How to Investigate and Analyze the Components of a Generator Engine and Machine Industry

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HOW TO INVESTIGATE AND ANALYZE THE COMPONENTS OF A GENERATOR ENGINE AND MACHINE INDUSTRY

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PERSEMBAHAN

بِسْمِ اللَّهِ الرَّحْمَٰنِ الرَّحِيمِ

Robbi zidnii 'ilmaa, warzuqnii fahmaa, waj'alnii minash-sholihiin

"Ya Tuhanku, tambahkanlah ilmu (pengetahuan) kepadaku, dan berilah aku karunia untuk dapat memahaminya, dan jadikanlah aku termasuk golongannya orang-orang yang saleh"

FOREWORD

Our foremost and utmost gratitude to God The Almighty, for His abundant grace that allowed us, Deepublish Publisher to publish this book entitled ***How to Investigate and Analyze the Components of a Generator Engine***. This book presents how to investigate and analyze the components of a generator engine and machine industry. Comprised of eight chapters, this book unveils the investigation and failure analysis of a diesel generator connecting rod; investigation of injection spring damage failure in diesel engines; investigation and damage analysis of fuel supply pump at Komatsu engine using fishbone analysis; damage analysis of the induced draft fan component; investigation and analysis of the electric generator diesel engine connecting rod; investigation and analysis of the quality of the water pump engine; identification of radiator cap damage to engine temperature of Toyota Kijang 5K; as well as investigation caterpillar pneumatic damage analysis to improve availability performance of type 150 extruder engines.

As a publisher that–above other missions–prioritizes its role to educate and glorify mankind, as well as to utilize science and technology to its best, we do not only attend to the work of established writers, but we provide the room and facility for people who wish to express their creativity and innovation in writing and conveying ideas and values.

Our warmest gratitude and appreciation to the authors who have given us trust and contribution to the perfection of this book. Hopefully, this book is useful, and educative, and contributes well in glorifying mankind and the utilization of science and technology in the country.

Deepublish Publisher

PREFACE

We give thanks to Allah *Subhanahu wa ta'ala* for all His blessings and gifts so that we can finish this book. May prayers and greetings always be poured out on the noble person who is an example for all of us, Nabi Muhammad saw.

This book presents how to investigate and analyze the components of a generator engine and machine industry. The discussion presented starts from the problems that occurred, a review of failures, the strategies used to the output of an investigation.

Thanks to the help and cooperation from all parties, we were able to complete a book with the title: How to investigate and analyze the components of a generator engine and machine industry.

May Allah Swt. give blessings to all of us, ease of heart and mind so that it is easy to understand part by part of this book. Hopefully this book can provide benefits to readers and provide enlightenment in the development of science.

Cileungsi, 6 April 2024

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FAILURES IN DIESEL GENERATOR CONNECTING ROD

Connecting rods are mechanical components that convert the piston alternative motion in the crankshaft rotational motion. They are subjected to a complex state of stresses which includes compression stresses associated to the pressure exerted by the combustion gases, and tensile stresses related to the inertia of the components in motion, either alternative or rotational [1], [2]. Failures in con-rods have been reported in the literature, being associated to fatigue, overload bending, bearing failure, improperly adjusted bolts, spalling, and assembly deficiencies

A. Fuel Leak in Diesel Engine

The use of generators in power plants, whether private or state, must meet work safety requirements. Some contaminants such as diesel, oil or other substances must be cleaned in the generator area. Some of these substances can cause pollution that affects engine performance. Fuel leaks in the fuel lines affect the fuel supply and can cause engine fires. Damage to the fuel pipe is often caused by problems with the fuel line leading to the injection system. Several methods have been introduced to predict and locate the source of damage through diagnosis using tools or water.

Several studies show that joints in fuel pipes experience fatigue which results in fires [1]. There is a lot of damage to the heat exchanger tube, namely cracking. This damage is caused by vibration

[2]. Failure in the fuel injection pipe is caused by vibrations which have an impact on operations due to the large amplitude of the vibrations [3]. Fuel pressure has an important influence on mode frequency. The maximum Stress Tensor and Vibration Velocity appear at the frequency position of the first order mode [4]. Common rail pipes used in diesel engines experience damage caused by design angles, curvature and outer diameter [5].

The diesel engine used by PT. X suffered damage to the cylinder fuel channel number 10. After the examination was held, a fuel leak was found. From the data it was found that the fuel line was damaged after 8,922 hours of operation.

Based on the conditions above, several actions are required, namely analysis of fuel line components, microstructure testing, chemical composition testing, as well as EDX and EDS testing. Action is required to find the root cause of damage to the fuel line tube.

B. Failure Mechanisms

The fuel injection pressure has a maximum pressure, with engine vibration during operation will affect the performance of the fuel line. In high-pressure fuel pipes in diesel engines, it is prone to failure [1].

To prevent diesel engine operational failure due to fuel system failure, proper maintenance is required, especially on the components in the fuel system [2].

Damage characteristics depend on fuel properties, injector geometry and, flow conditions upstream and downstream of the injection nozzle. An understanding of the damage behavior within the fuel nozzle is necessary. Numerous efforts have been made to understand this phenomenon and its effects on injector nozzles[3].

The inner diameter of the high-pressure fuel pipe has a significant effect on the fuel injection process and diesel engine performance. The spray impact force per nozzle hole of the pump passage nozzle of a conventional injection system for a diesel engine (based on the spray momentum flux) and the injection pressure (on a fuel injection pump test kit) are measured. By varying the fuel injection amount and pump speed, the influence of the inner diameter of the high pressure fuel pipe on the fuel injection process and the fuel injection characteristics for each nozzle are analyzed [4].

This paper presents the results of an analysis of the failure of a high-pressure diesel engine fuel injection channel which caused a fire in a public transportation bus. The fuel injection lines had been in service for 18 months, and two of them were cracked at the point where they connected to the engine injectors. This damage caused a fuel leak and ultimately a fire broke out in the bus which spread to the passenger cabin and caused quite serious damage. Failure mechanisms were analyzed by visual and SEM inspection of the fracture surface, identifying fatigue as the primary cause of ultimate failure. Microstructural analysis, microhardness measurements along with chemical analysis are carried out to check for possible deviations in the structure and/or composition of the material. The results show that fatigue failure occurs due to decarburization of the outer surface of the high-pressure channel [5].

C. Identification Strategies for Diesel Engine Problem

The initial action is to identify the problem of damage to the fuel tube line which results in the diesel engine not being able to operate [6]. Primary and supporting data collection is carried out through field inspections, visual inspections and operational data collection

Next, an investigation and identification of the problem is carried out. A visual inspection is carried out with direct inspection of damaged materials. It is necessary to carry out a visual inspection before carrying out more detailed tests. This inspection is carried out to detect material surface defects and to determine conditions related to damage that occurs in the diesel engine system.

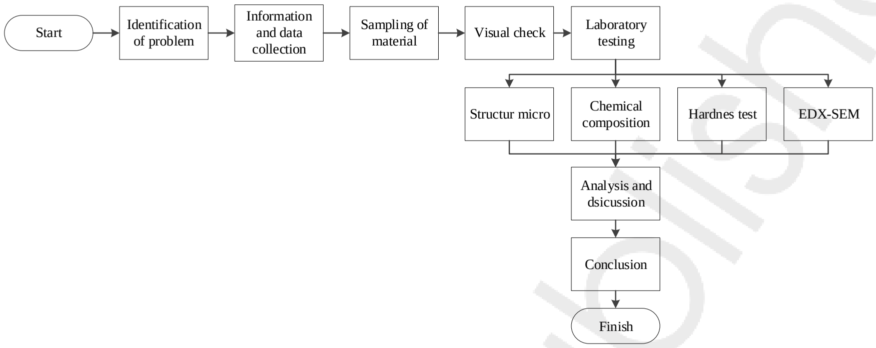


Figure 1 Identification scheme on diesel engine tube fuel line components

Figure 1 shows the flow of examination carried out on diesel engine tube fuel line components.

Material sampling test is carried out on damaged fuel lines.

Collection of supporting data is carried out through field inspections and retrieval of operational site Trouble Report (STR) data. The next stage is to collect the data needed to support problem solving based on the examination focus. The required data was obtained using two methods, namely direct observation and interviews with operators and with the operator's leadership regarding unit damage history.

Performing visual inspection investigations carried out by carrying out general and direct inspection of damaged materials.

Visual inspection by directly inspecting the fuel tube material. This visual observation is important before carrying out more detailed tests. To detect any defects on the surface of "TSFL". This visual observation is important to determine the next inspection steps regarding the pattern of damage that occurs.

Material testing, such as chemical composition testing, metallographic image hardness testing, macro structure observation, fractography, and SEM EDX testing were carried out to support this examination.

Hardness testing is intended to determine the material used in the fuel line tube against plastic deformation, is used to provide an indication of the value of tensile strength (tensile strength), wear and abrasive resistance of the material, to detect the resistance of the fuel line tube material to penetration on the surface, as well as checking for any degradation of its mechanical strength. The results of this hardness test will be compared with the literature data whether it is in accordance with the specifications or not. Some things to note in the hardness test are:

- The surface of the test sample must be in accordance with the characteristics of the material, not subject to carburizing, case hardening, and other similar processes.
- The diameter of the trace can be seen and calculated using magnification through an optical microscope.

