

# A Design Method based on analyzing remanufacturability

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## Abstract

With research on the problem of remanufacturing optimal design for remanufacturability, the remanufacturability assessing indicator assessment system is established with three aspects; based on the assessment system, the key design parameters are extracted, and the quantifying relationship between the key design parameters and remanufacturability is founded. After optimizing the key design parameters for feedback, the design scheme with the optimal remanufacturability is obtained. In the end, the input shaft components of QR type manual transmission are analyzed with simulating remanufacturing disassembly, and some optimized suggestions are given to validate the method.

**Keywords:** remanufacturability; remanufacturability assessment; remanufacturing optimal design; manual transmission

## 1 Introduction

To upgrade the function of the used products, based on the guidance which is the whole life-cycle design and management, Remanufacturing Engineering (RE) is the technology and the engineering for the restoring and the reconstructing of the used products, with the guide lines which are high quality and efficiency, saving energy and materials and environmental protection and the means which are the advanced technology and the industrialization production<sup>[7]</sup>. Differing from maintain and the recycle, Remanufacturing Engineering is a new research domain and industry. And it is the optimization resource circulating process to upgrade and restore the used products for circulating products, with several advanced technology such as Surface Engineering.

There are many remanufacturing factors determined by the design of the products, so it is available that calculating the remanufacturability of the products and adding the design requirements for remanufacturing to decrease the cost and improve the resources utilization in the design phase. Nowadays, there are many research productions in the fields of the remanufacturing design, and some of them have been applied in the industry. Yasushi Umeda<sup>[6]</sup> has analyzed key design elements for the environmentally conscious design in the context for the inverse manufacturing. Susumu Okumura<sup>[1]</sup> has proposed a life-design method which can minimize the total environmental impact of a reuse-intended unit and determine an optimal design parameter vector of the strait. Reyes<sup>[3]</sup> has discussed the methodology assess the reliability and acceptability of used parts for use in the remanufacturing of machines. Lily H. Shu<sup>[4]</sup> has emphasized the effects of fastening and joining methods on remanufacture and compared the fastening methods

that are used in the case studies with alternative fastening methods. Guenther Seliger<sup>[5]</sup> has described the design of a Modular Housing Platform which has the capability of accommodating components as a means of achieving cost savings and increased efficiency in the remanufacturing process. Zhong Junjie<sup>[9]</sup> has established a synthetical method based on DFA for assessing the remanufacturability of a product and it is important for remanufacturing. Qin hua<sup>[2]</sup> has concluded that remanufacturability of the part or component of the vehicle with a recycle economy model of end-of-life. In most of these studies, the research activities have been emphasized with attention been given to analyzing only one or some aspects of the products remanufacturing process, and the remanufacturing design would not be available without the remanufacturability quantitative assessment system. With the above problems, the experiment, simulating the remanufacturing procedure to analyze the remanufacturability of the manual transmission, has been taken. And with the remanufacturing procedure model in this experiment, the mapping relationship between the design parameters and the remanufacturability of the products has been founded. Moreover, the remanufacturability assessment system and the method of remanufacturing optimal design are presented.

## 2 Remanufacturing design

In the remanufacturing design, it is an optimal design procedure which contains assessing the used product remanufacturability, simulating the remanufacturing process and optimizing the remanufacturability of the new design scheme with the requirements of the remanufacturing engineer<sup>[10]</sup>. In other words, the remanufacturability of the products is emphasized as a major element in the remanufacturing design. Thus, after analyzing the design parameters which would influence the remanufacturing procedure, it is available to optimize the design scheme for a better remanufacturability (more easily remanufacturing and less cost) and a optimizing remanufacturing process (margin, function and pollution).

The remanufacturability is one of the inherent attributes determined by the design scheme of product. Therefore, with detailedly simulating, experimenting and analyzing the remanufacturing procedure, the key factors which could decide the remanufacturability would be extracted. Then, based on the feedback design model, the key factors of the scheme could be optimized to improve the remanufacturability and adjust the remanufacturing

process for an optimal resources utilization (shown in Fig 1).

