Journal of the Society of Korea Industrial and Systems Engineering
Vol. 34, No. 4, pp.179－188, December 2011.

자동차 교류발전기의 재제조 프로세스 설계

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Remanufacturing Process Design for Automotive Alternator

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재제조는 사용 후 제품을 체계적으로 회수하여 분해, 세척, 검사, 보수조정, 재조립 등의 공정을 거쳐 원래의 성능을 유지할 수 있도록 만드는 과정이다. 자동차 교류발전기를 재제조하기 위해서는 재제조품에 요구되는 품질 및 신뢰성을 확실히 달성하기 위하여 공정 별 복잡한 작업들에 대하여 세부적인 사항들을 결정하고 이를 설계하는 일이 중요하다. 본 연구의 목적은 재제조를 위한 최적의 공정설계를 위해 FMEA를 활용한 체계적인 가이드라인을 제시하여 재제조품의 품질 및 신뢰성을 확보하는데 있다. 코어 부품의 상태 수준에 따른 작업과정과 재정비여부를 결정하기 위해 위험성 지표에 의한 방법도 연구되었다. 특히, 재제조기업의 사례연구를 통하여 FMEA의 유용성과 가이드라인의 적절성을 보여준다.

Keywords : Failure Mode and Effect Analysis (FMEA), Remanufacturing, Risk Ratings Matrix. Alternator

1. Introduction

Remanufacturing offers a significant role for reducing raw material consumption, energy, landfills and labor, economic savings and provides significant environmental benefits. Recent ecological concerns as well as government legislation have dramatically increased the demands of product life cycle engineering and motivating manufacturers in many countries to deal with product recovery at the end of the product life cycle. Therefore, Remanufactured products not only conserve the raw material but also associated with upgrading and adding the value-added to the products [7].

According to the World Trade Organization, remanufacturing describes the process in which a recovered good, or core, is transformed through cleaning, testing, and other operations into a product which is tested and certified to meet technical and/or safety specifications and has a warranty similar to that a new product [12]. The automotive industry is one of the largest remanufacturing sectors in the world. There is special emphasis on the automotive industry, as it is a key industry in the European country and a 50 billion dollar industry in the USA alone and at least 100 billion dollar industry throughout the world [4]. Automotive components that are being remanufactured include starters, alternators, engine blocks, clutches and carburetors. The remanufacturing market for alternator currently is the most developed market where alternators are mass produced and remanufactured by most of automotive companies [5].

The challenge of remanufacturing is to return a used product or core as-good-as new at a price that is significantly 60~80% lower than that of a new product. In order to achieve this, there must be a superlative execution of

논문접수일 : 2011년 10월 28일　　논문수정일 : 2011년 11월 25일　　게재확정일 : 2011년 12월 15일
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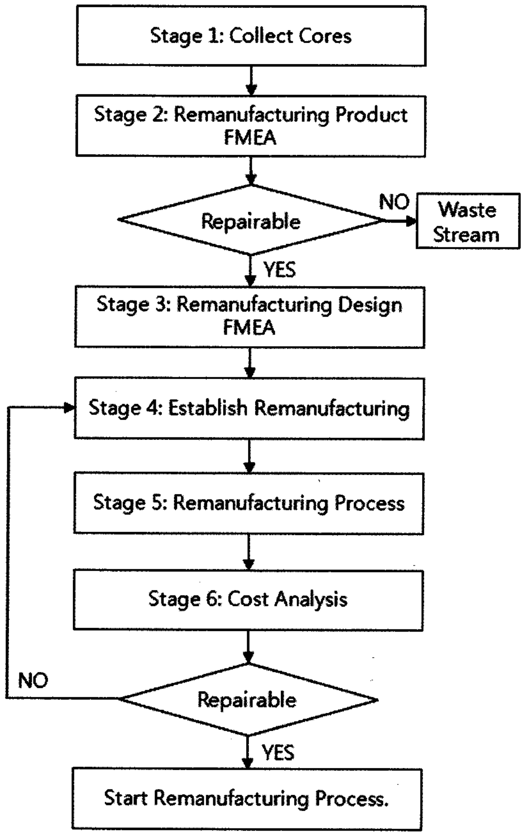
remanufacturing by recognizing how the product fails, which remanufacturing process suit the best for the product and the cost of the remanufacturing process. Therefore it is necessary to adopt a systematic approach by using a risk-based method because a deficiency in any remanufacturing processes of a product could lead to a risk or problem with its quality and reliability.