In testing the hardness of the spring tube fuel line, the test used is the Vickers method at BPPT B2TKS/LIPI-Puspitek Serpong, Tangerang-Banten

Chemical composition test aims to determine the material of the fuel line tube so that a comparison can be made between the design material and the actual material composition of the fuel line tube. The tool used to check the chemical composition is the Optical Emission Spectrometer, which was carried out at STP-Puspitek Serpong.

The chemical testing steps are carried out as follows:

- Cutting of the test object.
- Perform grinding or sanding on the test object.

Putting the test sample on the test site and then firing argon gas to 99.99% on the surface, and further testing

Material Corrosion Rate Testing (SEM-EDX) used in this examination is explained below:

i. SEM testing aims to identify the source of the cause and the beginning of crack propagation from components that experience temper color, surface oxidation, corrosion products, and certain texture forms. Tests can be performed using an optical microscope or Scanning Electron Microscopy (SEM) on the fuel line tube.

ii. The SEM test was also followed by the EDX test using the EDX machine at LIPI/STP-Serpong. Products that are damaged are taken by dredging the product on the internal part of the fuel line tube. This retrieval must be careful because if it is contaminated with other substances it will affect the test results. The EDX machine will shoot X-rays at the sample, then some of the light will be reflected by the sample and some will be absorbed or penetrated into the sample. With the difference in the amount of light reflected or absorbed, the composition of the constituent elements of the sample can be known

iii. To analyze the chemical elements of the fuel line tube specimen using an energy dispersive X-ray Spectroscopy (EDS or EDX) tool. This characterization relies on the study of the interaction of multiple X-ray excitations with the specimen. To stimulate the emission of characteristic X-rays from a specimen, a high-energy beam of charged particles such as electrons or protons, or an X-ray beam, is focused onto the specimen to be studied. The amount and energy of the X-rays emitted from the specimen can be measured by means of an energy-dispersive spectrometer. The energy of the resulting X-rays is characteristic of the energy difference between the two shells, as well as a structural characteristic of the 40 atoms of the emitted element, allowing the elemental composition of the specimen to be measured. This EDX test was carried out to determine the composition contained on the surface of the plate.

This observation aims to determine what phases are present in the material. **Microstructure testing** was carried out with a stereomicroscope (Hatta, 2012). The magnification used is 100X and 500X. Microstructure observations were carried out by giving a 2% nital etching agent to the sample so that the phases formed could be identified. Before conducting metallographic observations, to obtain photos of the microstructure there are several stages that must be passed, namely the sanding, polishing, and etching stages. The testing procedure for these three stages is as follows:

i. After getting the sample pieces, the mounting process is carried out to facilitate the process. The resin and hardener are stirred slowly until evenly distributed and then poured on the sample in a cylindrical container, waiting for it to harden.
ii. Prepare tools and materials needed for the sanding process (sandpaper, bottles, water, and sanding machine). The sandpaper used has a grit value of 100, 200, 400, 600, 800, 100, 1200, and 1500.
iii. Sanding gradually, starting from the lowest grit sandpaper (100) to the highest grit (1500). Every time the sanding process is carried out, water is always flowing so that the gram transfer runs smoothly and does not damage the sandpaper.
iv. Each time the sandpaper is replaced, the test sample is rotated 900 so that the direction of the new stroke is perpendicular to the direction of the old stroke.
v. After the sanding process is felt to be quite good (marked by a flat, uneven and smooth surface) then the sample is then polished using a polishing machine with a velvet cloth base with alumina as the abrasive particle used.
vi. This polishing process is stopped when the surface of the material is sufficiently smooth and shiny. Then the final stage of work is done, namely etching. Nital 2% was used as an etching agent, wherein the sample was then immersed in this etching agent for 5 seconds. The samples were then rinsed with alcohol and water and then dried in a dryer.
vii. After the etching process is complete, microstructure observations can be carried out.

Analysis of data and findings in the field was carried out with the aim of getting an idea of whether the conditions that occurred were in accordance with initial assumptions. The analysis was carried out using the fishbone analysis method to obtain an initial conclusion as to whether there was wear on the fuel line tube. The conclusions from the initial analysis will be followed up by carrying out a technical analysis of the main causes of suspected damage to the fuel line tube. The final analysis was carried out on the economic aspects of the planned improvements to the generating unit to reduce disruptions and loss of electricity production [6].

Analysis of corrective action plans are carried out after the main cause of disruption to the generating unit is known. In this process, an analysis will be carried out regarding the actions that need to be taken to overcome long-term problems, different from before, namely by carrying out corrective maintenance after damage occurs to one of the components without repairing the main cause. This process is carried out after determining the main cause of the disturbance in the generating unit. Failure is damage to machine components [8]. There are several factors that contribute to engine failure. Examples include poor design, contaminated fuel, unskilled labor, lack of proper maintenance, long working hours, poor fuel quality, poor fuel management techniques, lack of vigilance, and modification of spare parts. All of the above is made for failed machines. To avoid these things, it is necessary to explain to the personnel responsible in the engine room so that they can use and apply correct maintenance. Because maintenance minimizes the possibility of failure [9].

D. Exploring the Problem of Damage to the Diesel Engine

The visual inspection and fault tree analysis, based on the fuel test results, all test parameters are within specification. These test results indicate this fuel is suitable for further use [3].

Table 1 Discoloration in the shank area of the connecting rod #10

TEST	RESULT	SPECIFICATION		UNIT	ASTM METHOD
		Min	Max		
API Gravity @ 60 °F	39	31	42	N/A	D-1298
Density @ 15 ºC	830	815	870	Kg/m^3	D-1298
Ash Content	0.003		0.01	% Wt	D-482
Kinematic Viscosity @ 40 ºC	3.27	2.0	5.0	mm^2/s	D-445
Sulphur Content	0.181	-	0.35	% Wt	D-5185
Conradson Carbon Residue	0.030	-	0.10	% Wt	D-189
Water Content	197	-	< 500	ppm	D-1744
Flash Point P.M.cc ºC	64	60	-	°C	D-93
Fuel Cleanliness**	18/16/13	-	18/16/13	N/A	ISO 4406

The color change in the connecting rod occurs in the calf, as seen in Figure 2. In the middle of the calf, the color appears darker than other parts. It is suspected that there was a compression leak and lubrication failure in the cylinder which was observed resulting in discoloration of the connecting rod.

To obtain more detailed results regarding the causes of discoloration of the connecting rod in the shank area, a fault tree analysis (FTA) was carried out as presented in Figure 2. There are four blocks representing compression leaks, lubrication system failure, incomplete combustion system, and twisting of the each connecting rod. Compression leaks - Wear on the liner walls causes compression leaks, where the liner walls are shiny. Apart from that, the piston ring is stuck because there is carbon in the piston ring gap so it cannot expand. Lubrication system failure - Failure of the lubrication system on the oil cooling jet, where the oil cooling jet cannot lubricate the bottom of the piston, so that the oil cannot absorb heat and causes heat to propagate to the connecting rod. Incomplete combustion system - The injector is damaged/drops due to fuel quality, where the combustion ratio is incomplete between air and fuel or the air filter is clogged caused by air quality contaminated with dust or humid air [16]. Twisting of the connecting rod - The cooling system in a diesel engine has quite a big influence on engine operations, where the cooling system functions to absorb heat generated from the combustion process, as well as friction between metal and metal, if the cooling system is hot, the performance of engine components will decrease [17], [18].

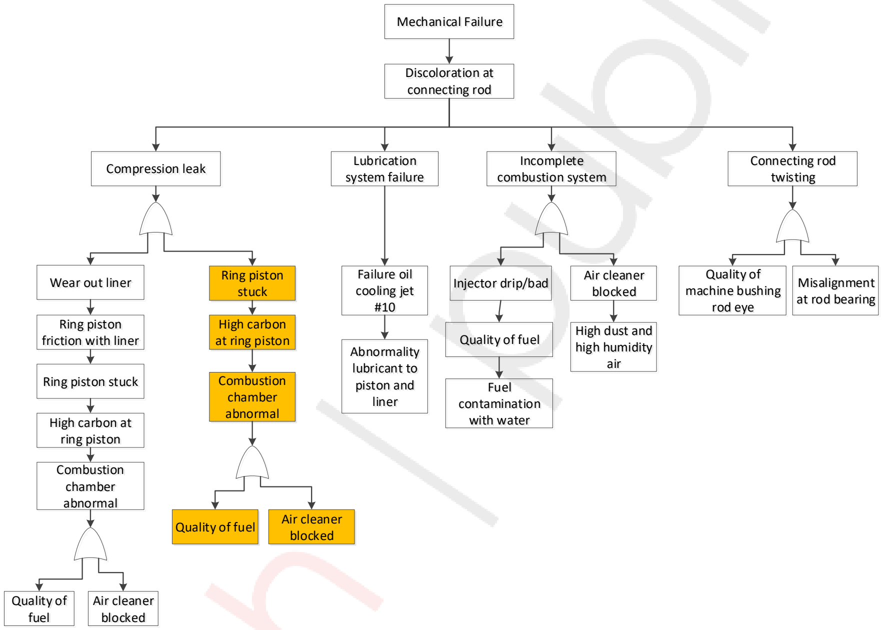


Figure 2. FTA on the connecting rod diesel engine 3516 B

SEM analysis was carried out on a surface that had discoloration. SEM tests were intended to determine the cause of discoloration on the connecting rod surface [7], [8], [9]. The surface shows the formation of an iron-oxide structure, namely the formation of morphology following the results of the SEM test are presented in Figure 3.