After analyzing the remanufacturing procedure the design scheme, the remanufacturability of the product design can be calculated. That is, informed by the design scheme, the mapping relationship ( $\Phi(P_R)$ ) between the key design parameters ( $P_R$ ) and the remanufacturability of the products has been established. And based on the mapping relationship, the object function which contains

the key design parameters is founded for the remanufacturability. Then, with adjusting the key design parameters ( $P_R$ ), the improved design scheme is obtained. Finally, the optimal design scheme of the optimal remanufacturability is presented after assessing the improved design scheme whether has satisfied the design requirements.

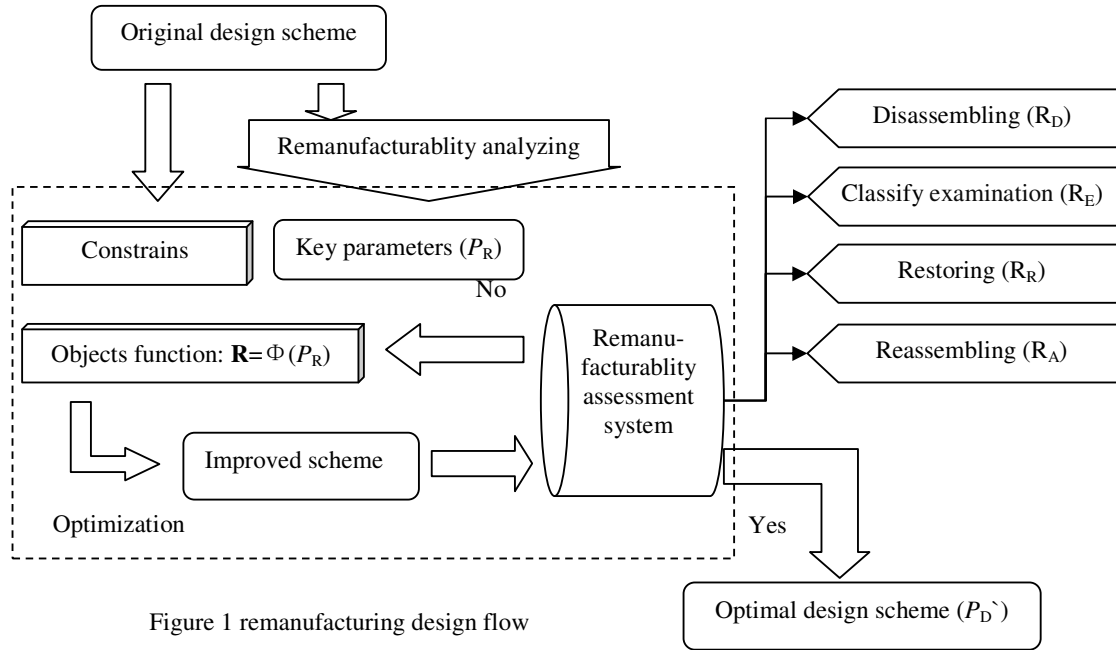


Figure 1 remanufacturing design flow

### 3 Remanufacturability assessment

Generally speaking, the remanufacturability is the capacity to gain the original product performance with the remanufacturing validly determined, and it can be qualitative and quantitative calculated and be determined by the configurable parameters, the failed state and the remanufacturing technology [8]. To calculate and assess the remanufacturability validly and accurately, the assessing indicator of remanufacturability assessment system is established (shown in Fig 2)

#### 3.1 Technological Feasibility (TF)

In the remanufacturing procedure, the mainly seven phases are disassembly, cleaning, classify examination, restoration, parts examination, reassembly and product examination. Because of the different technical levels in these phases, the most representative processes (disassembly, examination and restoration) are selected to analyzing the remanufacturability validly, and the relational assessing indicators are established. The technological indicators which represent the technological feasibility of the remanufacturing could be expressed as follows:

$$T = T_D + T_E + T_R = \frac{1}{t_D + t_E + t_R + t_A + t_0} \quad (1)$$

Where,  $T$  = total technological feasibility,  $T > 0$ ;

$T_D, T_E, T_R$  = the respective technological feasibility in the disassembly, examination and restoration;

$t_D, t_E, t_R, t_A, t_0$  = the respective time cost in the disassembly, examination, restoration, reassembly and accessorial processes,  $t > 0$ , and the processes in the phase  $i$  can not be implemented while  $t_i \rightarrow \infty$ .

