Analysis of Elementary Technology Considering the Remanufacturing of Used Machinery: A Case Study

Yongsung Jun[1(✉)] and Yungchul Yoo[2]

[1] Korea National Cleaner Production Center, KITECH, Seoul, Korea
yxjasp@kitech.re.kr
[2] Reliability Lab, Construction Equipment Technology Institute, Jeollabuk-Do, Iksan, Korea

Abstract. Globally, the circular economy is emerging as a key issue for industrial innovation by enhancing the efficiency of resource use and promoting resource circulation. Remanufacturing is to recover the product after use to maintain its original performance through a series of production processes. Machine tools experience various operational problems such as malfunction, damage to parts, and deterioration after the service life has elapsed. Remanufacturing technology has several common technologies that can solve similar failures among different items, and can be largely divided into existing remanufacturing process technology and technology for upgrading the performance of a machine. A systematic technical background is needed to ensure the performance and reliability of remanufacturing products, but so far there are few cases of research on machine tool remanufacturing in Korea.

Therefore, in this study, machinery items with high frequency of use and marketability among machine tools were reviewed as targets for remanufacturing. For the remanufacturing of used machine tools, failures to be solved by functional characteristics of target parts were identified, and remanufacturing elementary technologies were classified and analyzed, respectively. In addition, basic studies such as major performance, Failure Mode and Effect Analysis (FMEA) were conducted for the used machine tools.

Keywords: Remanufacturing · Machinery · Machine Tool · Failure Mode and Effect Analysis

1 Introduction

Globally, the circular economy is emerging as a key issue for industrial innovation by improving the efficiency of resource use and promoting resource circulation. Remanufacturing is the process of recovering a product after use at the end of its lifecycle and systematically manufacturing it to maintain its original performance through a series of production processes [1]. Therefore, remanufacturing is considered as one of the means for sustainable product production because it has a high effect of reducing energy consumption and recycling resources. Remanufacturing industry has a significant market

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size in various sectors such as aerospace, heavy duty & off-road (HDOR), automotive parts, and machinery [2]. As of 2019, the global machine tool market size was 84.2 billion dollars in production, and the trade volume between countries was 46.2 billion dollars in exports and 44 billion dollars in imports [3].

The entire process of machine tools is managed by the International Organization for Standardization (ISO) TC39. The scope of machine tool standardization includes the removal of materials or the processing of metals, woods and plastics by pressure [4]. According to the KS (Korean Industrial Standards), a machine tool is defined as a machine that removes unnecessary parts by cutting or grinding a metal workpiece to create a necessary shape [5]. After the service life of 10 to 20 years has elapsed, machine tools have various operational problems such as malfunction, damage to parts, and aging. As a result, they tend to be sold after repair, sold as used goods, recycled material (scrap metal), or discarded. Machine tools are considered good remanufacturing targets as more than 80% of their materials are made up of recyclable metallic materials. It has the effect of saving energy and resources putting in the iron production process from ore, and also contributes to the reduction of carbon emission. It is necessary to develop remanufacturing technology and disseminate products for industrial machine items with high versatility, productivity and business potential among industrial machines after use. Failure is a phenomenon in which a product fails to perform a required function or does not meet its intended performance. IEC 60050–191 classifies failure, fault, and error according to the degree of failure. Failure Mode and Effect Analysis (FMEA) is a qualitative failure analysis technique that analyzes failure modes and effects of components or devices constituting a system in a bottom-up method [6]. It finds failure modes that can occur in machine tool systems and systematically analyzes their causes and effects to determine priorities. In addition, it is necessary to establish an improvement plan to remove potential failures that may occur in machine tools in use in advance, solve problems in advance, and continuously improve [7, 8].

In machine tools, the remanufacturing procedure consists of disassembly, cleaning, reverse engineering, function restoration, software reinstallation, and data upgrade for applying the latest technology after use. Although a systematic technical background is required to ensure the performance and reliability of machine tool remanufacturing products, there have been few cases of research on machine tool remanufacturing in Korea so far. Therefore, this study conducted a case study of elementary technology analysis considering remanufacturing targeting some of the used machine tools.