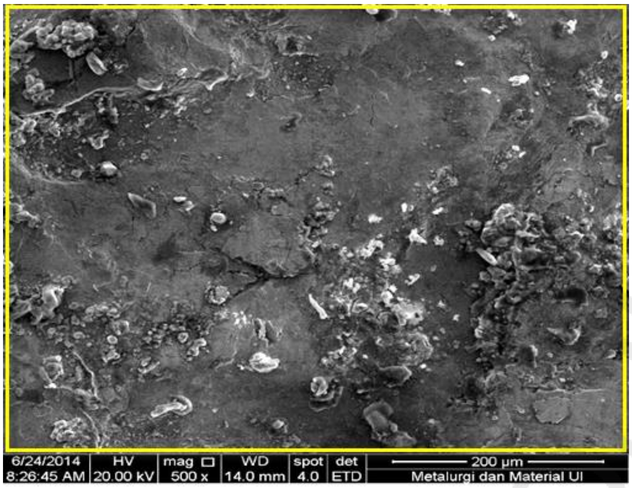
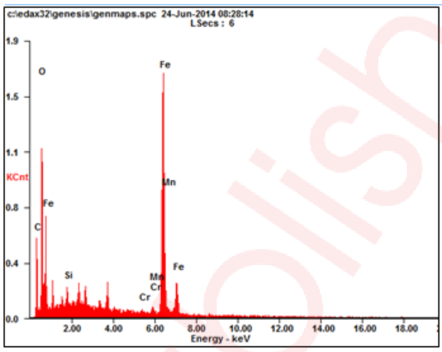


Figure 3. SEM material discoloration with a magnification of 500x

EDX analysis in **Figure 4** which shows the high levels of iron (Fe) and oxygen (O) confirms that the formation of iron-oxide on the metal surface is due to the influence of heat



Element	*Wt%*	*At%*
CK	22.68	42.41
OK	25.86	36.31
SiK	01.43	01.14
CrK	00.43	00.18
MnK	01.05	00.43
FeK	48.55	19.53
Matrix	Correction	ZAF

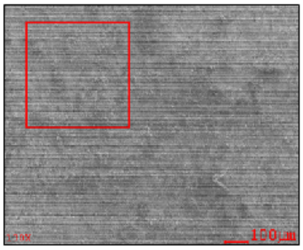


Figure 4. EDX examination of discolored connecting rod material in the shank

Based on the service guide of the diesel engine, the material for making connecting rods is included in the type of alloy steel. Alloy steel is an alloy steel that has ductile properties and high tensile strength. This steel is composed of 0.05–0.25% carbon using micro alloys V, Ti, Nb, or Mo (0.01–0.1%). From the **chemical composition test**, it was concluded that the connecting rod material is H15220 AISI 1522H alloy steel, as described in Table 2. Based on the chemical elements from the test results there is no relationship with color changes on the connecting rod.

Table 2. Chemical composition of connecting rod

No	Element	Value of Elemental Content (% by weight)	Grade Limit H15220 AISI 1522H
1	Fe	98.003	
2	C	0.238	0.170-0.250
3	Si	0.188	0.150-0.350
4	Mn	1.249	
5	Cr	0.162	
6	Ni	0.017	
7	Mo	0.15	
8	Cu	0.011	
9	Al	0.034	
10	V	<0.002	
11	W	<0.002	
12	Ti	0.029	
13	Nb	<0.002	
14	S	0.036	
15	P	0.010	
16	Co	<0.002	

The microstructure analysis of the connecting rod, compare the area that has changed color with the area that is still normal [10]. This microstructure test is to determine whether there are elements of material defects from the connecting rod. From the change in color and type of heat transfer that occurs and as a reference the connecting rod is feasible to operate again or not[11]. Based on Figure 4 and Figure 5, the structure is composed of tempered martensite which both have sulfide impurities. From the three microstructure tests in sample 1, namely the discolored cross-section of the connecting rod, it is seen that there is no difference between the three and they are still in normal condition. Based on Figure 5 and Figure 6, the structure is composed of tempered martensite which both have sulfide impurities [8]. The impurity sulfide does not affect the color change of the connecting rod. Then the impurity sulfide has no relationship with the occurrence of color changes.

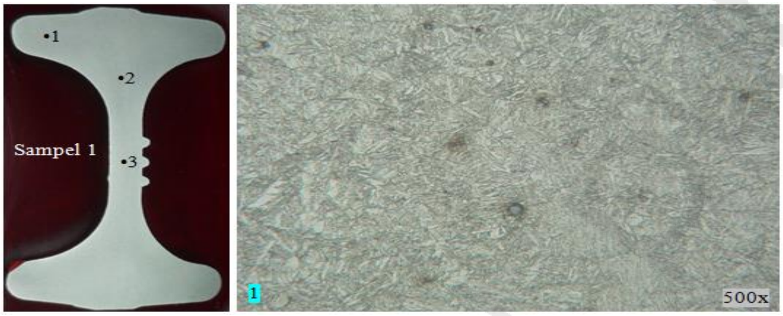


Figure 5. Microstructure of location 1

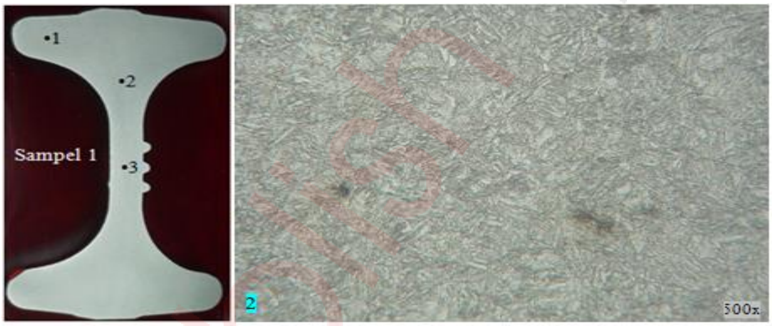


Figure 6. Microstructure of location 2

Based on Figure 6, it can be seen that the microstructure is the same as that of sample 1, namely the microstructure in the form of tempered martensite with sulfide impurities and the metal is still in normal condition.

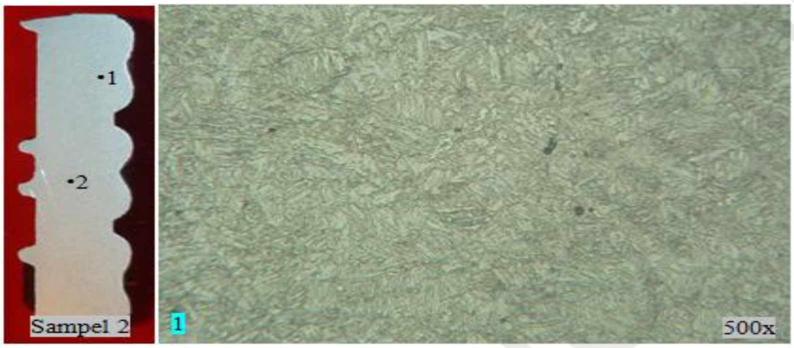


Figure 7. Microstructure of location 1

Based on Figure 7, the microstructure of sample 1, the results of the microstructural analysis can be obtained information, namely: a) the temperature increase that occurs in the #10-cylinder liner on the engine does not change the microstructure of the connecting rod material. After conducting a microstructure test, the temperature was 200°C, this condition was not able to change the hardness, strength and structure of the connecting rod. Based on the ASM Handbook [23] that alloy steel will experience temper embrittlement or temper brittleness at temperatures between 300-600°C where the steel will experience an increase in hardness and a decrease in ductility. b) the type of heat transfer that occurs which causes color changes in the connecting rod due to radiation.