#### 3.2 Economical Feasibility (EF)

Since the value of a remanufacturing product is equivalent to the value of a new one, the economical indicators which represent the economical margin of the remanufacturing have relations with the cost in the remanufacturing procedure. There are three aspects: the value of the remanufacturing parts, the cost of the remanufacturing processes and the cost in the other phases (packaging, transport etc.). Thus, the more cost was in the remanufacturing procedure, the lower economical feasibility of the product would be. And the economical feasibility could be shown as below:

$$E = E_V + E_D + E_E + E_R + E_0 = \frac{1}{e_V + e_D + e_E + e_R + e_A + e_0} \quad (2)$$

Where,  $E$  = total economical feasibility,

$E > 0$ ;  $E_V, E_D, E_E, E_R, E_0$  = the respective economical feasibility in the reclaiming, disassembly, examination, restoration and accessorial phase;

$e_V, e_D, e_E, e_R, e_A, e_0$  = the respective economical cost in the reclaiming, disassembly, examination, restoration, reassembly and accessorial processes,  $e > 0$ .

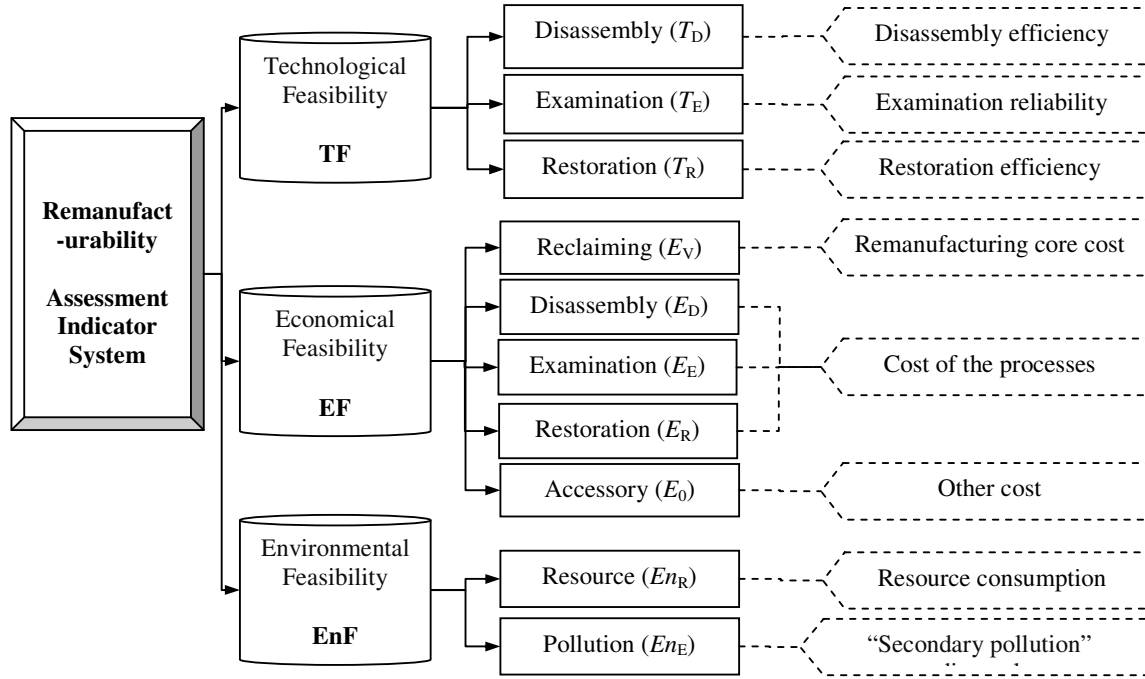


Figure 2 Remanufacturability assessment indicator

### 3.3 Environmental Feasibility (EnF)

Representing the environmental feasibility concentrated on the resource consumption and the “secondary pollution” disposal in the remanufacturing procedure, the environmental indicators are described as the cost of these aspects. Thus, the more pollution was produced and the more resource was spent in the remanufacturing procedure, the lower environmental feasibility of the product would be. And the economical feasibility could be expressed as below:

$$En = En_R + En_E = \frac{1}{c_R + c_E} \quad (3)$$

Where,  $En$  = total environmental feasibility,  $En > 0$  ;  
 $En_R$ ,  $En_E$  = the respective environmental feasibility in the resource cost and the “secondary pollution”;  
 $c_R$ ,  $c_E$  = the consumption of the resource (material, water and electricity, etc.) and the cost of disposing the “secondary pollution” (exhaust gas, waste residue, etc.),  $c > 0$  .

