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Determination of Failure Cause in Remanufacturing

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Abstract

Remanufacturing is a series of processes which makes the old product functionally equivalent and visually indistinguishable from a new product. In this research, we analyzed characteristics of target product (power steering oil pump of vehicle) and designed a new algorithm which let us know the cause process of possible failures that can be occurred after remanufacturing. Problems of remanufacturing process were identified by comparing and evaluating the most serious causes deduced by the algorithm which were applied to each failure type.

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Keywords: Remanufacturing; Failure; Cause; Algorithm; Power steering oil pump

1. Introduction

Remanufacturing is a series of processes which makes the old product functionally equivalent and visually indistinguishable from a new product [1][2]. Remanufactured product represents similar performance with new product, but needs only about 10 % of energy to make [3]. Also, it cost only 50~60 % of new product price [4][5]. But it is difficult to increase the market share of remanufactured product because of low consumer awareness [6]. To change the awareness of remanufactured product, we should improve the quality and reduce defect rate of remanufactured product. But under the current production system, some problems were detected in remanufacturing process. So, the purpose of this study is to reduce the failures of remanufactured product through finding the causes of failures.

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In the field of remanufacturing technology, many studies have been done about automobile parts (Table. 1). Paper [7] introduced the strategy for development of remanufacturing industry. Performance evaluation system between new product and remanufactured product was introduced in paper [8]. Paper [9] proposed a systematic guideline for remanufacturing process using the FMEA method in order to estimate the reliability and quality.

Because of intimate relation between each remanufacturing process and failure, it is important to identify the process which causes the failure. So, we designed a new algorithm which let us know the causing process of possible failures that can be occurred after remanufacturing. In this paper, we selected a power steering oil pump of automobile as a research object.

Table 1. Review of the remanufacturing technologies.

References	Contents
H. S. Mok [7]	- Identify the status of remanufacturing industry. - Analyse the problems of remanufacturing for automobile parts. - Propose the ways to foster the remanufacturing industry.
N. H. Chung [8]	- Failure analysis - Performance Evaluation System - Object : old starter motor
W. Jung [9]	- Identify the cause of failure using FMEA - Improvement of remanufacturing process - Object : old alternator

2. Analysis of characteristics and remanufacturing process

2.1. Characteristics of power steering oil pump

This hydraulically operated pump transmits the power to belt so that driver can steer easily at high speed or low speed. Power steering oil pump consists of 56 parts including several fasteners. These were classified into 5 different assembly groups according to their functions. This product is made of several materials. For example, material of main body is aluminum alloy and material of pulley is cast steel.