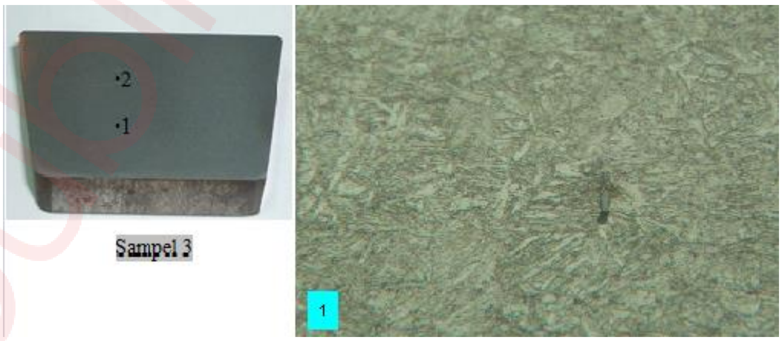


Figure 8. Location 1

Scanning Electron Microscopy (SEM) analysis shows that the connecting rod material changes color due to increased heat, namely the formation of iron oxide such as lepidocrocite (γ-FeOOH) morphology. This occurs from the level of heat received by the connecting rod, which is around 200°C. The color change that occurs in the connecting rod predominantly occurs by radiation, namely heat transfer from the liner wall to the connecting rod due to exhaust gas leaks into the engine crankcase. Where there has been damage to the piston ring on cylinder #10 which causes the piston ring to overlap and cannot expand, resulting in a compression leak in the combustion chamber. The impact of exhaust gas compression leaks will flow to the engine crankcase. The movement of the connecting rod which cannot go up and down with the working stroke causes the connecting rod to experience tensile and compressive forces. The follow-up to this examination is to carry out testing using CATIA software.

INJECTION SPRING FAILURE IN DIESEL ENGINES

The injector functions for the process of ignition of the fuel, and in the process of fogging the performance of the injector using Mechanical springs are used in the machine to provide flexibility, save or absorb energy. In general, it is classified as a spring wire, a flat spring or a special shape and there are other variances. Round or square wire round helical wire or spring and made to resist tensile, compressive or torsional loads.

A. Understanding Injector Component

The PLTD generating unit in Lombok is a power plant that is operated to meet electricity needs in the Lombok area. The capacity of the generating unit is 1 x 1200 kW which is in operation the baseload, for a total of 8 units and a contract power of 7,000 kW or 7 MW. The diesel engine (Gen-Set) uses diesel fuel supplied from PLN. Fuel consumption is controlled by PLN. How many liters of fuel is supplied and how many kWh must be taken into account. If there is a difference between the fuel supplied and the use, there will be a fuel penalty base on Specific Fuel Consumption (SFC) [12].

The electronic unit injection system is described in Figure 9, where parts of the system are 1) daily tank, 2) Strainer, 3) Primary filter, 4) fuel transfer pump, 5) Secondary filter, 6) Tubes Supply, 7) Injector, 8) Tubes return, 9) Fuel Cooler. Figure 9, shows the position of the damaged injector components in the diesel engine, because the price of the injector is expensive and in this case, it is of concern to researchers.

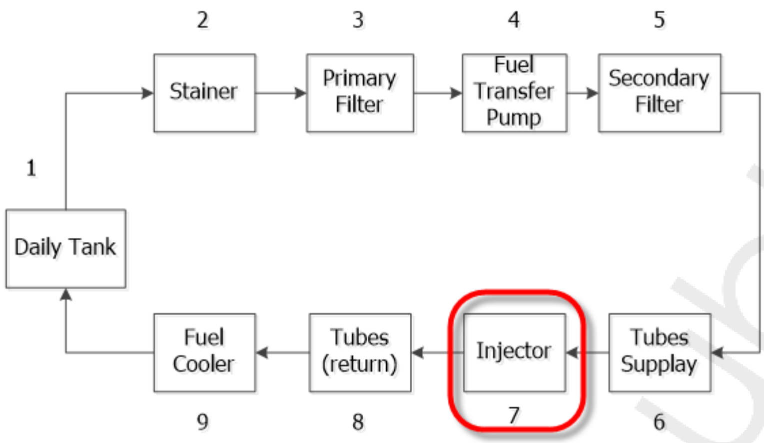


Figure 9. Fuel supply system.

In maintenance, the failures of diesel engine components are found so many. To find out the failure analysis of a component, further analysis must be carried out in order to reduce repair costs [13]. In the 30 minutes before the exhaust manifold was damaged or smoldering (glowing) and then an emergency trip (normal stop) was carried out by the operator. At the moment the injector spiral spring [14] broken, fuel pressure in the injector drops slowly, and the duration of spraying fuel will be longer, because the pressure inside the injector drops slowly, resulting in over-fueling and glowing [15]. Before the diesel engine malfunction occurred, the water jacket temperature, oil pressure, oil temperature, exhaust gas temperature occurred [16], described in **Figure 10** under normal conditions there is no significant increase when the damage occurs.

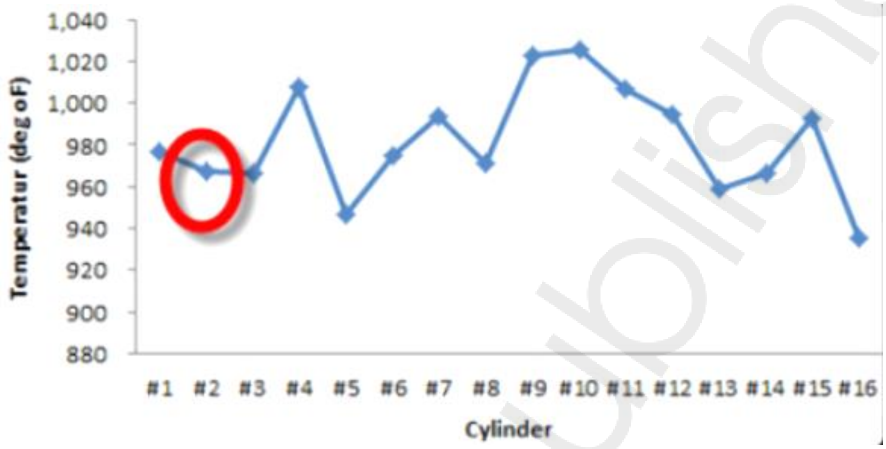


Figure 10. Trending exhaust temperature.

Figure 11 shows the generator set parameters from June to September. These parameters include load conditions (kW), oil pressure (oil pressure), temperature J/W normal conditions.

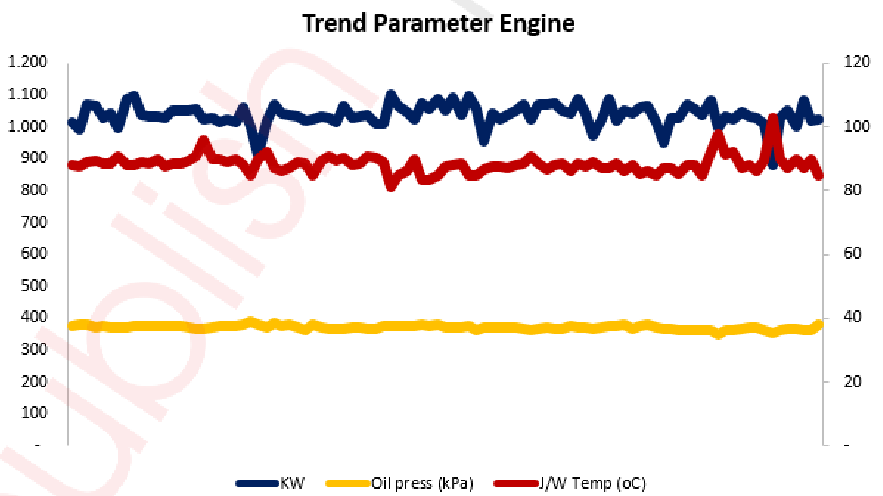


Figure 11. Trending kW, Oil Pressure, J / W Temperature

Injector repair requires fast time for the unit to operate immediately and is not subject to akWH penalty. Usually, repairs take a long time because the stock of parts is not available at the location or the dealer. Figure 12 shows the downtime of the unit failure and preventive maintenance of the generator set making the test sample. From the figure, it can be seen that the damage to the injector causes the longest downtime. This is due to the availability of spare parts.

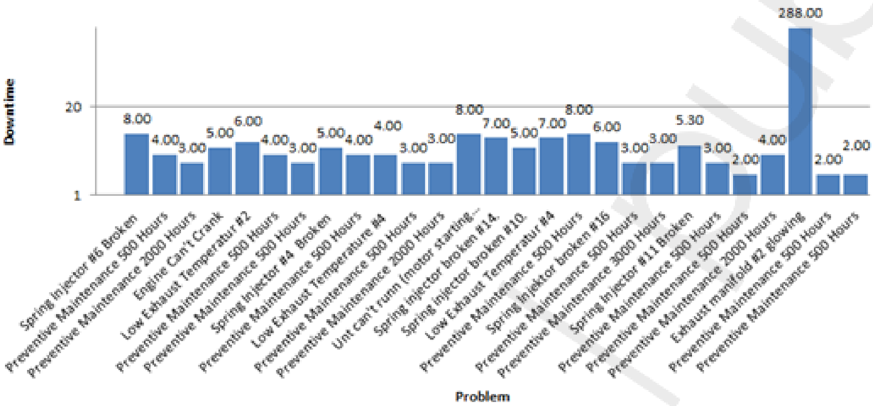


Figure 12. Downtime preventive maintenance and breakdown maintenance

Based on historical observations of data after Pareto downtime, it is clear that the damage to the injector components is quite high compared to the damage to other components, the damage to the injectors accounts for up to 80% of the damage.