Hammond et al. conducted a survey of automotive remanufacturers to uncover process difficulties and generated design-for-remanufacture guidelines and metrics [2]. Sherwood and Shu summarized the results of waste stream analyses of three automotive remanufactures and proposed the use of a modified Failure Mode and Effect Analysis (FMEA) to support design for remanufacture [11]. Parkinson and Thompson have presented a systematic approach for the planning and execution of product remanufacture based upon the FMEA method. Their case studies were on the remanufacture of an air-conditioning unit and a turbocharger [8].

This paper provides details on the development of FMEA in planning and execution of remanufacturing alternators.



<Figure 1> Remanufacturing Process Guideline

2. Guideline for Remanufacturing

In <Figure 1>, a guideline to remanufacturing is proposed. The first phase is to define the product risk assessment which includes stage 1 and 2. Product FMEA (PFMEA) is used to carry out the assessment on the parts. If the parts cannot be repaired, the parts will be delivered to waste stream. While, Design FMEA (DFMEA) will be established if redesign the parts is needed. PFMEA and DFMEA will lead to remanufacturing processes for the part. After that, process risk assessment will be conducted to determine Risk Priority Number (RPN) for every process in Process FMEA worksheet and this RPN is used to perform a cost analysis of the remanufacturing. Then, the decision for the product's value is taken concerning market value and costs. If the cost is irrelevant to be in the market, each stage of the remanufacturing processes must be reviewed again to select the appropriate process based on the cost savings.

2.1 Stage 1 : Collect Core

An analysis of the cores can be carried out by examining the average age of the cores. Generally, the received cores go through the stages of disassembly, cleaning and inspection. Sequences of processes are grouped according to part type after inspection.

2.2 Stage 2 : Remanufacturing Product FMEA

The analysis on the item's reliability and quality is performed using FMEA. As an initial step, PFMEA is created to determine criticality for the identified potential failure mode.

$$\text{Criticality} = \text{Severity} \times \text{Occurrence}$$

Based on customer's experience on the product failure, the potential failure mode is recorded. Criticality is used to prioritize failure modes on the product's part for corrective action. The criticality of failure modes in the remanufacturing PFMEA will function as a reference when carrying out the DFMEA and PFMEA. Thus, all the failure modes, effect and causes are understood and can be taken fully into account.

Severity and occurrence are estimated using FMEA tables in the appendix as guideline to get the criticality. The rating scale is from 1 to 10, with the higher number represents the higher risk. These evaluation criteria should be used consistently throughout the analysis activities. Potential failure modes with high severity ranking such as 9 or 10 required mitigation or corrective action (design modifications and maintenance). Failure modes with a rank of severity 1 should not be analyzed further. Criticality of 30 or above is proposed to have corrective action or repairability. Other variation of this cut-off point for criticality is possible by the organization or analysis team based on the characteristics of the process or product being analyzed or other factors. Parts that cannot be repaired or cannot fulfill its intended function are discarded and sent to the remanufacture's waste stream. <Table 1> is as a guidance to classify and prioritize the criticality of the part.

<Table 1> Criticality Rating Table.