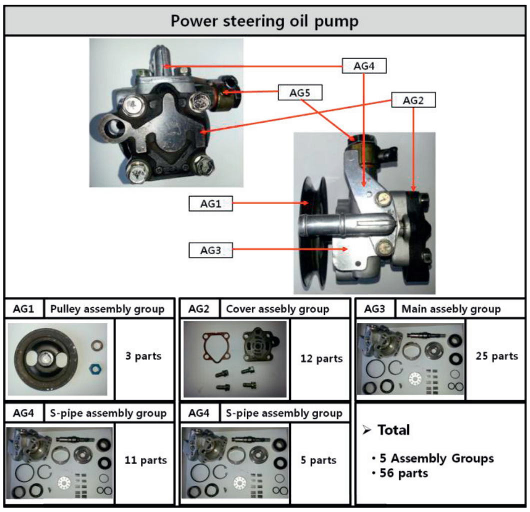
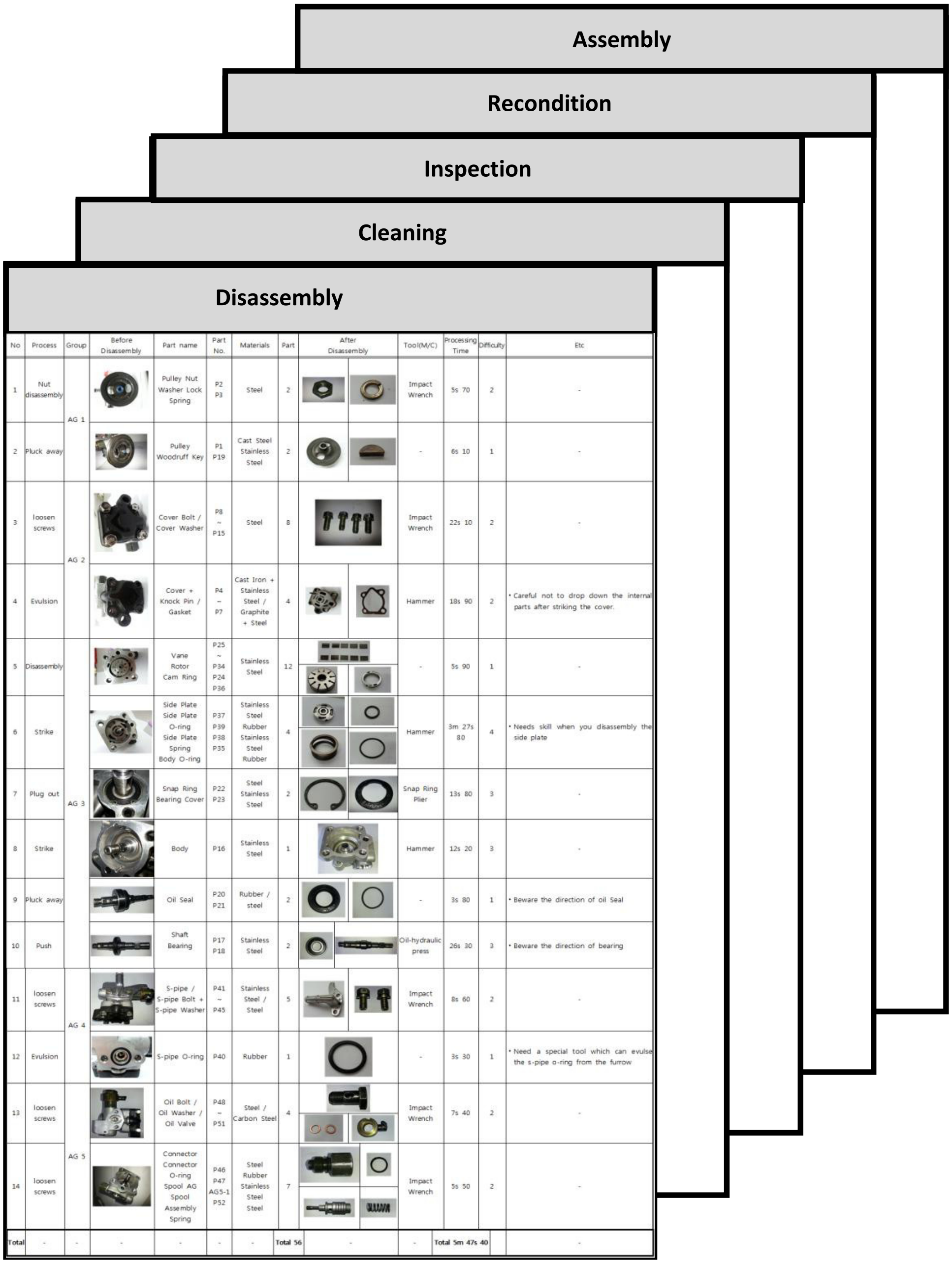


Fig. 1. Research object.

2.2. Analysis of remanufacturing process

There are 5 different steps in remanufacturing; Disassembly, Cleaning, Inspection, Reconditioning, Assembly [10]. Fig. 2 shows process number, process order, process names, information of parts, used tools, process time, materials of parts and so on [11]. We found that these processes can cause several failures in remanufactured products.