2 Research Method

In this study, I reviewed items with high frequency of use and marketability among machine tools widely distributed in industrial sites as targets for remanufacturing technology analysis. These items are 7 types of machines including lathes, injection molding machines, drawing machines, presses, milling machines, drilling machines, boring machines, and grinding machines. This study was conducted on lathes, injection molding machines, and drawing machines, and further research on the remaining items is planned in the future. The authors performed the FMEA procedure in collaboration with a research team from an OEM manufacturer of CNC lathe machines and injection

molding machines. For the remanufacturing of the used machine tool, the derivation of the failure to be solved by the functional characteristics of the target part and the classification and analysis of the remanufacturing element technology were performed respectively. In addition, basic research such as main performance, Failure Mode and Effect Analysis (FMEA), parts inspection, and part structure tree analysis was performed on the used machine tools.

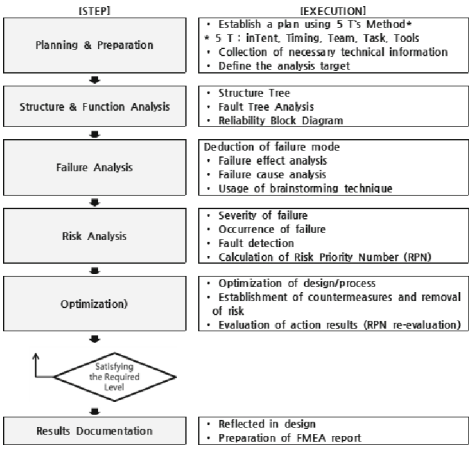

Fig. 1. Procedures for implementation of FMEA.

The procedure for performing FMEA for element parts of remanufactured machine tools is shown in Fig. 1. First, in the planning and preparation stage, the 5 T's Method (inTent, Timing, Team, Task, Tools) utilization plan is established, and analysis target definition and prior information are collected according to the purpose of FMEA. Structure Tree, Fault Tree Analysis, and Reliability Block Diagram were presented by analyzing the components and interrelationships of the items to be analyzed in the structure and function analysis stage. In the failure analysis stage, the type of failure was derived by referring to failure cases of the target machine tool and similar products in the past. In addition, a brainstorming meeting was held with experts from the research team, and related failure effects and failure causes were analyzed. In the risk analysis stage, the severity of the failure impact on parts and subsequent assemblies, systems, customers and legal restrictions was evaluated. We derived the Risk Priority Number (RPN) by considering the severity, frequency of occurrence, and degree of detection of the failure of the machine tool to be analyzed.

Figure 2 describes the failure mode and impact analysis form of remanufacturing elemental technology for elemental parts subject to remanufacturing in machine tools.

Analysis of failure mode and impact of remanufacturing element technology					
Mmanufacturing company		FMEA Team		Control Number	
System		Product Name		Model Number	
Writer		Date Created		Revision Date	

NO.	Part/ Function ①	Pfailure Mode ②	failure effect ③	sever ity ④	cause of failure or mechanism ⑤	Occur rence ⑥	Remanufacturi ng Design Evaluation Techniques (Management /Prevention/D etection) ⑦	Dete ctabil ity ⑧	RPN ⑨	Remanufact uring Recommend ations ⑩	person in charge/ complete due date ⑪	Action result ⑫				
												Action Details	Sev erity	Occ urre nce	Det ecta bilit y	RPN
1																
2																
3																

Fig. 2. Form for analysis of failure mode and effect of remanufacturing technology.

3 Results

3.1 Injection Molding Machine

(1) Overview of Injection Molding Machine

An injection molding machine is a machine that creates products of various three-dimensional shapes by injecting materials such as plastics or rubbers, melting them with heat, and then injecting high pressure into the mold. Injection molding machines are evolving in a direction to quickly respond to rapidly changing technological trends and productivity improvement demands, such as enlargement, thinning, and weight reduction of parts, and eco-friendly/substitute materials [9, 10].

The structure of the injection molding machine is largely divided into an injection unit, a clamping unit, a control system, and the like. Injection Mechanism is a device that supplies, measures, plasticizes and melts molding materials and injects them into the mold at high pressure. The clamping mechanism maintains the clamping force so that the mold does not open during resin injection, and when the resin cools and solidifies, it opens the mold and removes the molded parts. Mold, die plate, and tie bar or tie rod), clamping cylinder, ejector and other parts.

(2) Classification of remanufacturing element technology

The major remanufacturing element technologies of the injection molding machine were selected based on research and analysis data such as the injection molding machine's main performance, A/S data, overhaul, and parts structure tree, and remanufactured parts and performance-enhancing parts were selected. Following technologies were considered as element technologies for the remanufacturing process.