O/S	Minor (1-2)		Moderate (3-4)		Significant (5-6)		Major/Serious (7-8)		Catastrophic (9-10)	
Very unlikely (1-2)	1	2	3	4	5	6	7	8	[illegible]	[illegible]
	2	4	6	8	10	12	14	[illegible]	[illegible]	[illegible]
Unlikely (3-4)	3	6	9	12	15	18	21	24	[illegible]	[illegible]
	4	8	12	16	20	24	28	32	[illegible]	[illegible]
Likely (5-6)	5	10	15	20	25	30	[illegible]	[illegible]	[illegible]	[illegible]
	6	12	18	24	30	36	[illegible]	[illegible]	[illegible]	[illegible]
Very likely (7-8)	7	14	21	28	[illegible]	[illegible]	[illegible]	[illegible]	63	70
	8	16	24	32	[illegible]	[illegible]	[illegible]	[illegible]	72	80
Almost certain (9-10)	9	18	27	36	[illegible]	[illegible]	63	72	81	90
	10	20	30	40	[illegible]	[illegible]	70	80	90	100

Extreme	Very high risk, corrective action is needed as soon as possible.
[illegible]	High risk, needed to develop corrective action steps in the near future.
Medium	Medium risk, need attention and corrective action are performed if required.
Low	Minimum risk, manage by routine procedures.
Insignificant	Very low risk, records the findings, and review as necessary.

2.3 Stage 3 : Remanufacturing Design FMEA

Basically, remanufacturing DFMEA focuses on the part's component that needs to be repaired or remanufactured. If the components need to be redesigned, DFMEA is required. From PFMEA, the part that has high criticality will be analyzed for its component failure modes. For example, one of the alternator's part, the rotor has the highest value of criticality in PFMEA, thus in DFMEA, it will focus on the rotor's component that has failure modes. Therefore, in DFMEA the scope has been narrowed to the specific component and its failure modes. One of the important steps in FMEA is the assessment of risk of failure modes. RPN is a methodology for ranking and assessing the risk of potential failure modes. This is evaluated in three ways which are severity, occurrence and detectability.

$$\text{RPN} = \text{Severity} \times \text{Occurrence} \times \text{Detection}$$

Severity, occurrence and detectability can be estimated by using <Table 8> ~ <Table 10> in the appendices. In risk assessment process, customer requirements need to be included in the judgement of determining RPN. The assessment of RPN usually is based on the experiment and the personal judgements of the FMEA team.

Then, further effort has to be focused on how to reduce the risk. The initial focus should be oriented towards failure modes with highest severity rankings. When the severity is 9 or 10, it is crucial to address the risk through corrective action. For failure modes with severities 8 or below, assessment should then considered on the causes having highest occurrence and detection. Cut-off point for RPN can be helpful in decision making. RPN threshold of 140 is proposed, which means failure mode with RPN of 140 and above should be placed in priority for corrective action. 140 is chosen by an averaging process and arbitrarily selected, but it is a reasonable estimation in retrospect (study of other paper [6, 9, 10]). <Table 2> is a RPN matrix table that can be used in selecting failure mode for corrective action.

<Table 2> RPN Risk Ranking Table [1]

O/S	1	2	3	4	5	6	7	8	9	10
1	N	N	N	N	N	N	N	N	C	C
2	N	N	N	N	N	N	10	9	C	C
3	N	N	N	N	10	8	7	6	C	C
4	N	N	N	9	7	6	5	4	C	C
5	N	N	10	7	6	5	4	4	C	C
6	N	N	8	6	5	4	3	3	C	C
7	N	10	7	5	4	3	3	3	C	C
8	N	9	6	4	4	3	2	3	C	C
9	N	8	6	4	3	2	2	2	C	C
10	N	7	5	3	2	2	2	1	C	C

Note) N = No corrective action needed.
C = Corrective action needed.
Number (1-10) = Corrective action needed if the detectability rating is equal to or greater that the given number.

For example, if S = 8 (very high risk) and O = 1 (failure is unlikely to occur), there is no need to perform corrective action because even though the severity is high, the likelihood of failure mode to occur is very unlikely to happen (1 in 1,000,000 times). If S = 5 and O = 7, then corrective action is needed if detectability (D) = 4 or higher, based on cut-off point of 140 and above are required to perform corrective action. If S = 9 (risk is hazardous with warning) and O = 10 (persistent failure), corrective action is always required.