No	Process	Group	Before Disassembly	Part name	Part No.	Materials	Part	After Disassembly	Tool(M/C)	Processing Time	Difficulty	Etc
1	Nut disassembly	AG 1		Pulley Nut Washer Lock Spring	P2 P3	Steel	2		Impact Wrench	5s 70	2	-
2	Pluck away			Pulley Woodruff Key	P1 P19	Cast Steel Stainless Steel	2		-	6s 10	1	-
3	loosen screws	AG 2		Cover Bolt / Cover Washer	P8 ~ P15	Steel	8		Impact Wrench	22s 10	2	-
4	Evulsion			Cover + Knock Pin / Gasket	P4 ~ P7	Cast Iron + Stainless Steel / Graphite + Steel	4		Hammer	18s 90	2	• Careful not to drop down the internal parts after striking the cover.
5	Disassembly	AG 3		Vane Rotor Cam Ring	P25 ~ P34 P24 P36	Stainless Steel	12		-	5s 90	1	-
6	Strike			Side Plate Side Plate O-ring Side Plate Spring Body O-ring	P37 P39 P38 P35	Stainless Steel Rubber Stainless Steel Rubber	4		Hammer	3m 27s 80	4	• Needs skill when you disassembly the side plate
7	Plug out			Snap Ring Bearing Cover	P22 P23	Steel Stainless Steel	2		Snap Ring Plier	13s 80	3	-
8	Strike			Body	P16	Stainless Steel	1		Hammer	12s 20	3	-
9	Pluck away			Oil Seal	P20 P21	Rubber / steel	2		-	3s 80	1	• Beware the direction of oil Seal
10	Push			Shaft Bearing	P17 P18	Stainless Steel	2		Oil-hydraulic press	26s 30	3	• Beware the direction of bearing
11	loosen screws	AG 4		S-pipe / S-pipe Bolt + S-pipe Washer	P41 ~ P45	Stainless Steel / Steel	5		Impact Wrench	8s 60	2	-
12	Evulsion			S-pipe O-ring	P40	Rubber	1		-	3s 30	1	• Need a special tool which can evulse the s-pipe o-ring from the furrow
13	loosen screws	AG 5		Oil Bolt / Oil Washer / Oil Valve	P48 ~ P51	Steel / Carbon Steel	4		Impact Wrench	7s 40	2	-
14	loosen screws			Connector Connector O-ring Spool AG Spool Assembly Spring	P46 P47 AG5-1 P52	Steel Rubber Stainless Steel Steel	7		Impact Wrench	5s 50	2	-
Total	-	-	-	-	-	-	Total 56	-	-	Total 5m 47s 40		-

Fig. 2. Remanufacturing process of power steering oil pump.

3. Definition of failure mode

We analyzed a variety of possible failures in order to define failure modes. Identified failures were divided into two types: remanufacturing failures, and general failures. Fig. 3 shows the possible failures which were found at the remanufacturing company. Also, it shows how the failure of one part could affect the automobile. In this paper, we determined several failure modes which can be occurred by faults such as breakage or crack, assembly or reconditioning fault, parts aging, misusing of parts and so on. Some of these, such as parts aging, were classified as general failures which were not caused by remanufacturing process. The others were classified as remanufacturing failures. All these failures cause bad results on the product and can affect automobile as a failure mode such as steering malfunctioning, decreasing of discharge flow rate, noise.

