Improvement in Reusable Part Quality to Prolong Remanufactured Product Lifetime for Leading Heavy Equipment Remanufacturing Company in Indonesia

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Abstract— Remanufacturing is a process of reusing used parts with almost the same quality as new products. The 6D114 series engine components have the problem of a low contribution margin due to high production costs cause by small reuse ratio of the used parts. The piston part has a replacement ratio of 100%. This study aims to reduce production costs by increasing reusable parts, especially piston parts. Reusable criteria parameters for pistons are obtained from the reverse engineering. Then the process of remaining life assessment is carried out by looking at the effect of the wear level on the ring groove 1 and 2 pistons, a performance test is performed, specifically the compression pressure test and blow-by pressure test. And to validate the simulation results and performance tests, a seeding test is carried out on the unit. From the results of this study, it is found that the parameters for determining the reusable part of the piston are the worn-out value of the piston ring groove, compression pressure, and blow-by pressure. From the reusable piston results, it can reduce the cost of purchasing piston parts by 98.8%. This resulted in an increase in the contribution margin from 7.8% to 12.6%.

Keywords—remanufacturing, contribution margin, piston, remaining life assessment, reverse engineering.

I. Introduction

The continuous development of the heavy equipment industry is parallel with the growth of the business sector. In turns, many companies use heavy equipment in their work activities. Referring to data from HINABI the Indonesian Heavy Equipment Association in the first quarter of 2017, it reached 1,153 units, increase 86.3% annually compared with the same period in the last year of around 619 units. Meanwhile, in 2nd quarter of 2017, the national heavy equipment industry recorded sales of 2,467 units.

Remanufacturing is the process by which heavy equipment that has been used is reprocessed so that it becomes a product that has a renewed value. The remanufacturing process is part of the uncertainty of time, quantity and quality of the components that returned after use. Components that returns, will see decreasing value over time, this is why the remanufacturing process must be carried out immediately in order to attain substantial revenue and sizable company profits. Remanufacturing products are expected to use used parts as much as possible without reducing product quality. Quality is almost the same as new products, which is 80% of new products. And has a maximum price of 50% of new products [1].

One of the leading heavy equipment remanufacturing companies in Indonesia has problems related to costs. The company's standard production cost has a minimum contribution margin of 32%, this will become a standard in order to get a 2-digit Gross Profit (GP).

The problem of this research is The process of changing the piston due to the absence of a standard parameters for determining the reused part will cause high spare part costs which will produce a low margin of contribution. In addition, without clear parameters it will result in poor quality and durability, which can lead to increased product failure in remanufacturing components. In this case, the maximum value of wear on the piston has not been determined to be reused and to obtain the durability and quality in accordance with the standard company.

The objective of this research are:

1. Reducing the production cost of the 6D114 Series engine unit model PC300-8 caused by changing piston parts with brand new parts in the remanufacturing product.

2. Defining the parameters that can be used for determining the reused part. Specifically, on the piston.

II. LITERATURE REVIEW & RESEARCH METHODOLOGY

A. *Remaining Life Assessment.*

The design of a component is always made with the aim of avoiding failure. Estimating the life of a component usually requires long-term properties, which were not visible during the initial design phase. Due to the old method that inefficiently calculates the remaining life, there are several approaches that can be taken to carry out this Remaining Life Assessment. One of them is through modelling, using software that can simulate various kinds of working conditions and provide output such as fatigue life or factor of safety which can be taken into consideration in determining the remaining life. The complex nature of the fatigue phenomenon can be better analyzed by testing using the S-N curve, which shows the relationship between the applied stress and the number of cycles required to fail. With this curve it will be much easier to predict the life of each engine component.

B. *Piston.*

Piston is a component of an internal combustion engine that functions as a suppressor for incoming air and a recipient of the combustion shock in the liner cylinder combustion chamber. This engine component is held by a connecting rod that gets an up and down motion from the rotating motion of the crankshaft.

The piston works without stopping as long as the engine is running. This component experiences an increase in temperature and high pressure, as such it is absolutely necessary for a piston to possess high resistance. Therefore, manufacturers now prefer aluminum alloy composite (AlSi).

The size of this piston gap varies depending on the type of engine. Generally, between 0.02 to 0.12 mm, using the right. Gap size is very important. The reason is, if it is too small it will cause no gap between the piston and cylinder when the conditions are hot. This condition will cause the piston to press the cylinder and damage the engine.