Due to the limitations on resources, time, technology, and other factors, it is very important to look at the information identified to decide upon an approach and determine how to best prioritize the risk reduction that best serve for the organization and customer.

2.4 Stage 4 : Establish Remanufacturing Processes

Remanufacturing processes can be carried out after established DFMEA and the processes will be based on the recommended actions that are proposed to reduce the failure modes. Using a process flow diagram, the remanufacturing production processes are compiled into their sequential operations.

2.5 Stage 5 : Remanufacturing Process FMEA

The PFMEA should begin with a general process flow diagram to understand the remanufacturing operations being analyzed. The scope of the process flow diagram should include all remanufacturing operations from processing individual components to assembly. Then, requirements for each process should be identified where it provides a description of what should be achieved at each operation. The requirements will provide a basis to identify potential failure modes. It is important to review the historical information about the part and the component when it is manufactured.

All the remanufacturing operations data are entered into the Process FMEA worksheet including useful information from DFMEA and historical information.

The risk assessment on RPN is similar in DFMEA, but severity, occurrence and detectability can be estimated by using <Table 11> ~ <Table 13> in the appendices.

2.6 Stage 6 : Cost Analysis

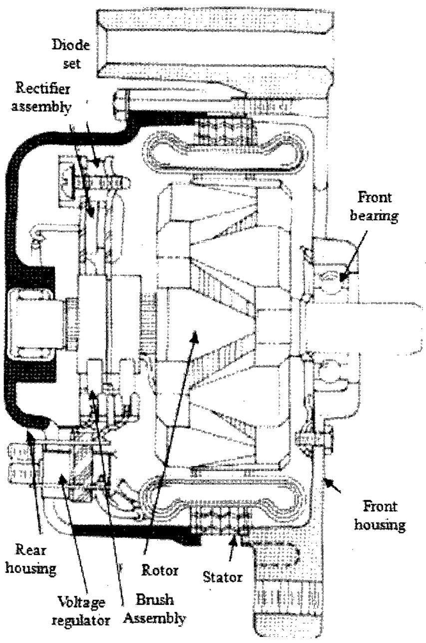
The purpose of this stage is to estimate the cost associated to each remanufacturing process whether it is acceptable to the market or require some adjustment to achieve large gains. Activity-Based Costing (ABC) is the most suitable system in estimating the cost because the concept of this method is to predict the costs based on the activities involved [3].

For analysis purpose, the chart of RPN/cost against each activity could be a useful method of assessment. The chart indicates the resources level allocated for each activity. From the result, unreasonable resources allocated to the process can be detected. A process with high maximum RPN value could be classified as a high risk activity and could probably have a low level of resources allocated to them causing small amount of cost required to reduce the risk. On the other hand, the low risk activity with high resources allocated to them has the opportunity to reduce the process cost without involving the process risk. This method seeks to reduce cost whilst improving the quality of the product by selecting alternatives resources, modifying the process plan and selecting the alternative actions.

3. Case Study : Alternator Remanufact-Uring Process

A case study for alternator remanufacturing was carried out at an automotive parts company. The objective of the study is to illustrate the implementation of the comprehensive remanufacturing guidelines. The company had been starting the alternator remanufacturing process without any documentation so they do not know the benefits of applying the FMEA method. This is essential in remanufacturing industries to produce a high quality product at low cost.

The alternator is used to generate Direct Current (DC) for charging the car battery and to powering vehicle electrical loads when its engine is running. The following is a brief general idea for the operating system of an alternator. <Figure 2> shows the components in an alternator. When engine runs, a belt drives the pulley to rotate alternator rotor. When it rotates, the field current which is supplied passes through the wire coil and produces a magnetic field around the core. As the rotor turns within the stator windings, the magnetic field sweeps through the windings producing an electrical current which is an Alternating Current (AC). Output diodes allow current to flow in one direction while blocking the current flow in the other direction and produce DC voltages that pass through the diode trio providing field current to the alternator regulator. The regulator is used to control the amount of field current input that allows passing through the rotor winding. The brake vacuum pump that attached to the alternator used to increase the brake power for the heavy load vehicles like truck as the driver's force for braking is not enough. The vacuum is stored in vacuum tank while the engine is working to increase the brake power.