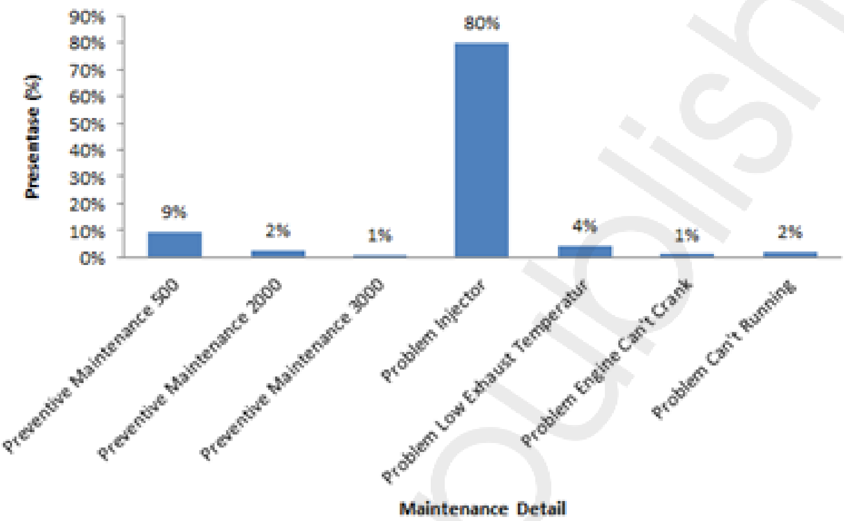


Figure 13. Graph of total injector failure downtime

Costs incurred due to injector failure +/- Rp. 20,000,000, and a penalty kWH Rp. 6,000,000. The total cost of the injector is Rp. 26,000,000 / event includes (Labor, Parts, Misc, Penalty kWH). Each overhaul (TOH, STOH, GOH) is replaced by an injector, according to the replacement interval (9000, 18000, 27000).

Based on the history of replacing injectors during overhaul, last high school STOH: 49174, last high school GOH: 58799. At the time of the first failure the injectors had a lifespan of 6189 hours. The second failure was 3864 hours. The injector spring is damaged and cannot be reused. Damage to the injector spring affects the combustion system while the unit is operating. Premature helical coil spring failure is caused by the diameter of the wire and the number of turns of the coil spring [5]. The purpose of this study was to analyze the causes of failure of the injector springs related to the quality of the material and its maintenance system.

B. Qualitative Strategy in Identifying Injector Spring

Examination on injector springs was carried out using qualitative methodology. Some of the actions taken are 1) Carrying out field observations of damage to injector components, 2) Carrying out visual inspections of damaged injector springs, during operation, 3) Taking test samples on the injector springs, 4) Fractography laboratory examination of test samples to determine damage to the broken injector spring, 5) Metallographic examination of the test sample to determine the microstructure of the injector spring, 6) Examination of the hardness test of the test sample on the quality of the material, 7) Checking the chemical composition of the quality of the material, 8) SEM EDX examination of the corrosion rate of the injector spring material, 9) Checking maintenance data, 10) Results and discussion of data obtained in carrying out laboratory tests and unit maintenance data, to determine the root cause of injector spring damage.

As for the flow chart in analyzing the injector spring, which is described in **Figure 14**.

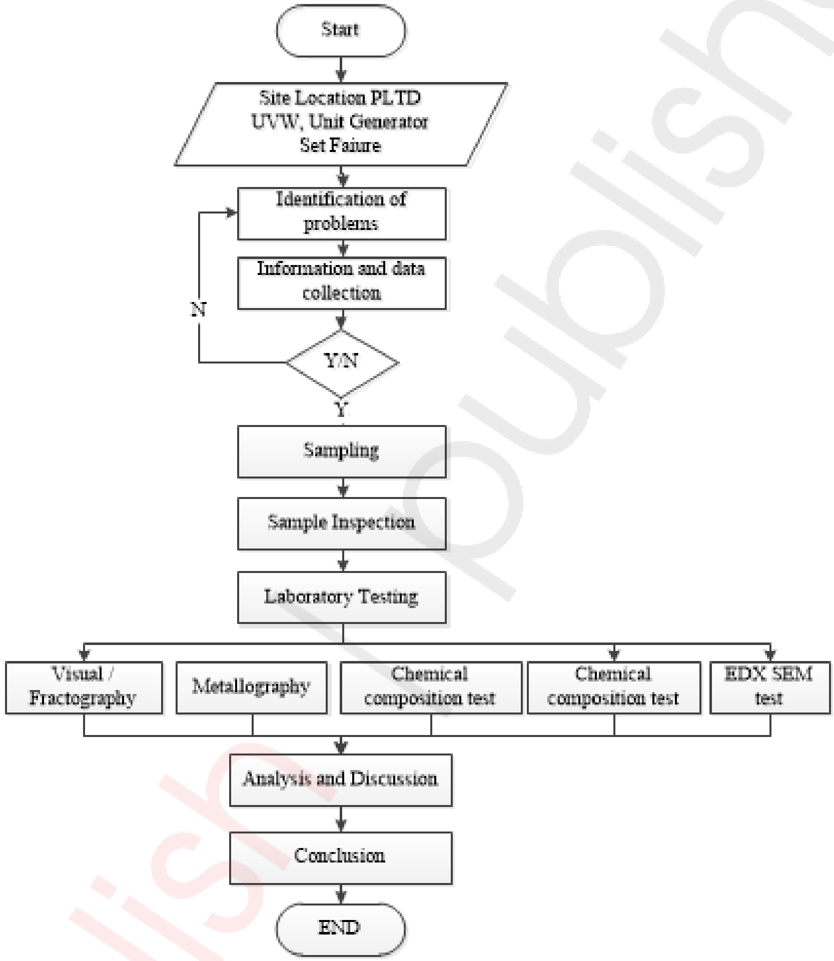


Figure 14. Examination scheme of injector spring

C. The Root Cause of Injector Spring Damage

In the examination on injector spring damage, several tests were carried out, so that the results could determine the root cause of the damage.

The visual inspection of the spiral spring injector, A wire diameter Ø 7.0 mm and Ø 48 mm spring circumference suffered a fracture in the first circle [17].

Figure 15. Photo macro injector

The macro photo in **Figure 16** shows the injector springs. The center point of the fracture is a load-bearing area and is the center of high stress concentration. It can be seen from the circumference of the fracture that there are crush defects between springs and spring defects. Spiral loop spring 3 is the initial fault that occurred first.

Figure 16. Broken shape of the injector spring

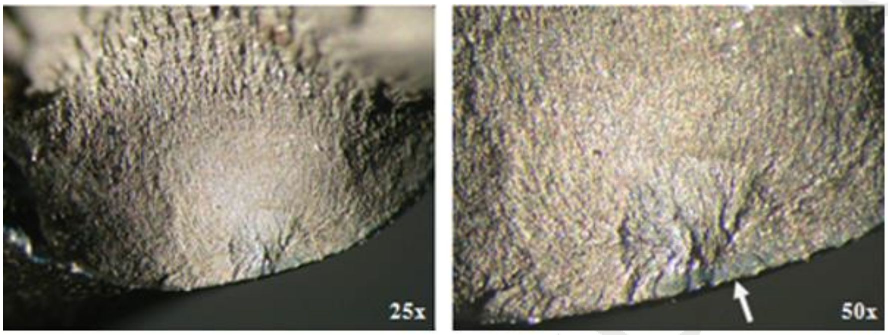


Figure 17. Benchmark of injector spring fault

Metallographic testing 1 microstructure in the form of ferrite and there are inclusions or sulfides (long black spots)[18] and Metallographic samples of the cut lengthwise or splitting the initial fracture area and the location of the microstructure location in the image.

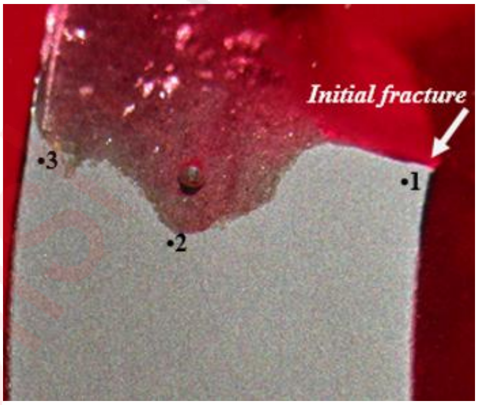


Figure 18. Position of Microstructure

Figure 19 shows the microstructure of the spring test sample 1 in the form of tampered martensite. Tampered Martensite occurs when the metal is heated to below a critical temperature after the hardening process. The crushing process will affect the steel mechanics on tensile strength.

Figure 19. Microstructure of tampered martensite

Figure 20, with 500x magnification, contains secondary cracks due to dynamic load. Secondary crack is caused when a break occurs and is not the cause of the damage. At 500x magnification, inclusions were found on the subsurface [19].