- Restoration technology using 3D additive manufacturing technology without remanufacturing worn parts for hydraulic cylinders and hydraulic pumps
- Restoration technology such as chrome plating and laser cladding for hydraulic cylinder rods, hydraulic pump pistons, and piston shoes
- State inspection of core parts, inspection instrument and jig tool optimization

- Technology that optimizes the number of revolutions according to the operating load by replacing the induction motor that supplies hydraulic power to the hydraulic injection molding machine with a servo motor
- Monitoring technology that provides information so that management and maintenance can be performed in a timely manner to extend the life of the injection molding machine by preventing failures in advance

(3) FMEA result of injection molding machine

The analysis results of failure modes and effects of remanufacturing element technology on element parts subject to remanufacturing of injection molding machines are shown in Fig. 3. The main components of the cylinder are piston seal, rod seal, cylinder tube, piston, rod, Hush & wearing, head and rod cover, cushion ring and plunger, etc. Seal parts have the functions of preventing oil leakage, preventing foreign substances from entering, and preventing rod wear. However, malfunctions such as abrasion, breakage, and hardening of seals due to long-term use of these parts result in reduced function and efficiency and shortened lifespan. In the case of cylinder tube and piston rod, due to failure causes such as abrasion, deformation, and damage, the efficiency decreases and the operation becomes impossible. Hush & wearing protects the piston seal and rod seal, but malfunctions such as damage and wear due to overload and foreign substances occur. The head and rod cover are key parts that maintain airtightness inside the tube, but they lose their function due to failures such as high load and deformation.

NO.	Part/ Function ①	Failure Mode ④	Failure Effect ⑤	Sev erity ⑥	Cause of Failure	Occ urre nce ⑦	Remanufacturing Design Evaluation Techniques (Management/Preventio n/Detection) ⑧	Data ctabi lity ⑨	RPN ⑩	Remanufacturing Recommendations ⑪	Person in charge/ complete due date ⑫	Action result ⑬				
												Action Details	Seve rity	Occu renc e	Data ctabi lity	RPN
1	piston seal/ leak prevention	leakage	reduced efficiency, stick slip	7	abnormal material, deterioration of life/ Seal wear, breakage	9	Visual inspection	5	315	exchange of new goods	KIM	exchange	7	5	2	70
		seal breakage	Decreased function, shortened lifespan	6	abnormal material, overpressure/ wear, hardening	7	Visual inspection	6	252	exchange of new goods	KIM	exchange	6	4	2	48
2	rod seal/ Prevention of ingress of abnormal material	leakage	Reduced efficiency, shortened lifespan	7	abnormal material, deterioration of life/ Seal wear, breakage	9	Visual inspection	5	315	exchange of new goods	KIM	exchange	7	5	2	70
		seal breakage	Loss of pressure resistance, leakage	6	abnormal material, overpressure/ seal breakage	7	Visual inspection	6	252	exchange of new goods	KIM	exchange	6	4	2	48
3	cylinder tube/ Maintain rod and piston structure	damage	inoperable	8	Overload, external shock/ excess pressure	5	Visual inspection	2	80	-	-	-	8	3	2	48
		transform	external leakage, shortened lifespan	8	Overload, external shock/ generation of external force	4	cleaning, visual inspection	3	96	-	-	-	8	3	3	72
4	piston/ pressure load transfer	Wear	reduced efficiency, inoperable	9	Overload, friction	5	laser measurement	8	360	3D Restore	KIM	restoration	9	3	3	81
5	road/ Power and traction transmission	coating surface scratches	reduced efficiency, no output	10	abnormal material, Thread wear, corrosion	6	inspection of magnifying glass	6	360	coating repair	KIM	restoration	10	4	2	80
		rod deformation	reduced efficiency	9	Overload, external shock/ load generation	6	Laser measurement, visual inspection	3	162	3D Restore	KIM	restoration	9	4	2	72
6	DU Bush & wearing/ thread protection	damage	shortened lifespan	5	abnormal material, overload/ Lateral load, contact surface damage	5	cleaning, visual inspection	5	125	exchange of new goods	KIM	exchange	5	3	2	30
		Wear	external leakage	5	abnormal material, deterioration of life/ long time use	5	cleaning, visual inspection	6	150	exchange of new goods	KIM	exchange	5	3	3	45
7	head and rod cover/ Maintaining airtightness inside the tube	Assembling bolt damage	loss of pressure resistance	3	Repeat operation, vibration/ excess pressure	4	cleaning, visual inspection	2	24	-	-	-	3	2	1	6
		cover deformation	mechanical shock generation	3	Overload, external force generation/ transform	4	cleaning, visual inspection	2	24	-	-	-	3	2	1	6