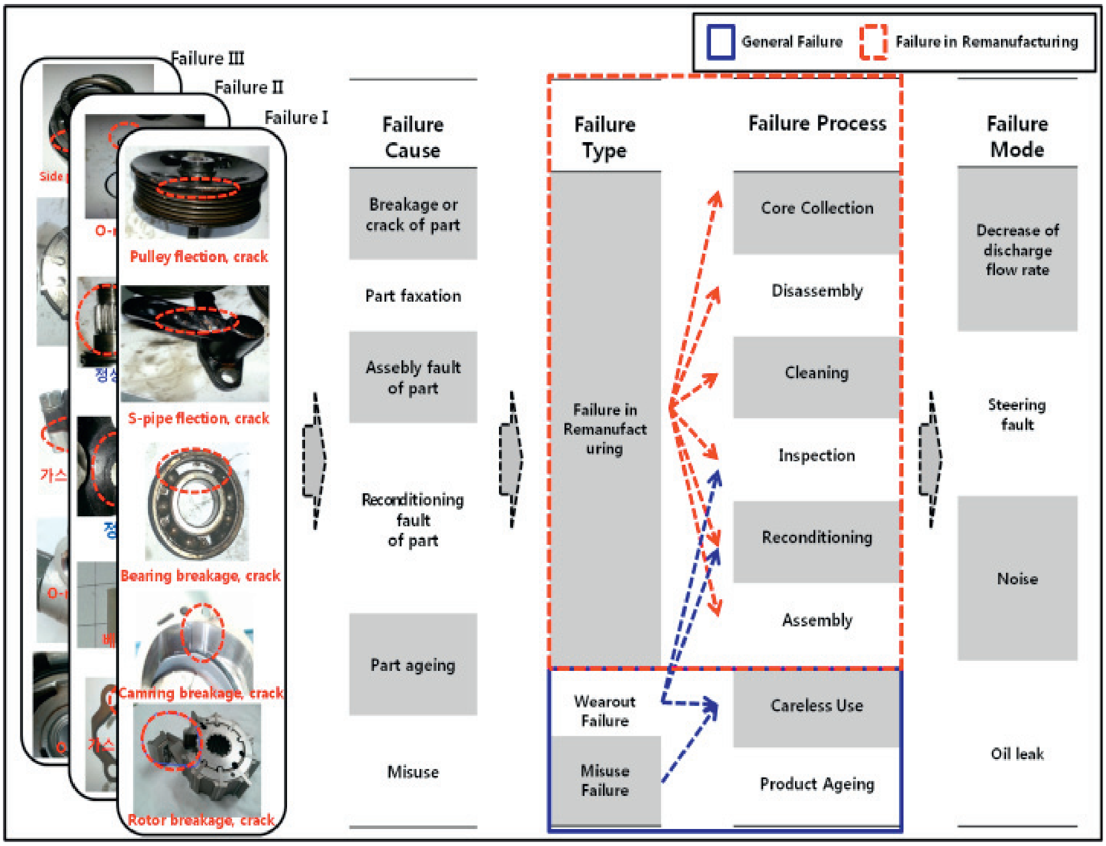


Fig. 3. Failure mode of oil pump.

4. Algorithm for determining the cause of failure in remanufacturing process

4.1. Factors for design of algorithm

Fig. 4 contains 5 significant factors which we considered when designing the algorithm. Each of them includes characteristics of parts, marketability, weighting factors, evaluation criteria and classification of failure [11]. Details are arranged for each factor in Fig. 4.

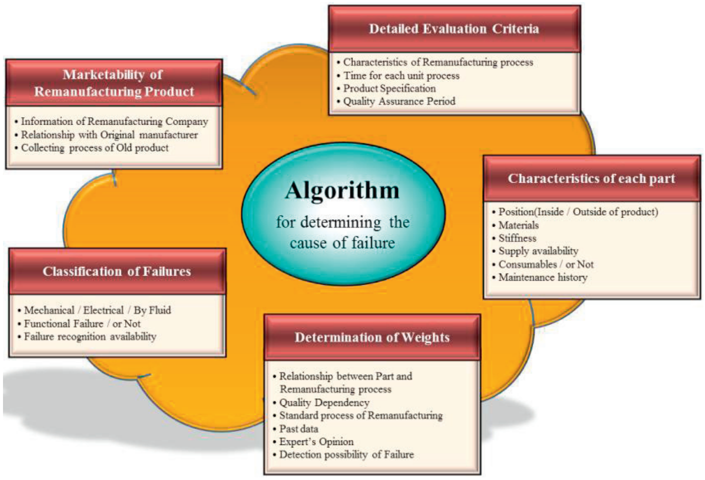


Fig. 4. Considering factors for algorithm.