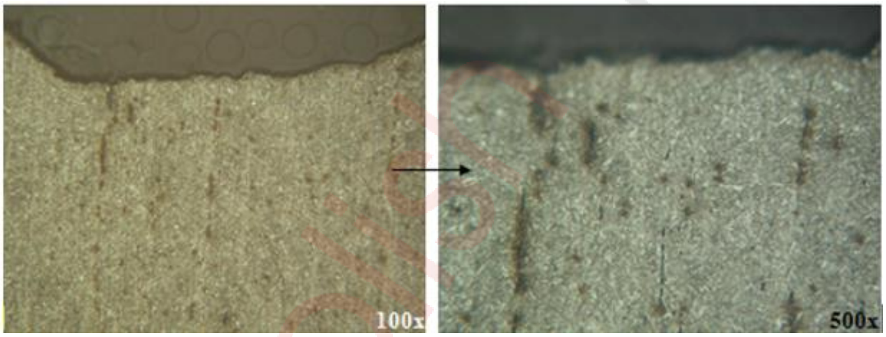


Figure 20. Magnification of 100x and 500x

Figure 17 describes the benchmark that occurs in spiral springs showing the benchmark from point A-C. In a reference from "Daniel P. Dennis, Ph.D., PE, How to Organize And Run a Failure Investigation, ASM International Material Park, Ohio 44073-0002, www.asminternational.org", that the indication of the benchmark is a form of a fatigue fracture in injector spring [20].

The chemical composition testing shows that the spiral spring 1 contains low alloy steel where the C values of 0.609 and Fe 98.8 are described in Table 3 and the composition is homogeneous and there is no correlation with the damage to the spiral spring. As for low carbon steel, chemical composition C: 0.05-0.35%, Mn: 0.25-0.90%, medium carbon steel chemical composition C: 0.36-0.65%, Mn: 0.70-0.90%, high carbon steel carbon values above 0.65-1.6% , Mn 0.65-0.90% is brittle, toughness decreases, hardness and strength value increases [21].

Table 3. Chemical Composition of spiral spring.

No	Element	Result (wt %) Pegas Spiral 1
	Fe	98.8
	C	0.609
	Si	2.15
	Mn	0.753
	Cr	1.03
	Ni	0.257
	Mo	0.0181
	Cu	0.0060
	Al	0.0010
	V	0.0932
	Ti	0.0018
	S	0.0047
	P	0.0077
	Co	0.0015
	Nb	0.0447
	W	0.0400
	Pb	0,0222

The material hardness test is carried out at one point, in order to get maximum results. From the results of this hardness test, it was obtained an average value of 576 HV, and based on this analysis, the correlation of the injector pheasant fracture was irrelevant with the hardness test.

The spiral spring test uses 2 samples and 3 (three) points to determine the comparison of each sample point and compare the material hardness from the values obtained from the material hardness test and in **Table 4** with the average value for sample A: 592, sample B: 595, sample C: 576 homogeneous conditions. As for the material hardness test, there is no relationship with the damage to the spiral injector spring.

Table 4. The hardness of spiral spring material

No	VALUE HARDNESS TESTING, HV
	Sample
1	612
2	593
3	585
4	592
5	593
6	
	Average : 595

SEM (Scanning Electron Microscopy) and EDX (energy-dispersive X-ray Spectroscopy) testing were carried out to analyze the fracture surface formed both on the surface of the fracture and on the surface on the outside of the spring. This SEM EDX analysis is intended to determine the elements contained in the injector spring, then it can be used to identify the type of material that is formed on the surface of the injector spring which is broken and, on the outside, the elements contained consist of iron (Fe), oxygen (O), carbon (C), silicon (Si), and sulfur (S). At the carbon content (C), the value of area 1: 13.73, area 2: 18.06, area 3: 15.52 is the impact on the equipment used, which should have a low carbon value below the value of 5.

The results of SEM EDX in the test area of each point are to determine the material content of the corrosion elements in the spiral spring material.

Table 5. Elements of the first area 1 spring with SEM EDX

Element	Elemental Content (mass%)		
	Area 1	Area 2	Area 3
C	13,73	18,06	15,52
O	11,75	20,16	10,47
Si	1,8	1,87	1,81
Cr	0,84	0,84	0,86
Fe	71,88	58,97	71,33

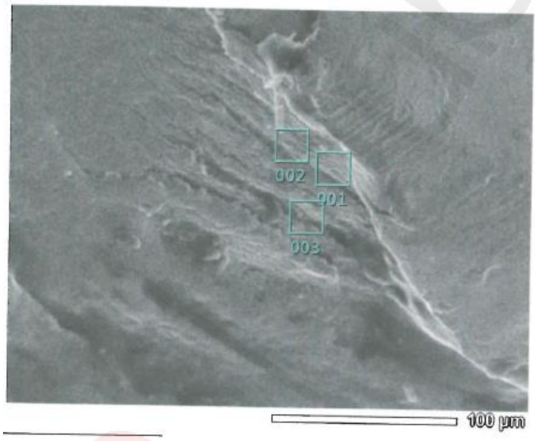


Figure 21. SEM EDX position [22]

If the injector springs are disconnected, the generator unit does not operate. Incidents of such damage often occur.

The analysis of the injector spring material is explained below:

From visual inspection on the spiral spring, fracture occurs in the third circle from the bottom and thinning on the surface of the spring. The metallographic results indicate benchmarking of the fracture shape, which indicates fatigue fracture. The shape of the initial fracture of the injector fracture. Secondary crack on the fracture surface as a result (impact). The test results of the chemical composition of the content of Fe 98.8, Cr 1.03, C 0.609, that the low alloy steel spiral spring material contains high C. The elasticity of the spring is quite high. The result of material hardness testing for spiral spring 1 has an average value of point A: 592, point B: 595, point C:

576, while spiral spring 2 has the average value of point A: 576, point B: 586, point C: 561.

The maintenance analysis of the injector spring material is presented as follow:

Change of engine oil, oil filter, fuel filter, is done every 500 hours, while the air filter is changed every 1500 hours. Injector replacement is carried out every 9000-hour intervals. Any breakdown connected to the injector is immediately replaced by using forecasting parts.

From the discussion of damage to the injector spring, it is known that the spring broke due to the entry of spring material, thereby affecting the internal tension of the spring. In Figure 16, the initial fault of spring 3 from the bottom is the initial fault. From the metallography results, it can be seen that there is a fatigue fault, which is a benchmark for the initial fault that the fault that occurred was a fatigue fault. Metallography results show the presence of fatigue fractures. There is a large amount of sulfide throughout the injector spring material, this is an element that results in reduced mechanical elasticity. SEM EDX testing shows no correlation between injector spring damage.

THE DAMAGE OF FUEL SUPPLY PUMP AT KOMATSU ENGINE

A. Komatsu Fuel System

The Komatsu fuel system is designed to supply the Komatsu engine with fuel, as well as its storage and cleaning.

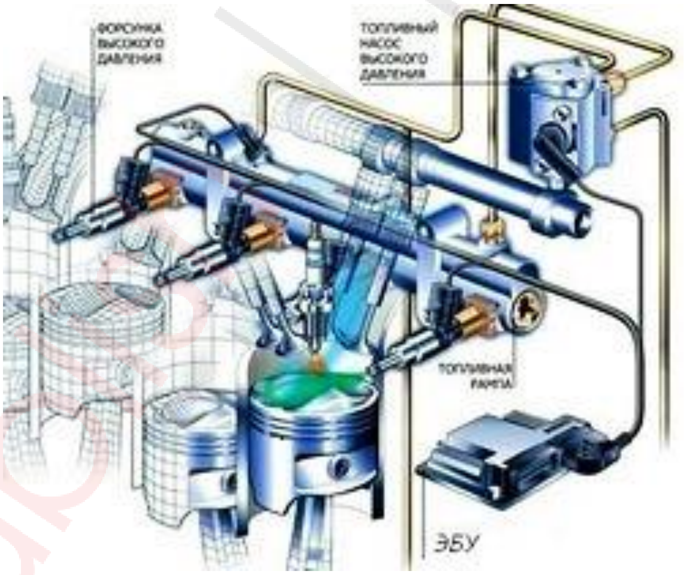


Figure 22. Komatsu fuel system

The structure of the Komatsu fuel system includes a fuel tank, a fuel pump, a fuel filter, an injection system that are connected in series by fuel lines.

The high-pressure fuel pump Komatsu (Komatsu HP pump) is one of the main components of the diesel injection system. Komatsu Pump, performs, as a rule, two main functions: injection under pressure of a certain amount of fuel; regulation of the required timing of the injection. With the advent of battery-operated injection systems, the injection timing control function is assigned to electronically controlled injectors.

The incoming fuel is cleaned in a Komatsu fuel filter. The fuel filter of the fuel system of diesel engines has a pressure reducing valve that regulates the working pressure in the system. Excess fuel is diverted from the valve through the fuel drain line. With a certain periodicity, the fuel filter assembly or, just, the Komatsu filter element is replaced.

The Komatsu high purity fuel filter is the most vulnerable place in the fuel system, because it is its capacity that is broken due to low temperature. To warm up the Komatsu fine filter, heaters of a shroud (overhead) type are used. The Komatsu injection system is designed to form a fuel-air mixture by fuel injection.