Fig. 3. Analysis of failure mode and effect of remanufacturing element technology (Injection Molding Machine)

The main components of an oil cooler are heat exchangers and condensers, piping and welds, compressors, valves, oil storage tanks, oil pumps and motors, fan motors, and control panels. The heat exchanger and condenser function as fluid energy transfer and cause system failure due to refrigerant leakage, refrigerant flow stop, oil leak, oil flow stop failure. Pipes and welds must be kept airtight, and failures such as cracks and breakage occur. The compressor performs a refrigerant compression function, and the main causes of failure are bearing damage, valve failure, and seal leakage. Oil circulation is the main function of oil storage tanks and oil pumps, and errors in the oil system occur due to oil contamination, leakage, and pump failure. The fan motor acts as a heat sink and the main cause of failure are bearing damage, which causes oil temperature to rise. When the control system composed of the control panel circuit and sensor malfunctions, it causes the entire system to malfunction.

3.2 CNC Lathe Machine

(1) Overview of CNC Lathe machine

A CNC lathe is a type of machine tool that cuts a workpiece using numerical control through a computer and is used in the metal processing field. The CNC Lathe is a representative metal cutting machine that rotates the workpiece and performs cutting, sanding, drilling, turning, etc. using a tool to symmetrically process the workpiece with respect to the rotation axis. CNC lathe technology is trending towards high-speed, multi-axis, complex, precision and smart, which greatly improves cutting ability by reducing lead time and shortening machining time to increase the efficiency and productivity of the machining process, and changing the machining method while using the existing tool. In the CNC lathe, the main units are Bed unit, Spindle drive unit, X-axis assembly unit, Z-axis assembly unit, Head stock unit, Tail stock unit, Chuck, Tool post, Splash guard, Electric control unit, Hydraulic unit, Lubrication It is composed of unit, chip conveyor, and operating panel [9, 10].

(2) Classification of remanufacturing element technology

In the CNC lathe, the main remanufacturing element technology selected remanufactured parts and performance-improved parts based on research and analysis data such as the main performance of the CNC lathe, A/S data, overhaul, and part structure tree. The following technologies were considered as element technologies for the remanufacturing process.

- Linear axis positioning accuracy, spindle runout through the development of replacement technology for precision transfer parts (LM Guide, Ball Screw, etc.) and headstock (Shaft, chuck, spindle drive, etc.)
- Optimization of remanufacturing process to restore old products to the new level and computerized programming of work procedures
- Restoration technology that reprocesses parts using metal lamination, cladding, and metalizing technologies to reinforce large structures such as beds
- Technology that can reduce power consumption of accessories (hydraulic pumps, coolant pumps, conveyors, etc.) by more than 15% compared to existing

products by upgrading electric control devices such as controllers and applying standby power reduction technology to remanufacturing equipment

(3) FMEA result of CNC lathe machine

Figure 4 presents the results of analysis of failure modes and effects of overall remanufacturing element technology for element parts subject to remanufacturing of CNC lathe machine. The CNC lathe, FMEA for deriving element technology was performed for the remanufactured parts, the Ball screw and the spindle drive unit [11]. The main parts of Ball Screws are screw shaft, nut, return pipe, deflector, pipe press plate, wiper or seal, and steel ball etc. The return pipe and deflector function as a ball transfer function, and due to failure causes such as wear, deformation, and destruction, ball transfer is impossible. The wiper or seal prevents foreign substances from entering and leakage occurs when worn. Steel ball rotates and supports load, but failures such as fusion, deformation, destruction, and abrasion occur and cause noise, vibration, and friction increase.