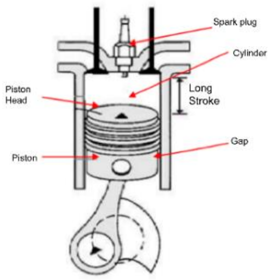


Fig. 1. *The gap between the cylinder piston and the combustion chamber*.

C. *Blow-by Pressure.*

One of the most common problems in the heavy equipment industry caused by wear is blow by. Blow by is a phenomenon where there is gas pressure entering the crank case. This happens because over time the piston rings or the groove on the piston are worn out so that it cannot completely insulate air or other contaminants. This is quite dangerous because the content of water particles can damage the oil. And when the air filtration process is not optimal, coarse particles enter the air compressor and this is what causes wear on the piston rings and liner walls.

TABLE I
STANDARD BLOW-BY PRESSURE TABLE PC-300 [2]

	Kondisi	Unit	Standar	*Permissible*
Blow-by Pressure	at rated HP	kPa (mmH_2O)	Max 1,57 (169)	Max 2,55 (260)

D. *Contribution Margin.*

Contribution margin is a cost-volume-profit analysis part of management accounting against profit margins in sales per unit and is useful in carrying out various calculations or used as a measure of operational impact.

Total Contribution Margin (TCM) is total revenue or sales (Total Revenue (TR or Sales) without variable cost (Total Variable Cost (TVC)):

$$TCM = TR - TVC \quad (1)$$

Zhen, et al [3], conducted research on diesel engines that have been remanufactured with a life cycle analysis approach and advanced restoring technology, the objective of this study is to analyse the benefits of the remanufacturing process by comparing 3 methods, which are (1) newly remanufacturing, replacing whole parts with new parts. (2) Performing remanufacturing based on life cycle assessment on parts that have been previously used. And the last method is (3) advanced technology restoring, repairing parts that have been damaged by the advanced technology repair method to get a better lifetime than the parts used. In a lifetime, the method (1) and (3) restoring advance technology have a better lifetime than the method (2), but when viewed from the cost parameter, methods (1) and (3) resulting in high production costs. This becomes a separate concern in this study that low lifetime does not mean it cannot be used, and it is necessary to do research on whether the low lifetime of method (2) can reach the lifetime that the customer expects.

Balaji, et., al. [4], conduct research on diesel engines with advanced technology restoring methods. The objective of this research is to increase the durability of the piston that is repaired using the HVOF (High Velocity Oxy Fuel) method. This study still focuses on the repairing process of the piston part that is damaged in the crown area. There are several parameters used to determine the reuse process of the piston part, such as the absence of pitting damages on the piston surface, and if such damage occurs, repair must be carried out to increase the durability of using the part.

M. Fonte, et., al. [5], conduct research on diesel engine crankshaft using the lifecycle assessment method. The simulation process is carried out to determine the fatigue life time of the crankshaft part. The simulations approach can determine whether the crankshaft part is reusable or not reusable. Research conducted by M. Fonte can be applied to other parts in the engine, for the process of determining reusable criteria.

Of the three studies, the plan in this research is to combined several research methods that have been carried out to be applied to the 6D114 Komatsu engine piston. By combining the method of checking the worn dimensions of the piston and also the finite element analysis using Solidwork software, to determine the effect of the worn-out level on the piston groove on the fatigue life of the Komatsu 6D114 piston engine, the target is to make reusable criteria for the Komatsu 6D114 piston engine in order to ensure lifetime of piston parts that are used again with the lifetime expected by the customer in the remanufacturing business.

III. RESEARCH METHOD

A. Research Flow Chart.

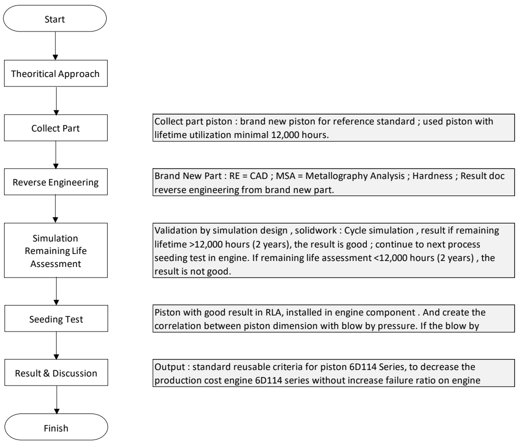


Fig. 2. Research flow chart

B. Reverse Engineering

In the reverse engineering process, it is required for some data to be known. Among those data are:

a. Design Part.

b. Material & Mechanical Properties Part.

used piston parameters are observed from several areas that experience wear after being used to operate for a minimum of 18,000 hours or about 3 years. Where the level of wear that becomes the focus of this research is the area of ring groove 1 and ring groove 2, where those are the 2 areas that have been mostly worn out. As for ring groove 3, the actual measurement results did not experience worn out. The ring groove area can be seen in the figure below.