The fuel system works as follows. When the ignition is switched on, the fuel pump pumps the fuel into the system. When passing through the fuel filter, it is cleaned. Then the fuel enters the injection system, where the spraying and the formation of the fuel-air mixture occurs.

A feature of diesel fuel is an increase in viscosity with a decrease in temperature, which is accompanied by turbidity, crystallization and further solidification. With a significant increase in viscosity, the normal operation of the fuel system is disrupted, up to the complete cessation of the supply of diesel fuel. To counteract these negative factors on the Komatsu Heavy Equipment diesel heaters are used.

B. Understanding Fuel Supply System and Its Damage

Damage to the fuel supply pump on the Komatsu SAA12V140 Series engine affects engine performance and can cause a fire when the unit is operating. Fuel supply pump [23] This is not only used on one unit of heavy equipment but also used on all heavy equipment currently operating in companies operating in the mining sector.

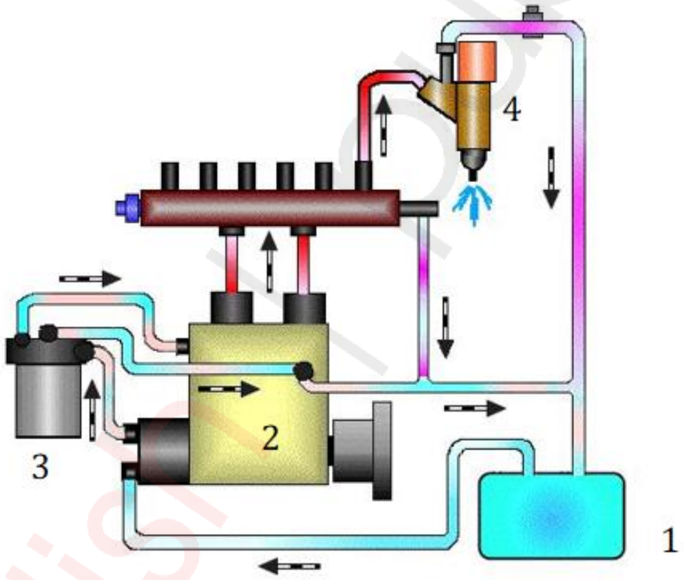


Figure 23. Fuel supply system [24]

Figure 23 explains the fuel supply flow in a Komatsu engine. Where in number 1, this fuel tank functions as a reservoir and cooler. Number 2, the fuel injection pump or called FIP, functions to supply fuel to each cylinder and is adjusted to the number of cylinders per engine. Number 3, Fuel filter, this part functions to filter micron-sized particles, according to the manufacturer's design. This fuel filter is replaced every 250 hours or according to the service manual for each unit. Number 4, Injector which functions to spray fuel into each cylinder. This fuel supply system works in accordance with cylinder timing. After leaving the fuel injection pump, the fuel returns to the fuel tank for the cooling process [15].

Figure 23 explained that there were indications of a fuel leak in the fuel supply pump component. The seepage that occurs will have an impact on the pump when it is used. Contamination will also cause external particles to enter the fuel supply pump and damage other components. In parts that experience leaks, this can be caused by damage to the O ring seal, the formation of grooves, or contamination during installation [23].

Figure 24. Fuel leak.

The pump section supplies this material to find out spare parts when damage occurs, which spare parts must be replaced and make repairs or reconditioning easier as explained in Figure 24**.**

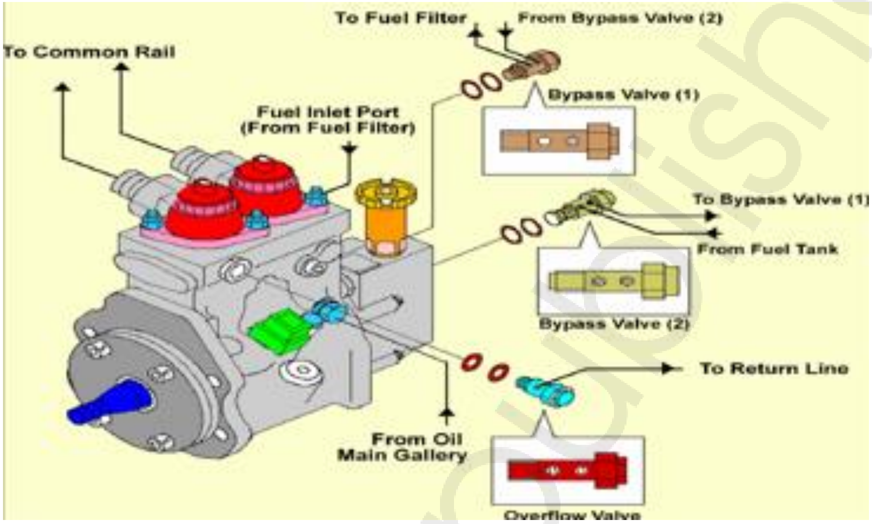


Figure 25. Fuel supply pump parts[24].

To improve the reliability of the engine fuel system, typical fault factors of the engine fuel system are analyzed from structural and functional points of view. The fault characteristics are obtained by constructing a fuel system fault tree [25].To overcome the problem of PT diesel engine fuel systems that cannot be maintained in the field, a portable signal acquisition and analysis system for PT diesel engine fuel systems was developed[26].The aim of this examination is to find out the root cause of damage to the fuel supply pump, so that it does not happen again and cause the heavy equipment to not operate.

C. Damage Identification Strategies

Figure 26 explains the flow of the examination carried out. The method used is based on identifying damage based on findings in the field, so that examination is more focused on one engine component. Observations were carried out to find out whether there were other causal factors [27], resulting in a leak in the fuel supply pump. This observation also requires data on repairs to units that have failed at the fuel supply pump, how many times it has failed, as well as data on overhaul times.

This maintenance data is needed to find out the history of replacement of the fuel supply pump, whether it is replaced on a scheduled or unscheduled basis, and how long the repair process takes from when the unit stops until the unit returns to operation [28].Visually inspect these components to determine the cause of the fuel leak. If all the data is complete, a discussion is carried out and compiling all the findings obtained, to determine the cause of the damage that occurred and then determine the conclusion of the cause of the damage [29].

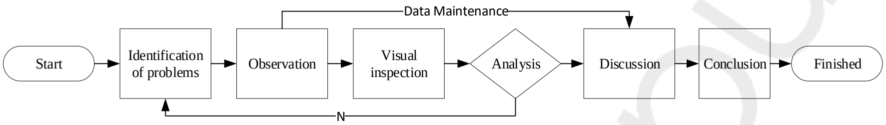


Figure 26. Damage Identification Flow

D. The Root Cause of the Damaged Fuel Supply Pump

It is known that the fuel supply pump is damaged. The seal and lip seal on the supply pump are worn. There are several factors that cause wear, including seal installation that is not tight or even not in accordance with Figure 24. This wear can also be caused by the age of the components.

Figure 27. Damaged fuel pump parts.

There are many factors that cause particles in the delivery valve hole, 1) fuel quality, 2) fuel filtration quality, 3) contamination during component reconditioning. The impact of this contamination will affect pump performance and shorten component life.

Figure 28. The delivery valve hole contains particles.

The hole in the Delivery Valve has particles stuck to it. This occurs due to poor cleanliness of the Hole Delivery Valve as explained in Figure 28.

Figure 29. Stopper delivery valve

The Stoper Delivery Valve is experiencing wear in Figure 29. This occurs because there is dirt on the Delivery Valve, causing the parts that rub together to wear more quickly.

Figure 30. Valve assembly

Figure 30 valve Assy experienced chipping. This happens because there are dirty particles that are also compressed. Chipping falls into the fatigue wear category. This is due to surface interactions where the surface experiences repeated loads and leads to the formation of micro cracks. Microcracks coalesce and cause peeling of the material.

Figure 31. Plunger delivery valve

Figure 31 plunger delivery valve experiences wear when moving up and down in the plunger chamber due to dirt in the fuel used. This wear occurs because two materials rub against each other and in between there are debris or dirt carried by the fuel [28].

From the **fishbone analysis** in Figure 32, it can be seen that there are many factors that influence the quality of the Fuel Supply Pump reconditioning process. Next, improvements need to be made to improve the component reconditioning process.

Method: Reconditioning of the fuel supply pump has not been carried out internally but from another party (manufacturer). The company does not provide a repair guide, any damaged components must be sent to the manufacturer's dealer.

Machine: Repairs carried out often result in damage or redo work. When testing was completed and carried out, there were no standard tools, so the components that had been repaired were not tested.

Material: Overhauling the unit requires quite a large amount of money, every time you overhaul the fuel supply pump you have to buy a premium one from the manufacturer. Because some component parts such as the inner part and the fuel supply pump are almost the same.

Man Power: Manpower to carry out fuel supply repairs has never received training. So manpower is not sure if they are asked to make repairs.

