_7	4/3	4/3	4	2	4/5	2/3	1	2	4/9	4/7	1/2	1
CN_8	2/3	2/3	2	1	2/5	1/3	1/2	1	2/9	2/7	1/4	1/2
CN_9	3	3	9	9/2	9/5	3/2	9/4	9/2	1	9/7	9/8	9/4
CN_{10}	7/3	7/3	7	7/2	7/5	7/6	7/4	7/24	7/9	1	7/8	7/4
CN_{11}	8/3	8/3	8	4	8/5	4/3	2	2	8/9	8/7	1	2
CN_{12}	4/3	4/3	4	2	4/5	3/2	1	1	4/9	4/7	1/2	1

The results of the importance of functional characteristics show that consumers are more likely to consider the following characteristics: efficient, remanufacturable and low noise.

B. Function analysis

In the design, according to the function tree (Fig. 5), it can be known that the functions correspond to their working methods and mechanical parts.

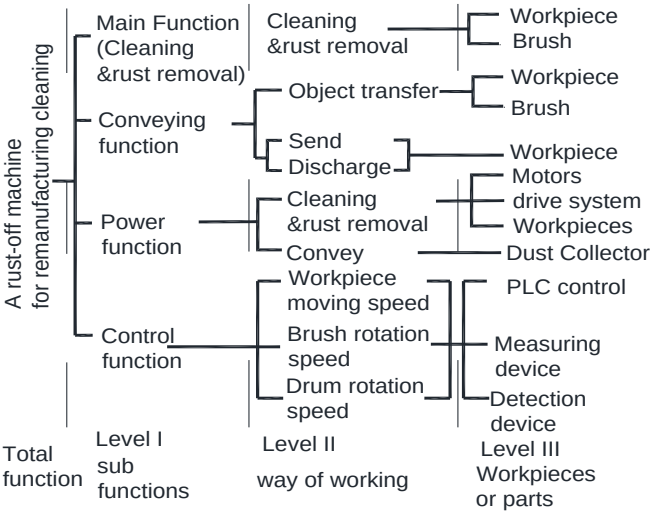


Fig. 5. Function tree about a descaling machine for remanufacturing cleaning

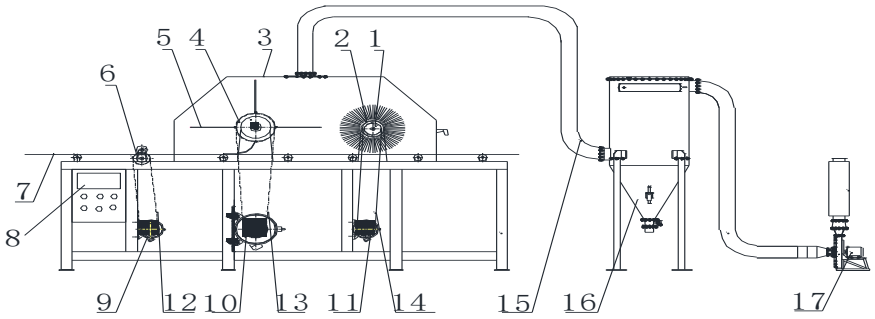
TABLE 3. Functional structure expansion solution domain

Functional elements	Structure	Expansion Structure
Coarse descaling	Flexible cable	fine steel、 steel wire rope、steel wire、copper wire、iron wire
Fine descaling	Rolling brush	Parallel wire brush、 Steel wire brush、Winding spring wire brush、Copper wire brush
Steel plate conveyor	Roller	Chain conveyor、Raceway、Conveyor、Drum motor、
Dust removal	Dustor	Dry mechanical dust collector、Bag filter、Wet dust collector、
Protection	Protective shield	Steel plate shield、Glass shield
Reduction	Reducer	Planetary gear reducer、Cylindrical gear reducer 、Turbo worm gear reducer

C. Obtain structural scheme

TABLE 3 shows the multiple mechanical structures that can achieve the same function and construct the functional structure expansion solution domain. Structure solution: steel wire rope + steel wire brush+ raceway + bag filter++ steel plate shield + cylindrical gear reducer.

The main mechanisms of a descaling machine for remanufacturing cleaning are the transmission device, the rough descaling device, and the fine descaling device. The design scheme diagram of the device mechanism is shown in Fig. 6.



1. Steel wire brush 2. Roller; 3. Steel plate guard; 4. Steel plate to be descaled 5. Steel wire rope 6 Press wheel 7. Steel plate 8. Console 9-11Motor 12-14. Belt 15. Pipeline 16. Bag filter 17. Cylindrical gear reducer

Fig. 6. Scheme of a descaling machine for remanufacturing cleaning

IV. RUSULTS AND DISCUSSION

In this case, unlike most structural design studies, this paper first collects customer requirements before designing a descaling machine. The customer mainly considered the characteristics of efficiency, remanufacture and low noise. There are various mechanical structures to achieve these functions. And the optimal structural solution is a steel wire brush as the rust removal mechanism, and a bag filter as the dust removal mechanism. The structure scheme is designed out of descaling machines for remanufacturing cleaning to meet the customer's requirements. It also meets the current low-carbon and environmental protection concepts.

However, as the data in the correlation matrix between customer needs and functional characteristics constructed is based on expert ratings, we need to reduce some subjectivity.

V. CONCLUSIONS

In this paper, with the help of the QFDE method, we have obtained a structural solution for the descaling machine that

meets the customer's needs and performs relatively well. The descaling machine for remanufacturing cleaning uses steel wire rope as flexible cable and steel wire roller brush to remove the rust layer on the surface of steel plates, which can achieve the best result without damaging the base structure of steel plate.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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