NO.	Part/ Function ①	Failure Mode ②	Failure Effect ③	Sev erity ④	Cause of Failure ⑤	Occ urre nce ⑥	Remanufacturing Design Evaluation Techniques (Management/Preventio n/Detection)⑦	Det ecta bilit y ⑧	RPN ⑨	Remanufacturing Recommendations ⑩	Person in charge/ complete due date ⑪	Action result ⑫				
												Action Details	Seve rity	Occu rrenc e	Dete ctabi lity	RPN
1	Screw shaft/torque transmission and load bearing	fatigue destruction	Increased friction, reduced efficiency	8	Stress Concentration/Fitting	7	Visual inspection	2	112	material change rework	KIM	new replacement	8	4	2	64
		Wear	poor performance	9	Not aligned/overloaded	8	3D measurement	6	432	3D restoration and coating	KIM	restore	9	5	2	90
		bending	transport impossible	8	Overload/plastic deformation	4	Laser displacement measurement	3	96	-	KIM					
2	Nut/torque transfer and load bearing	fatigue destruction	Increased friction, reduced efficiency	8	Stress Concentration/Fitting	7	Visual and non-destructive inspection	2	112	material change, rework	KIM	new replacement	8	4	2	64
		Wear	poor performance	9	Not aligned/overloaded	8	3D measurement	6	432	3D restoration and coating	KIM	restore	9	5	2	90
3	return pipe/ ball transport	Transform/ destroy	Ball transfer impossible	5	overload/destroy	2	Visual inspection	2	20	-	KIM	-				
4	deflector/ Ball transport	Wear	poor performance	5	overload / spalling	4	3D measurement	3	60	-	KIM	-				
		Destruction	Ball transfer impossible	6	overload/destroy	2	Visual inspection	2	24	-	KIM	-				
5	Pipe Pressing Plate / Pipe Fixing	Transform/ destroy	Ball transfer impossible	5	overload/destroy	4	Visual inspection	2	40	-	KIM	-				
6	Seal / prevention of abnormal material	eak/intrusio n	Noise, friction, temperature rise	6	Improper lubrication/wear	5	Visual leak inspection	5	150	Seal structure and material review	KIM	new replacement	6	2	2	24
7	Ball/rotation and load bearing	fusion	screw shaft fixing	9	Loss of lubrication/wear	3	Visual and operational inspection	4	108	Lubricant Review	KIM	Lubricant change	9	3	2	54
		transform	rotation fixed	9	Overload / Brinelling	6	Inspection by magnifying glass	6	324	Load Design Review	KIM	new replacement	9	3	3	81
		Destruction	Increased vibration, transport impossible	9	overload/cracking	4	Visual and operational inspection	4	72	-	KIM	-				
		Wear	Increased noise/vibration	10	Fatiguo overload Lack of lubrication / spalling, scuffing	8	Inspection by magnifying glass	6	480	material change	KIM	new replacement	10	5	2	100
		corrosion	rotation fixed, Increased noise/vibration	7	Seal fatigue, foreign matter inflow/current corrosion	6	Visual and operational inspection	3	126	Material change, coating technology review	KIM	new replacement	7	4	3	84

Fig. 4. Analysis of failure mode and effect of remanufacturing element technology (CNC lathe machine)

The spindle drive unit is a device that enables cutting by transferring the power of the CNC lathe to the belt or gear and transmitting the rotational power to the chuck that bites the workpiece. The main components of the spindle unit are Spindle, Bearing, Color, Pulley, Housing, etc. [12]. In spindle drive unit, the main shaft functions as a power transmission and support function, and the precision decreases and the lifespan are shortened due to failures such as abrasion and bending. The pulley performs a power transmission function, and the efficiency decreases due to wear and cracks. Bearings rotate and support functions, and precision is reduced due to increased friction and clearance. Housing functions as a structure and self-maintaining, and its strength decreases due to failure causes such as cracks and wear. Linear Motion Guide (LM Guide) is a part that supports and guides the load in linear motion. The main components of Linear Motion Guide are linear rail, linear block, end plate, guide bar, end seal,

seal plate, scrapper, u-bending, retainer, ball, nipple connector, etc. The linear rail acts as a guide, and poor positioning accuracy occurs due to failures such as wear and plastic deformation in linear motion guide. The end plate and guide bar function as a steel ball circulation, and friction increases in case of breakage. The end seal and seal plate function to prevent the inflow of foreign substances, and poor lubrication occurs due to wear and deterioration. The scrapper removes impurities, and plastic deformation occurs due to the inflow of foreign substances and increased friction. U-bending, retainer, ball, etc. function to support the steel ball, and abnormal operation and noise occur due to failures such as abrasion, cracks, and deformation.

4 Summary

In this study, we implemented the functional characteristics of major parts, failure derivation, classification of remanufacturing element technology, and Failure Mode and Effect Analysis (FMEA) for the remanufacturing of machine tools. The results derived from this study are as follows. As machine tools are made up of about 80% reusable metal materials, they are therefore considered good remanufacturing targets. It is necessary to develop remanufacturing technology and disseminate products for industrial machine items with great versatility, productivity and business potential. The main remanufacturing element technologies of the Injection Molding Machine were divided into remanufacturing process technology and spec-up technology, and among them, the results of FMEA for cylinder and oil cooler were presented. In CNC lathe machine, the results of FMEA for Ball Screws, Spindle Drive Unit, and Linear Motion Guide were presented.

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