Informed by the remanufacturability assessment indicators above, the total remanufacturability of the product is formed by the coupling of the respective remanufacturability in every remanufacturing phase. In other words, with the remanufacturability assessment indicators, the remanufacturability in one remanufacturing phase, such as the disassembly, could be analyzed and assessed, and the design of the product and the relative remanufacturing procedure could be optimized for the optimal remanufacturability in this phase.

## 4 Remanufacturing optimal design for parts

The basic procedure of the optimal design method is: with the remanufacturing procedure simulation which is based on the original design scheme, analyzing the mapping relationship ( $\Phi(P_R)$ ) between the design parameters ( $P_D$ ) and remanufacturability ( $\mathbf{R}$ ), the key design parameters ( $P_R$ ) are extracted. Based on the mapping relationship, the design parameters ( $P_D$ ) are adjusted for a better remanufacturability ( $\mathbf{R}$ ). Finally, the optimal design scheme which has the optimizing remanufacturability ( $\mathbf{R}_0$ ) is obtained. Moreover, the remanufacturing optimal design can be operated into two phases:

### 4.1 Remanufacturability analysis

In the remanufacturability analysis phase, informed by the protracted experience and the relational data of the homologous products, the remanufacturing factors of the new design scheme could be analyzed and calculated by designers. Besides, with the simulating remanufacturing procedure based on the design scheme, the original mapping relationship ( $\Phi(P_R)$ ) between the design parameters and the remanufacturability is established. And with analyzing the original mapping relationship, the key design parameters ( $P_R$ ) which have important relations with the remanufacturability of the product are extracted. Finally, the quantitative mapping relationship ( $\Phi_i(P_R)$ ) between the key design parameters and the remanufacturability assessment indicators (technological, economical and environmental) is confirmed.

### 4.2 Remanufacturability optimization

Based on the quantitative mapping relationship ( $\Phi_i(P_R)$ ), the key design parameters ( $P_R$ ) are adjusted to improve the remanufacturability ( $\mathbf{R}$ ). Meanwhile, with

analyzing and describing the design constraints, the multi-constrained optimization model is set up.

Finally, with the optimizing model, the optimal design scheme is presented.

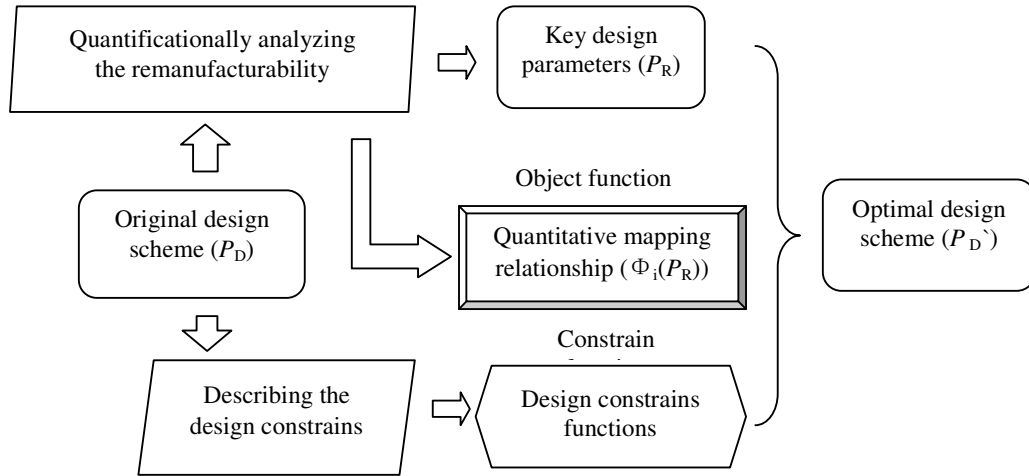


Figure 3 Remanufacturing optimal design model

With the key design parameters ( $P_R$ ) as the optimizing variable, the quantitative mapping relationship ( $\Phi_i(P_R)$ ) is founded as the object function. And after analyzing the design conflictions between remanufacturing requirements and other requirements, the design constrains are quantified as the bound of the object function: the constraint functions (shown in Fig 3). To sum up, the optimization model for energy-saving are:

$$\begin{cases} \text{Find } P_R \\ \text{min } T = \Phi_t(P_R) \quad E = \Phi_e(P_R) \quad En = \Phi_{En}(P_R) \quad (4) \\ \text{s.t } g_j(P_D) \leq 0 \end{cases}$$

Where,  $g_j(P_D)$  = constraint function, other requirements of the original design scheme; Then, the optimal design parameters ( $P_R^*$ ) are searched with an appropriate optimization algorithm for this optimization problem. Finally, after assessing the remanufacturability of the new design scheme, the optimal design scheme will be presented to satisfy the remanufacturing design requirements.