TABLE III
THE MEASUREMENT RESULTS OF THE USED PISTON

Measurement Area	Check Point	STD	Piston No. (Actual)					
			1	2	3	4	5	6
Outside Diameter (Piston Skirt)	X-X	114	113,89	113,89	113,89	113,89	113,89	113,89
	Y-Y		113,89	113,89	113,89	113,89	113,89	113,89
Worn out outside diameter			0,11	0,11	0,11	0,11	0,11	0,11
Clearence piston ring to piston groove	Top Ring (Ring Groove 1)	114,17	114,16	114,16	113,80	113,80	113,79	113,80
	Worn out Ring groove 1		0,01	0,01	0,37	0,37	0,38	0,37
	2nd Ring (Ring Groove 2)	114,18	114,18	114,18	113,99	114,03	113,93	114,00
	Worn out Ring groove 2		0	0	0,19	0,15	0,25	0,18
	Oil Ring (Ring Groove 3)	4,00	4	4	4	4	4	4
	Worn out Ring groove 3		0,00	0,00	0,00	0,00	0,00	0,00

This study the variables used to determine the remaining life of a piston part are as follows:

TABLE IV
WORN OUT VARIABLE ON RING GROOVE

Variable	Worn Out (mm)		
Top Ring Ring Groove 1	0	0,3	0,5
2nd Ring Ring Groove 2	0	0,3	0,5

B.1. Material & mechanical properties part.

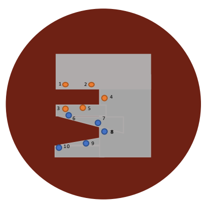
By using XRF, and the result like in the table below.

TABLE V
X-RAY FLUORESCENCE RESULT ON PISTON 6D114 SERIES.

X	Al	Si	Cu	Ni	Mg	Fe	Mn	Ti	Zn
1	77.93	14.9	3,1	1,966	1,35	0,425	0,165	0,094	0,036
2	78.71	14.76	3,71	1,958	0,63	0,422	0,187	0,087	0,036
3	75.67	18.56	3,07	1,941	-	0,395	0,177	0.140	0,039
4	76.40	16.70	3,23	2,04	0,88	0,416	0,170	0,069	0,043
5	74.67	18.26	3,26	1,977	1,05	0,445	0,162	0,100	0,044
6	76.22	16.81	3,28	2,003	0,94	0,407	0,174	0,103	0,040

Based on this table, it can be concluded that the standard that comes closest to the composition of the material is ADC14 with the following composition standards: reference data *ASM* Specialty Handbook: Aluminium and Aluminium Alloys. Based on the JIS standard [6], the ADC14 material has a hardness of 135 HB (can be seen in table 5.4), which means that when converted into Vickers ADC14 it has a hardness of 137 HV.

TABLE VI
HARDNESS TEST RESULT OF BRAND-NEW PISTON ENGINE 6D114 SERIES

Area Test	Groove	No.	HV	Average
	1	1	136,1	134,54
		2	135,8	
		3	133,2	
		4	135,2	
		5	132,4	
	2	6	137,4	136,16
		7	133,8	
		8	135,7	
		9	135,8	
		10	138,1	

The results of the three tests on the new piston material, namely the XRF test, microstructure analysis and also micro hardness, found that the type of piston material of the 6D114 Series engine is aluminium alloy with the ADC14 type. The data will have inputted during the remaining life assessment simulation process using Solidwork software.

C. Remaining Life Assessment Process.

Remaining Life Assessment is carried out by means of the fatigue lifetime analysis approach. Giving load to the software repeatedly, to find out the weakest area in the design part so that we can know the lifetime of the piston design part 6D114 Series. In carrying out the fatigue lifetime analysis process, several data are required to be inputted into the Solidwork software.

1. Design Part.
2. Material and Mechanical Properties.
3. S-N Curve Material.
4. Load that occurs on parts (Pressure, Temperature).