<Figure 2> The Components of Alternator

3.1 Remanufacturing Guideline Implementation

This case study is concerned about the implementation of remanufacturing guideline that has been discussed previously. The systematic guideline consists of several stages that make it more convenient for planning the process in remanufacturing. This alternator case study deals with the whole guidelines in detail. The remanufacturing process involves all of the components of the alternator. The alternator consists of many components such as, rotor, stator, voltage regulator, rectifier, and the housing. All these components have to be checked and analyzed one by one during the remanufacturing process to ensure that the quality is as same as the new goods.

3.1.1 Collect Cores (Stage 1)

Cores that have been collected from the supplier have unknown quality. The supplier will provide the Original Equipment Manufacturer (OEM) standard that will be used to the remanufactured product in order to ensure that the product will function in the manner that it was intended. Then, the cores were partly dismantled to determine the damage to the parts. There are some cores that cannot be repaired and become scrap and are forwarded to the waste stream.

3.1.2 Remanufacturing Product FMEA (Stage 2)

The overall parts in alternator were checked after disassembling activity. Potential failure modes for each component are identified in <Table 3> and have been analyzed by filling up the PFMEA sheet to obtain the criticality number. An extract of the remanufacturing PFMEA is shown in <Table 4>. From the analysis, alternator rotor is found to be the most damaged part. The possible remanufacturing actions show the subject to review during remanufacturing design and process FMEA.

The other components have little damage and can be reused after inspection, cleaning and washing is performed to the alternator housing, fan and pulley system. Instead of that, the stator failure is a rare case where the potential failure mode is open circuit. For this kind of failure mode, the stator should be repaired using hard soldier to refurbish the connection. However, voltage regulator is the most common component which fails in the alternator, due to the component sensitivity. In some event, only replacement can be done to eliminate the risk of the product. For the rectifier, Diode Trio is the most common part that fails producing the "dead battery in the morning" symptom. The way to overcome it is by replacing the diode with new ones.

In <Table 4>, the criticality for the alternator rotor is high which is 45. The part damage may cause pump and rotor failure. Obviously part wear requires redesign to make it functional as the criticality is over 30. For the bearing problem, the criticality is also over 30 which need to be prioritized. Corrosion is a subject that has a low criticality value therefore visual check for the part is adequate.

3.1.3 Remanufacturing Design FMEA (Stage 3)

The DFMEA stage is done only if necessary. From the PFMEA, it stated that redesign is required as there are worn parts on the alternator rotor shaft. In that case, the analysis is carried out at the alternator rotor itself. The DFMEA aids in the assessment of the alternator rotor shaft design to en-

<Table 3> Alternator Potential Failure Modes, Causes and Effects

Component	Function	Failure modes	Causes of failures	Effect of failures
Housing	Supports the internal parts. Acts as a heat sink to dissipate the heat generated by the internal parts and components.	Bearing failures Dirt, oil and grease.	Overload and V-belt tension incorrect. Because of the heat sink properties.	Growling and howling noise from the alternator. Decreased the life of alternator.
Rotor	Spins in the centre of the alternator charged of variable current levels and to produce a variable magnetic field. Positions the pump rotor on the end of the shaft.	Wear on the serrated part of shaft. Failed to move. Corrosion on the rotor. Internal short or open circuit.	Friction between rotor shaft and pump rotor. Bearing failure Lack of lubrication Wires burned.	Alternator failure. Rotor failure Short lifetime No output production
Stator	Produces the actual power.	Open or ground.	One or more wires in the part burned, broke and shorted to ground due to an insulation failure.	Reduce the amount of current produced from the alternator.
Voltage regulator	A control device to control the amount of field current input that allows passing through the rotor winding.	Misfire problem.	Short circuit problem.	Too little current will run down the battery and too much can damage it.
Rectifier	Convert AC power to DC power.	Weak diode.	Over time limit.	Low current output.