## 5 Case study

The remanufacturability of the key parts disassembly is the most important parts in the remanufacturability analysis<sup>[11]</sup>. Thus, in this paper, the input shaft parts of QR type manual transmission are analyzed with the

experiments of simulating remanufacturing disassembly. Informed by the data form the experiments, there are two major design factors:

### 5.1 Conjunction disassembly

Many technological factors in the disassembly are influenced by the conjunctions, such as the sequence planning, the disassembly time and so on. Moreover, the conjunctions in the remanufacturing disassembly should not be simply to assembly, some conjunctions, such as welding, pressing etc, which are useful in the assembly, would increase the cost of the disassembly.

### 5.2 Damage restoration

Decided by the function and the assembly of the products, most of the conjunctions are selected in the easily assembling type. Thus, in the disassembly of these conjunctions, there would be some damages which determine the restoring process and cost. Therefore, the damage restoring in the remanufacturing is depended by the conjunctions. Based on the analysis above and the experiment date, the remanufacturability of the two factors is presented in the table 1.

Remanufacturability			e, t = the respective cost and time in each phase
Disassembly	TF	406 s	
	EF	406 $E_M$ + 100 $e_{TY}$ + 40 $e_{TS}$	
Restoration	TF	14 $t_{RC}$ + 10,102 $t_{RM}$ + 36 $t_{RX}$ + 10,235 $t_{RD}$	
	EF	14 $e_{RC}$ + 8,418 $e_{RM}$ + 36 $e_{RX}$ + 10,235 $e_{RD}$	

Table 1 the remanufacturability analysis of the input shaft parts

Informed from the table 1, there are two aspects which influence the remanufacturability of the input shaft parts:

(a) Due to the input shaft parts designed to distribute on the inside and outside of the basic box-body, the disassembling working face should be frequently

changed. Thus, the disassembly time is increased to weak the technological feasibility. Furthermore, with the working time of the disassembly implement increasing, the cost in the disassembling is high and the economical feasibility is weak.

(b) The disassembly remanufacturability is weakened with the locknut assembled in the end of the input shaft. Because of the low disassembling efficiency and the high disassembly damage ratio of the locknut, both of the technological feasibility and the economical feasibility is weak. Therefore, the locknut conjunction should be replaced with the other kinds of the conjunction, such as retainer ring etc.

With the requirements of the functions and structural strength in the general design, based on the mapping relationship in the table 1, the conjunctions should be optimized as follows:

(a) Decreasing the amount of the parts: because of the small amount of the parts disassembled, the disassembling efficiency will be increased.

(b) Avoiding the screw-thread conjunction, especially the locknut conjunction: with the low disassembling efficiency and the high disassembly damage ratio of the screw-thread conjunction, the disassembling efficiency is low, and the cost of the damage restoration is high.

(c) Reducing the interface: the interfaces between the parts should be reduced and be displaced with the other parts. In this way, the restoring damage will be decreased and the cost of the restoration is low.

## 6 Conclusion

In this paper, based on analyzing the remanufacturability of the product in the design phase, the quantitative mapping relationship between the key design parameters and the design parameters is obtained, and the remanufacturability assessment indicator system is established. Furthermore, the remanufacturability could be optimized for the optimizing remanufacturability of the product with the quantifying relationship and the assessment system. Finally, this method are validated to meet the remanufacturing design requirements by this instance of the input shaft parts of QR type manual transmission, and it could be also applied in the material selection, structural optimizing design, etc. There would be several further research aspects:

(a) Remanufacturability analysis:

The remanufacturability of each key part is respectively analyzed and calculated, and all of them should be coupled as the total remanufacturability of the products to assess the product remanufacturing.

(b) Remanufacturing design:

With the quantitative mapping relationship established in each phase of the remanufacturing, the design parameters could be optimized in the detailed design for a better remanufacturability of the product.

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