The parameters mentioned above need to be prepared before carrying out the fatigue lifetime analysis process.

Actual Load in piston when combustion process.

PC-300-8

power = 184 kW
d = 114 mm
a = ¼ x 3.14 x (0.114)² m²
N = 6
n = 4
l = 135 mm = 0.135 m
k = 1000

$$184 = \frac{p \times 0.135 \times ¼ \times 3.14 \times (0.114)^2 \times 4 \times 6}{1000}$$

p = 5.566.643,46/6

p = 927.773,91 N

The S-N Curve used in this study is based on the results of research by Toshiro KOBAYASI, et al (1998).

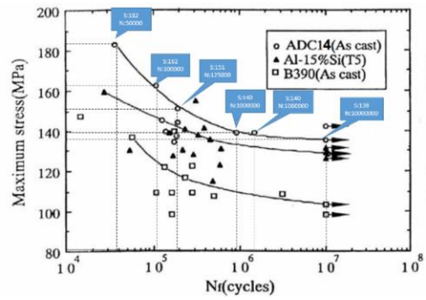


Fig. 3. *S-N Curve ADC14 (as cast)*

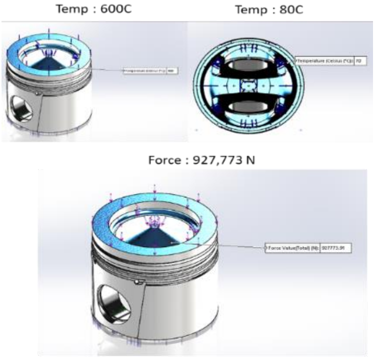
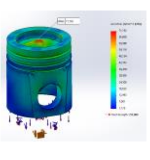
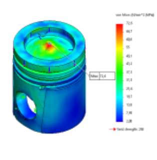
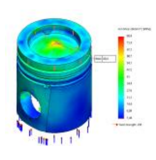


Fig. 3.7. *Load position*

IV. Result & Discussion

A. *Stress Analysis.*

TABLE VII
STRESS ANALYSIS RESULT

	Worn (mm)		
	0	0,3	0,5
Stress Analysis			
Maximum Load (Mpa)	71,762	72,6	80,4
Yield Strength (Mpa)	258		

From the results of stress analysis, it can be seen that the area with the highest load is in the piston crown area. However, the maximum stress value in that area is still below the yield strength value.

Equivalent stress itself functions to determine the critical area of the piston when given a work load and when it is at a working temperature. From the simulation results, it is found that from the three variable levels of worn on ring groove 1 and ring groove, all of the results show that the area on *crown* the piston receives the greatest load. According to Balaji, et al. [4] states that the area that receives the greatest load is the *crown area* of a piston, and repair needs to be done using advance technology, namely the HVOF method. High Velocity Oxy Fuel. This will be a concern in determining reusable criteria for reuse piston 6D114 Series that the within the piston crown there should not have been surface defects, such as pitting, scratch, pockmark, and dent.

Fig. 4. Original and piston in the transport utility vehicle engine

From the three stress analysis results, the higher the worn value in the area of ring groove 1 and ring groove 2, the value of stress received on the side *crown* the piston is getting bigger. This is in accordance with research by Deulgaonkar [7], that the area where the most damage to the piston is at the top of the piston or *crown* piston as shown in the image below.

B. *Factor of Safety Analysis.*

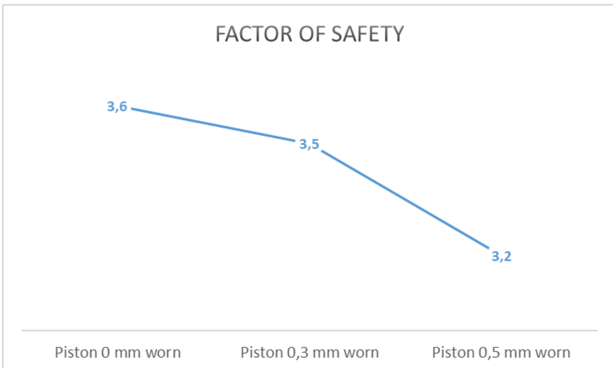


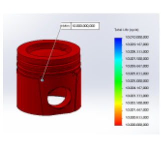
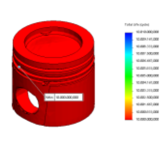
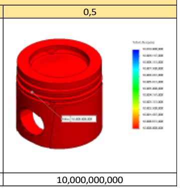
Fig. 5. Factor of safety result

The results show that the higher the worn value of ring groove 1 and ring groove 2, the lower the Factor of safety value of the piston design. Even so, the factor of safety value is still above 3. This is still in accordance with the standard value used by the internal company that the value of the factor of safety is at least 3, meaning that the part can accept a load 3x greater than the load used during the simulation.