4.2. Description of algorithm

Fig. 5 contains two check lists. Check list I shows part lists for each failure mode, test conditions, possible failures. Check list II identifies the link between failures and each process. It is necessary to refer Fig. 5 for finding the cause of failure by using the algorithm.

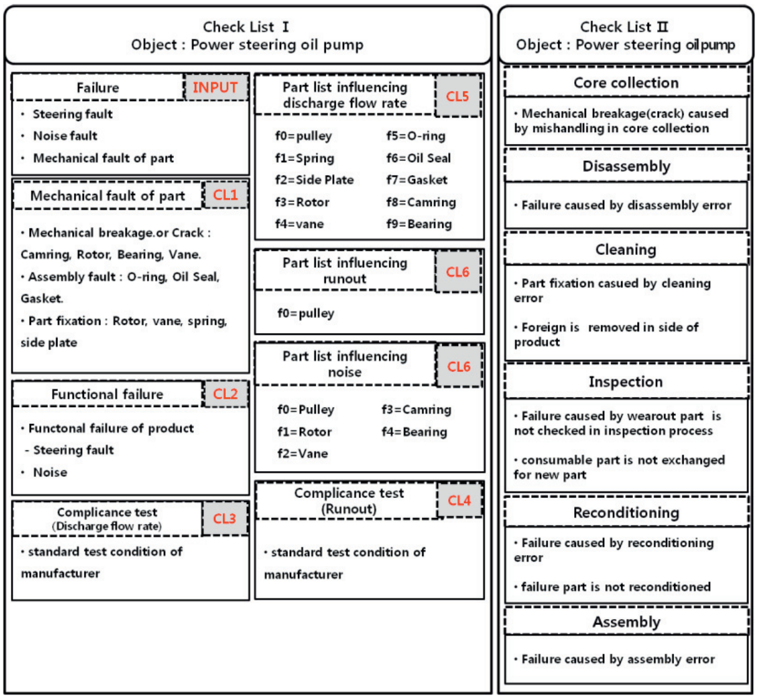


Fig. 5. Checklists for reference of algorithm.

Table 2. Description of steps.

Step	Description of steps
1	Determine failure type. In case of functional failure of vehicle : go to the step 2 In case of mechanical failure of parts : go to the step 3
2	Find out the part list which does not satisfy the standard criteria of compliance test
3	Define failure mode
4	Check whether the part can be supplied or not In case of YES : go to the step 5 In case of NO : go to the step 8
5	Check whether it is consumable part or not(ex. Rubber) In case of YES : go to the step 6 In case of NO : go to the step 10
6	Check whether the using period is longer than 3years or not In case of YES : go to the step 7 In case of NO : go to the step 10
7	Determine as a general failure
8	Check whether the part is located on the outside of the product or not In case of YES : go to the step 9 In case of NO : go to the step 13
9	Assign ‘core collection’ process as a cause of failure Keep going step 11
10	Check whether abrasion of part can be detected by the eyes or not In case of YES : go to the step 12 In case of NO : go to the step 13
11	Assign ‘disassembly’ process as a cause of failure Keep going step 12
12	Check whether foreign substances are detected inside of product or not In case of YES : go to the step 13 In case of NO : go to the step 14
13	Assign ‘cleaning’ process as a cause of failure Keep going step 14
14	Assign ‘inspection’ process as a cause of failure Keep going step 15
15	Check whether the part has been reconditioned or not In case of YES : go to the step 17 In case of NO : go to the step 16
16	Assign ‘repair’ process as a cause of failure Keep going step 17
17	Assign ‘assembly’ process as a cause of failure

Fig. 6 is an entire model of the algorithm which can be used to determine the failure cause process [10]. And Table 2 shows the steps as a description of the algorithm. For example, first step checks whether the inputted failure mode is mechanical failure or functional failure. If it is functional failure of automobile, we should test if there is decreasing of discharge flow rate or running out of pulley (how securely fastened). Otherwise, we should check through the rest of the algorithm. By following these steps, we can determine the cause process of possible failures.