<Table 4> PFMEA for Core Alternator

Item	Function	Failure Mode	Effect	Cause	O	S	C	Possible remanufacturing actions
Rotor	Rotates inside the stator coils to generate alternator (AC) current	Rotor shaft cannot move	Rotor failed	Bearing failed	5	8	40	Check the reliability of the bearing
		Corrosion on the surface	Short life cycle for the rotor	Lack of lubrication	4	7	28	Visual check on the grease if it is adequate
	Position the pump rotor on the end of the shaft	Wear on pump rotor and rotor shaft serration	Pump and alternator failed	Friction between rotor shaft and pump rotor	5	9	45	Redesign the joint technique for rotor shaft and pump rotor

<Table 5> DFMEA for Alternator Rotor

POTENTIAL
FAILURE MODES AND EFFECTS ANALYSIS
(DESIGN FMEA)

__System
__Subsystem
√Component Alternator rotor

FMEA Number 1234
Page 1 of 1

Design Responsibility Engineering section
Prepared by Ain/Liyana, Sungdo Tech
Model Year(s)/Vehicle(s) 2011/Truck/Hyundai
Key Date 2010 03 28
FMEA Date(Orig.) 2010 03 29(Rev.) 2010 04 01
Core Team Ain.Body Engineering, Liyana,Production

Item / Function	Potential Failure Mode	Potential effect(s) of failure	Sev	Class	Potential Cause(s)/ mechanism (s) of failure	Occur	Current Design Contol		Det	RPN	Recommended action (s)	Responsibility and target completion date	Action result.				
							P	D					Action taken	Sev	Occ	Det	RPN
Rotor Shaft Position the pump rotor that will operate the brake pump vacuum. Run the alternator with the help of bearing.	Wear on the end of shaft that position the pump rotor.	Seize the rotor causing pump to fail.	9		Friction with pump rotor during the process.	9		Redesign the attachment part.	7	5 6 7	Cut the wear serration.	Prod. Engineering Team 2010 05 03	Redesigned by change the serration to key slot technique	9	1	1	9

Note : P = Prevention, D = Detection.

sure that the rotor can be attached with the pump rotor.

<Table 5> shows the extract of DFMEA on the alternator rotor. Based on the extract, the RPN value is very high that is 567. This large number requires redesign to ensure that the rotor can perform its functions. Based on the risk rating table for RPN, the severity number of 9 combined with the occurrence number of 9 proved that the item needs corrective action. On the right side of the table is the evaluation of risks after actions taken. From the RPN value, the action taken seems to be successful since the differences between before and after RPN value are huge.

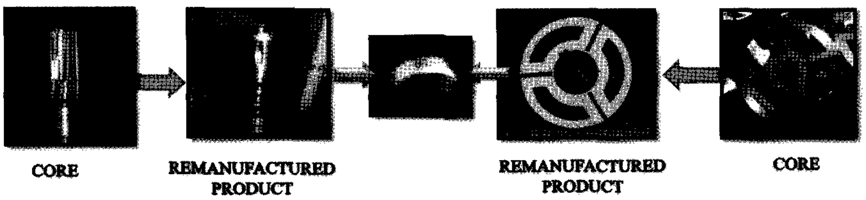
3.1.4 Establish Remanufacturing Process (Stage 4)

Remanufacturing process involved is the process of producing the redesign part on the alternator rotor. <Figure 3> shows the design part for rotor. The input product of this process is the core alternator rotor that has a worn out serrated portion at the end of the shaft. The worn out serrated part will be eliminated and the pump rotor can be attached to the alternator rotor shaft using a key slot as shown in <Figure 3>. Thus, the process for producing the key slot is of concern. The process should be established from the core purchasing to the end product. <Figure 4> shows the flow of the processes involved in making key slot on the rotor.