C. *Fatigue Lifetime Analysis.*

The fatigue lifetime simulation aims to determine the estimated remaining life of the previously used piston for a minimum of 12,000 hours.

TABLE VIII
FATIGUE LIFETIME RESULT

	Worn (mm)		
	0	0,3	0,5
Fatigue Lifetime			
Fatigue Lifetime	10,000,000,000	10,000,000,000	10,000,000,000

$$Lifetime = \frac{Amount\ of\ cycles\ x\ piston\ movement\ per\ combustion}{RPM\ x\ 60\ x\ hour(s)\ used\ per\ day\ x\ 365}$$

TABLE IX
CONVERSION RESULT REMAINING LIFE

Variable Worn (mm)	RPM	Fatigue Lifetime Cycle (Cycle)	Piston Movement	Work Hours/day (Hours)	Lifetime (Years)
0	1950	10.000.000.000	2	20	11,71
0,3	1950	10.000.000.000	2	20	11,71
0,5	1950	10.000.000.000	2	20	11,71

The data parameters used in the calculation are obtained from the shop manual unit which can be seen in table 2.1 then for the value of 2 on the piston movement per combustion, it is obtained from the diesel engine component which is a 4 stroke engine type, which is 1 time combustion occurs after 2 times the movement of the piston from the bottom dead centre to the top dead centre. As for work hours/day, it is assumed that mining companies use heavy equipment for 20 hours per day.

States that in the comparison of remanufactured components with three variables, namely newly remanufactured products, which means that all parts used for remanufactured products are replaced with new parts, then the second variable is remanufactured products which are given advanced technology restoring treatment to obtain dimensions such as new parts, have a durability lifetime better than parts that are reused based on a lifecycle assessment (LCA). However, in terms of production costs, variable newly remanufactured products and restoring by advanced technology have a higher cost. Because his research states the components that are restored through advanced technology have their own costs required for the restoration process, examples of the advanced technology restoring process can be seen in the table below:

TABLE X
ADVANCED TECHNOLOGY RESTORING PROCESS

Parts	Technology	Costs in Scenario 3	Costs of new parts	Ratio
Cylinder block	Arc spraying	660 ¥	11,000 ¥	6%
Cylinder head	Laser cladding	520 ¥	5000 ¥	10.4%
Crankshaft	Arc spraying	350 ¥	4300 ¥	8.1%
Connecting rod	Brush electroplating	43 ¥	480 ¥	8,9%
Camshaft	Brush electroplating	40 ¥	529 ¥	7.6%

The results of the three conversion results show that the remaining life for each piston has the same result, which is 11 years of use. This means without restoring advanced technology or changing parts. The remanufacturing process can be more efficient by checking the remaining life of a reused part. This can be efficient because there is no cost incurred for the process of replacing parts with new parts and also no costs incurred for the process of restoring part by advance technology. The results of the remaining life simulation show that the parts can be reused for 11 years, this is in accordance with company standards that require that parts that have been used and will be reused for the remanufacturing process have a minimum remaining life of 3 years. The durability of the components contained in reuse parts has a lower durability compared to components that have been replaced with new parts, and with parts that have been restored with advance technology. However, in this study it can be stated that even though the durability is low, it is still in accordance with company standards, namely with a warranty lifetime of 6000 hours or for 1 year and customer expectations of 3 years. In addition, although the simulation process of fatigue lifetime and remaining life assessment shows good results, before reusing the piston part, it is necessary to ensure the quality of the part, where the requirements of the reused piston can meet certain parameters. These parameters are compression pressure and blow-by pressure. This is in accordance with the results of research from Deulgaonkar [7].