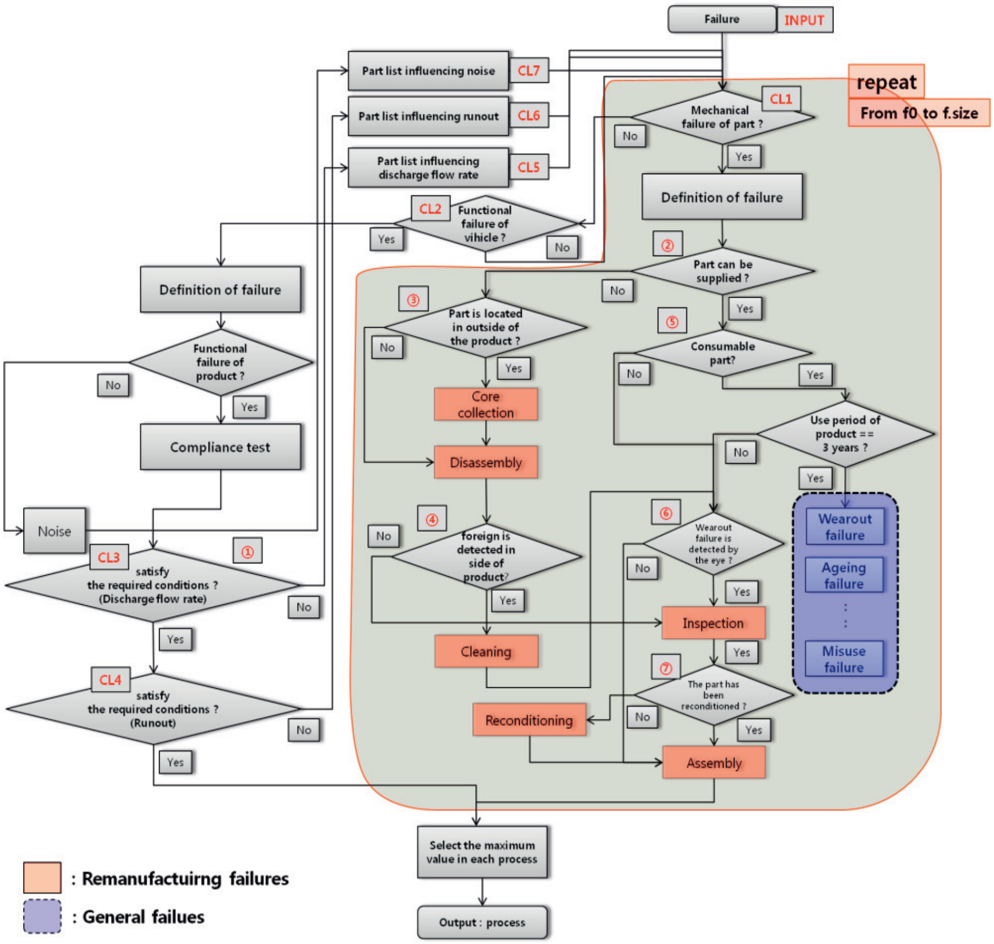


Fig. 6. Algorithm for determining the cause of failure.

4.3. Determining weighting factors

Table 3 contains several check lists which should be evaluated by weighting factors. Each weighting factor was determined based on expert’s opinion. Sum of weights for each check lists which correspond to the inputted data will be evaluated as a number for each remanufacturing process. The result will show the most closely related process with each causing part for failure.

Table 3. Weighting factors for each remanufacturing process.