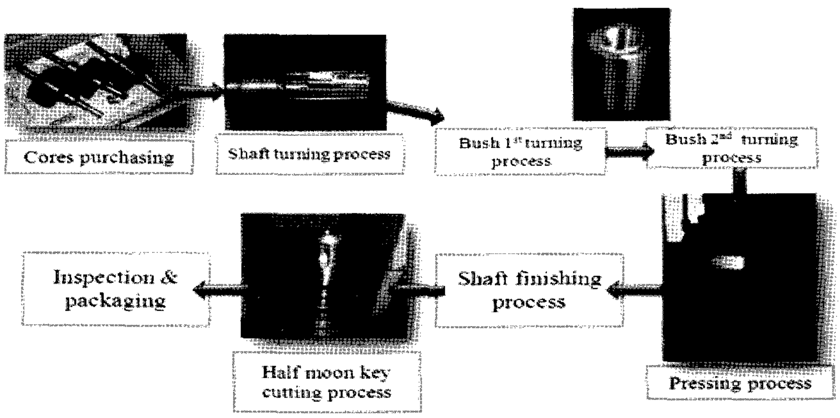
The damaged rotor undergoes eight processes to be remanufactured in the plant floor. The first step is core purchasing. The rotor core was cleaned and prepared for the remanufacturing process. Then, the serrated portion on the rotor shaft is cut by the turning process to produce the outer diameter to Ø10.99mm. A bush is inserted to obtain the actual outer diameter of the shaft that to fit the pump rotor. The bush undergoes two time turning processes which are first to cut a long rod into the required bush length and second to obtain the inner diameter.

The first turning process is to get the outer diameter of Ø15.2mm, length of 22mm to 32mm and to drill the inner bush by Ø10mm. The second bush turning process is to obtain the inner diameter of Ø10.87mm to Ø10.88mm. The next process is the bush pressing process to insert the bush to the shaft with a work pressure of $5kg/cm^2$. This special process required an inspection with UV light to inspect the surface of the shaft. Shaft finishing process takes part to acquire the outer diameter of Ø14.734mm to Ø14.707mm.

The most important process on the rotor is the half-moon key slot cutting process where the slot is made using milling machine with a tool diameter of Ø16mm, key width of Ø4.01mm to Ø4.04mm and key depth of Ø4.8mm to 5.0mm. Last process is the final inspection and packaging process. A Vernier caliper is used for inspection and grease is applied before packaging.



<Figure 3> The Redesigned Key Slot Technique



<Figure 4> Remanufacturing Processes for Rotor

3.1.5 Remanufacturing Process FMEA (Stage 5)

The PFMEA data sheet is completed for each process that is established. <Table 6> shows the PFMEA for press operation in which the bushing is press to fit the rotor shaft. The RPN values indicated is over 140. Due to the risk rating table for RPN, all the items require corrective actions. In the classification column, the symbol shows that special safety aspect has to be emphasized.

3.1.6 Cost Analysis (Stage 6)

The cost per unit is established and analysis performed on each activity. Using the ABC method, cost is divided into several alternator remanufacturing activities which are core purchasing and storing, cleaning, inspection and sorting, reconditioning and replenishment, reassembly and final testing and packaging. All the remanufacturing cost is divided into several portions which are labour costs, machine costs and overhead costs. The maximum RPN from each process has been extracted and will be used to ease the management evaluation. The RPN/cost quotient presented indicates the risk level of each process. <Table 7> shows the cost estimation for the alternator remanufacturing process.