D. *Performance Test Result Analysis.*

D.1. Compression Pressure Test Result

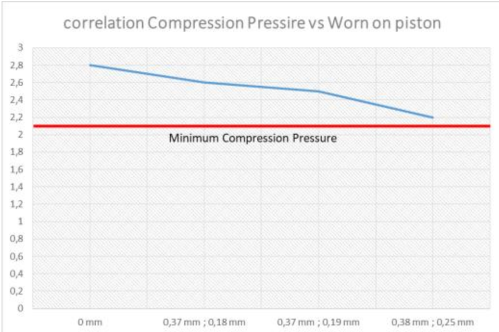


Fig. 6. Correlation compression pressure and variable worn on piston

The correlation between the value of compression pressure and pistons which has variables in the value of worn out in the area of ring groove 1 and ring groove 2 is that the higher the value of worn out in ring groove 1 and ring groove 2, the lower the value of its compression pressure. This is because the clearance between the piston ring and the groove is getting bigger which causes pressure leakage through the clearance gap. From Blow by pressure test result, the result is average 130 mmH20, std max 160 mmH20. The value of compression pressure is inversely proportional to the value of blow-by pressure, that is the higher the clearance value, the higher the blow-by pressure value will be, which leads to a higher chance of pressure leakage to the crankcase is greater.

E. Financial Analysis.

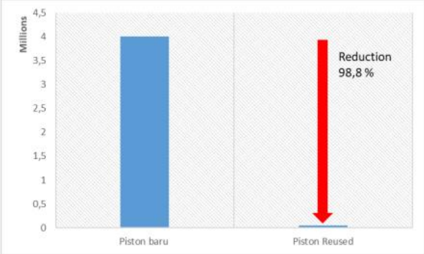


Fig. 7. Reduction cost of piston spare parts

This study uses 6 pistons that have been used for a minimum of 12,000 hours. Of the 6 pistons, after checking the remaining life assessment criteria, only 4 reused pistons can be used. This makes the replacement ratio from 100% to 33%. The reduction in the cost of piston spare parts to produce 1 engine component was 66%, whereas previously the total cost required to produce 1 engine component was 24 million rupiahs, it has now turned to 8,2 million rupiah. The impact of this reduction in spare part costs will have an effect on increasing the engine contribution margin for the 6D114 series from 7.8% to 12.6%.

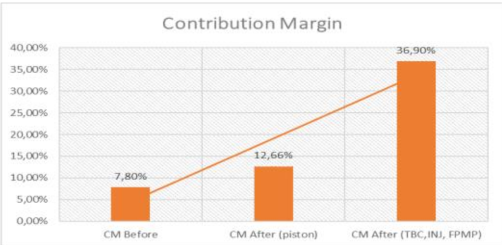


Fig. 8. *Contribution margin to result after development*

V. CONCLUSION & RECOMMENDATION

Based on the research that has been done, several things can be concluded, namely:

1 Reusable piston part criteria:

1.a. The result of structural analysis shows that the area of the piston that is most affected by the load is in the piston crown area, therefore the piston crown area becomes the checking portion for determining the reusability of a piston. If there is surface defect in the piston crown area, the piston cannot be reused. Surface defects such as pitting, pockmark, dent, etc.

1.b. The results of the fatigue lifetime analysis for the remaining life assessment process. The dimensions of worn out on the piston ring groove 1 and the piston ring groove 2 with variables 0 mm, 0.3 mm and 0.5 mm have the same results, namely 10,000,000,000 cycles or the conversion to years is equal to 11.7 years.

1.c. The Compression Pressure Test results from the three variable values of worn out on the piston ring groove 1 and piston ring groove 2 are still in accordance with the standard compression pressure range, which is min 2.1 MPa.

1.d. The blow-by pressure result from the reused piston installed on the engine component still fits within the existing standard range, which is 140 mmH2O while the standard is a maximum of 260 mmH2O.

2 The result from using reusable pistons is that it can reduce the cost of purchasing piston parts by 98.8%, where the price of new piston parts is 4 million rupiah, while the cost of the piston part reuse process is 45 thousand rupiah. The replacement ratio of piston parts has been decreased from 100% replaced to 33%. This resulted in an increase in the contribution margin from 7.8% to 12.6%.

Based on the research that has been done, there are several suggestions that can be given for further research, namely

1. The fatigue life test was carried out on the treated specimens to obtain an S-N curve so that the remaining life could be determined quantitatively.
2. To increase reusable ratio piston become 100%, refer to paper Aravindha, et al, 2020. Related to the repair process on piston crown that have surface defect.
3. Monitoring the seeding test until it reaches use of 1 year or 6000 hours in accordance with the warranty provided by the company to the customer. To increase validation of seeding test process.

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