Checklists for failure of each part		Answer	Weighting factors					
			Core collection	Disassembly	Cleaning	Inspection	Reconditioning	Assembly
①	Satisfying the required discharge flow rate?	Yes	-	-	-	-	-	-
		No	0.25	0.1	0.1	0.2	0.1	0.25
②	Available to supply the part?	Yes	0.1	0.1	0.1	0.5	0.1	0.1
		No	-	-	-	-	-	-
③	Located outside of the product?	Yes	0.3	0.1	0.1	0.2	0.1	0.2
		No	-	-	-	-	-	-
④	Available to detect the foreign substances with eyes?	Yes	0.1	0.1	0.3	0.3	0.1	0.1
		No	0.2	0.2	0.1	0.1	0.2	0.2
⑤	Consumable part?	Yes	0.1	0.1	0.1	0.5	0.1	0.1
		No	-	-	-	-	-	-
⑥	Available to detect the abrasion or hardening with eyes?	Yes	0.1	0.1	0.1	0.4	0.2	0.1
		No	-	-	-	-	-	-
⑦	Has the part been reconditioned or sealed before?	Yes	0.1	0.1	0.1	0.2	0.2	0.3
		No	-	-	-	-	-	-
Total sum								

4.4. Case study

To verify a validation of the algorithm, failure mode 'noise' was inputted through the algorithm. In CL1(checklist number which is marked in Fig. 6), as 'noise' is not mechanical failure, go to CL2. Because 'noise' is functional failure of vehicle, go to definition step from CL2. But 'noise' is not functional failure of product. So, go to CL7. In this step, we should check the applicable part list from Fig. 5. Pulley, vane, rotor, cam-ring, bearing are exist in the part list for 'noise'. First, pulley enters into algorithm. The result was shown in the table 4.

Table 4. The result with pulley through algorithm.

Checklists applicable to the 'pulley'		Answer	Weighting factors					
			Core collection	Disassembly	Cleaning	Inspection	Reconditioning	Assembly
③	Located outside of the product?	Yes	0.3	0.1	0.1	0.2	0.1	0.2
		No	-	-	-	-	-	-
④	Available to detect the foreign substances with eyes?	Yes	0.1	0.1	0.3	0.3	0.1	0.1
		No	0.2	0.2	0.1	0.1	0.2	0.2
Total sum			0.5	0.3	0.2	0.3	0.3	0.4

Table 5 shows that core collection is the most closely related process for failure mode 'noise' in the case of pulley. We also put the other parts through the algorithm in the same way. After that, we got the result which shows the link between failure mode 'noise' and each remanufacturing process.

Table 5. Relationship matrix between failure mode and remanufacturing process.

Failure Mode 'Noise'		Case	Remanufacturing process					
			Core collection	Disassembly	Cleaning	Inspection	Reconditioning	Assembly
Parts for each failure mode (Refer to Fig. 5)	Pulley	Mishandling	●	○	○	○	○	◐
	Vane	One sided abrasion		○	◐	●	○	○
		Fixation between vane and rotor		○	●			○
	Rotor	Abrasion, crack, breakage		○	◐	●	○	○
		Fixation between vane and rotor		○	●			○
	Cam-ring	Abrasion, crack, breakage		○	○	●	○	○
	Bearing	Abrasion, crack, breakage		○	○	●	○	○

Legends : ● Most closely related ◐ related ○ insignificantly related

Now we can say that, if we want to get rid of failure mode 'noise' in remanufactured Power steering oil pump, we should improve the cleaning process or inspection process.

Conclusion

It is necessary to find out the cause of failure in order to improve the quality and reliability of remanufactured product. But, previous studies on the relation between each remanufacturing process and failure are insufficient. So, we tried to determine the process which caused the failure. Preferentially, we defined failure modes by analyzing a variety of failures which could be occurred after remanufacturing. In order to identify the relationship between failure modes and each remanufacturing process, we designed a new algorithm. By using the algorithm, we could find the most closely related process with each failure mode. To check the validation of this algorithm, we conducted a case study for failure mode 'Noise'. We confirmed the feasibility of the algorithm by comparing with expert's opinions. Through the case study, we could determine the process which was responsible for failure. We anticipate that this study will contribute to make the upgraded standard process specification by finding the cause of failure. Also, this paper can be used to reduce failure rate and process defect rate.

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