<Table 6> Process FMEA for Alternator Rotor

POTENTIAL
FAILURE MODES AND EFFECTS ANALYSIS
(PROCESS FMEA)

FMEA Number 1234
Page 5 of 8

Item Bush and Rotor Shaft Design Responsibility Engineering section Prepared by Ain/Liyana, Sungdo Tech
Model Year(s)/Vehicle(s) 2011/Truck/Hyundai Key Date 2010 03 28 FMEA Date(Orig.) 2010 03 29(Rev.)
Core Team Ain.Body Engineering, Liyana,Production

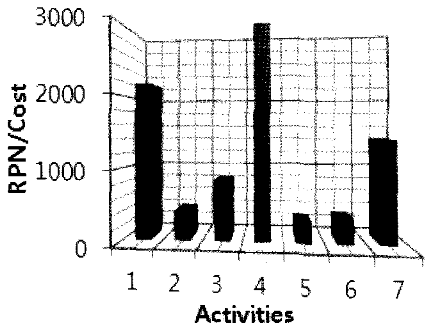
Process Function / Req 'ment	Potential Failure Mode	Potential effect(s) of failure	Sev	Class	Potential Cause(s)/ mechanism (s) of failure	Occur	Current Design Contol		Det	RPN	Recommended action (s)	Responsibility and target completion date	Action result.				
							P	D					Action taken	Sev	Occ	Det	RPN
Process #5 Pressing process - Press bush fix into shaft with high pressure - To obtain the original outer diameter of the shaft	- The bush is not fix correctly with shaft - Crack or fracture on the surface of the bush	- Part damage - Poor appearance - Poor performance	8	S	Pressure too low	5		Inspection with UV light to highlight defects	6	240							
					Mislocation the center between bush and shaft	5		Check the stopper location in every process	4	140							
					The diameter of shaft or bush is incorrect	6		Check diameter using vernier calliper	4	168							

Note : P = Prevention, D = Detection.

<Table 7> Process FMEA for Alternator Rotor

No	Activities	Activity costs($)**			Cost per unit	Max RPN	RPN/ cost
		Fixed costs		Variable costs			
		Labour	Machine	Overhead			
1	Core purchasing and storing	0.12	0.05	0.01	0.18	392	2177.78
2	Disassembly	0.62	0.13	0.11	0.86	350	406.98
3	Cleaning	0.11	0.08	0.20	0.39	327	838.46
4	Inspection and sorting	0.15	0.003	0.04	0.193	576	2984.46
5	Reconditioning and replenishment	0.87	0.98	0.90	2.75	789	286.91
6	Reassembly	0.66	0.15	0.5	1.31	444	338.93
7	Final testing and packaging	0.06	0.06	0.05	0.17	240	1411.76
	Manufacturing cost				5.853		

Note) **The value can change to other values according to the current currency rate.



<Figure 5> Graph of Remanufacturing Cost over Activities

<Figure 5> is the chart that indicates the resources allocation. This chart is necessary to determine which activity can be modified to reduce the costs. From the table, reconditioning and replenishment is a high risk activity with a low resource allocation. This activity has the opportunity to reduce the risk at cost by modifying the activity. For example, redesign the damaged alternator rotor component that will position the pump rotor from serration type to a key slot type will reduce the costs of activity for the rotor. For low risk activity such as final inspection and packaging, the opportunity to reduce the amount of cost can be done without disturbing the activity by controlling the activity cost like labour productivity, machine efficiency, and automation cost. Kaizen concept can be implemented to control all these activities by doing small continuous improvements in current process.

4. Summary

This paper outlines a systematic guideline for remanufacturing process using the Failure Mode and Effect Analysis (FMEA) method in order to estimate the reliability and quality of the remanufactured alternator. The method is just a tool to help, but the remanufacturer must determine the optimal remanufacturing process and specific inspection and production that will turn the alternator as-good-as new and place the product into the market with reliability and quality equal to a new product. FMEA is a method that is widely used in industry and has shown its value and effectiveness in the above remanufacturing case study.

Actions taken often result in a lower severity, occurrence or detection rating. Redesign may result in lower severity and occurrence ratings while inserting validation controls and maintenance can reduce the detection rating. The revised ratings are recorded with the originals on the FMEA template form. After these corrective actions and revisions have been established, evaluation of the ranks can be repeated, until the redesign and control parameters comply with safety standards.

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