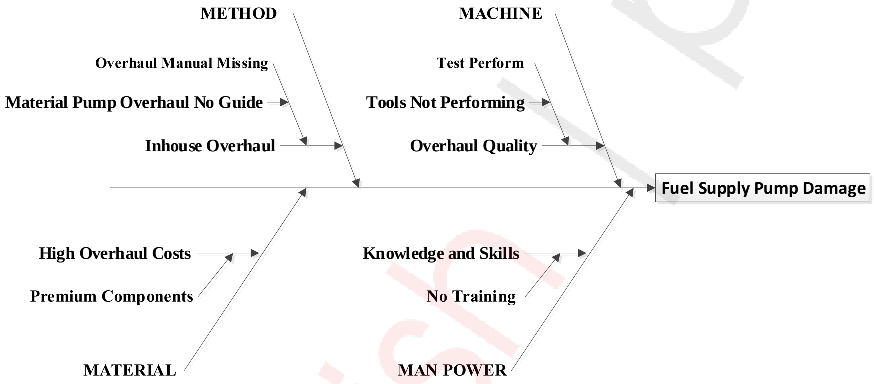


Figure 32. Fishbone Diagram

From the analysis carried out based on the facts of the damaged components and the fishbone diagram, the fuel leak at the fuel supply pump was contaminated with material, causing a leak when the unit was operated. This analysis is based on **Figure 24** and **Figure 26**.

THE PROBLEM OF DAMAGED INDUCED DRAFT FAN COMPONENT AT PLTU

ID systems use a fan located in the exhaust to pull combustion air through the burners and to pull the combustion products out of the furnace (see Fig. 1). This type of air supply is sometimes referred to as a “pull” system and is commonly used in SMRs. The fan needs to be designed to handle elevated gas temperatures although these temperatures should not be that high because there is normally an upstream convection section that removes a significant amount of energy from the flue gases before they reach the ID fan. The ID fan is sometimes referred to as a “hot” fan because it can handle those heated flue gases.

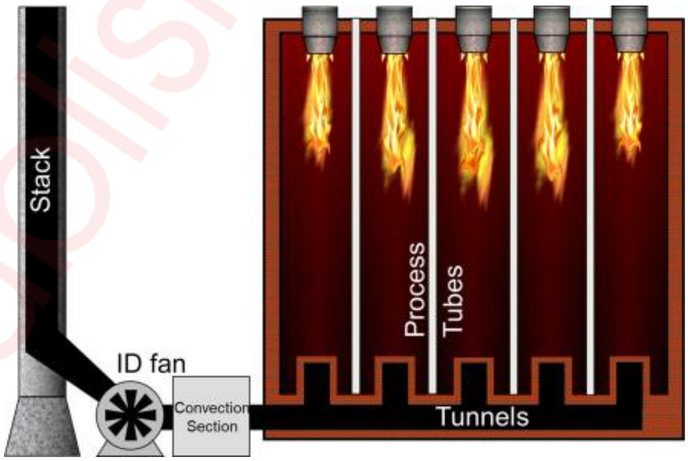


Figure 33. ID Fan

A. Understanding the Generating Unit

The generating unit of PLTU Nagan Raya PT. XYZ is a low-calorie coal-fired power plant built to meet the electricity needs of the West Aceh area. The capacity of the generating unit is 1 x 15 MW. Combustion in the furnace is supported by Primary Air and Secondary Air. Primary Air supplied by Primary Air Fan (PAF) [30]which is blown into the coal grinder (Pulverizer) then together with the coal powder flow to the furnace. The mixing of coal and air is assisted by a fixed dumper, which is an air mixer regulator, which causes turbulence which allows efficient combustion to occur [31]. Turbulence refers to the movement of air in the furnace, this is necessary because it can improve the mixing of air and fuel. To meet the needs of combustion air in the furnace, the boiler has a Forced Draft Fan (FDF) and Induced Draft Fan (IDF) which functions to provide Secondary Air [32].

During 2011 to 2013 the Electrostatic Precipitator (ESP) in the generating unit was not operated due to a defect in the high-voltage transformer so that the flue gas containing dust (by-product) was not captured by ESP. In this generating unit, 2 IDFs can be operated simultaneously or alternately. Damage to one type of fan automatically causes the outage in the generating unit to decrease, especially for fans that have no backup or back-up. The purpose of this study was to determine the root causes of IDF damage and determine corrective actions. The method in this study used fishbone analysis.

B. Primary Air Fan Accident

The torsional vibration shows anomalies at the smallest shaft diameter for the design conditions and the actual radius of the gutter is less than the design radius causing a significantly more stress concentration [33]. Induced draft fan (IDF) installed in the boiler in thermal power plants, namely induction IDF which functions to move exhaust gases out of the furnace and push them into the exhaust gas pile [34]. The causes of temperature spikes, as well as unit and production hazards, are introduced. It was shown that thermal power after the denitration system transformation, due to changes in air and gas system resistance, so that the entire system's aerodynamic field changes, can easily lead to a primary air fan (PAF) accident [32].

C. The Root Cause of Induced Draft Fan Damage

There were 61% of shutdowns that occurred due to 8 times the damage to the IDF, equivalent to a loss of operating hours of 911 hours. Failure mode in IDF is the occurrence of perforated blade plates and cones due to abrasion by fly ash, resulting in a decrease in exhaust gas suction capacity by fans, and vibration which causes damage to bearings and v-belts. **Figure 34** shows the types of damage that occurred to fan blades and cones that occurred during 2013.

Figure 34. Faulty IDF fan blade and cone

To see the overall concern for the PLTU Nagan Raya power plant unit according to the plan data and production achievement, in this study analysis was carried out using Fishbone Analysis in **Figure 38**. So that it is known that the area of concern has an impact either directly or indirectly on the performance of the generating unit so that it has an impact on the failure. Economics of operation and maintenance (O&M) of generating units during 2013. Areas of concern are in the following 4 things:

Table 6. Coal examination

Customer : PT. Bara Energi Lestari
Report No. : 08.12.00209.SP
Date Reported : February 15, 2012

Costumer Sample Id Estimate Cargo MT ± Lab Sample Id. Weight of Sample	UNIT	PLTU Gudang 01 Crusher 1,000 MT PDG-00383/12 104,705 Kg	PLTU Gudang 02 Crusher 3,000 MT PDG-00384/12 126,880 Kg
ANALYSIS			
1. As Received Basis (ar)			
Total Moisture	%	39,96	40,76
Gross Calorific Value	Cal/g	3485	3669
2. Air Dried Basis (adb)			
Moisture in the analysis sample	%	12,79	13,41
Ash Content	%	8,23	5,32
Volatile Matter	%	43,06	44,23
Fixed Carbon	%	35,92	37,04
Total Sulphur	%	0,19	0,17
Gross Calorific Value	Cal/g	5062	5363
3. Hardgrove Grindability Index	Index	46	42

Material: Based on secondary coal data for the Aceh and surrounding areas, it shows that the coal in the area around the PLTU is low quality coal with an average moisture content of around 40% and a calorific value of around 3,100-3,500 kcal/kg. Coal testing data in 2012 is under **Table 6**.

Method: During the examination, it was found that the operating conditions of the generating unit used the manual method both in terms of operating the boiler and turbine. Communication is carried out by 2 operator teams using radio (handy talky). There is no system interface between the boiler and the turbine. So that during operation the turbine operator monitors the performance of the turbine, operates the steam main valve and informs the steam needs to the boiler operator via radio.

Man (labor): The generating unit is operated by 86 employees, with 30 technical personnel working directly on complex mechanical and electrical equipment. The qualifications of the 30 technical personnel are known based on information about development and certification carried out through the training of PT. Indonesia Power with the module "Introduction to PLTU". In general, they perform well according to the minimum standard of operation of a PLTU.

Machine: The stoker boiler with a traveling fire grate used at PLTU Nagan Raya is under the specifications of the coal (lignite) used as fuel. This type of boiler can accommodate the combustion of high to low-quality coal. However, coal is used with an ash content of 8.23% [35], which is lower than required, which is between 10-15%, causing the ash layer to form on the grate to be less than 5cm. This caused the damage to the grate bar with an average occurrence of 40 pcs per month **Figure 35** during 2013. This damage did not cause the operation of the generating unit to stop, because grate bar replacement could be carried out while the boiler was operating.

Figure 35. Failed grade bar

Based on the literature study, it was found that the due diligence report document stated that ESP had not functioned since 2011. The non-functioning of the dust collector, in this case, the ESP, had a direct impact on the age of the IDF. The concentration of dust in the combustion gas stream is still very high, causing the IDF's operating life to be very short because IDF is not designed to handle gases with high dust concentrations. Also, the combustion gas released by the chimney in dusty conditions is currently polluting the community around the PLTU.

IDF damage begins with an increase in amperage on the electric motor or the motor experiences an overload. This condition was discovered during routine inspections. Damage occurs when the rated ampere is 470 Ampere to 490 Ampere either constantly or hunting. This increase is the result of abrasion on the fan blade so that the blade rotation against the shaft becomes unbalanced. Increasing the ampere in the electric motor will develop a vibration that can be felt by the operator. If the vibrations that occur are not followed up, the IDF's performance will decrease until physical damage occurs to the fan blade and the IDF casing. IDF final failure will also damage the bearing, bearing housing, and v-belt. The IDF damage curve is shown in **Figure 36**.

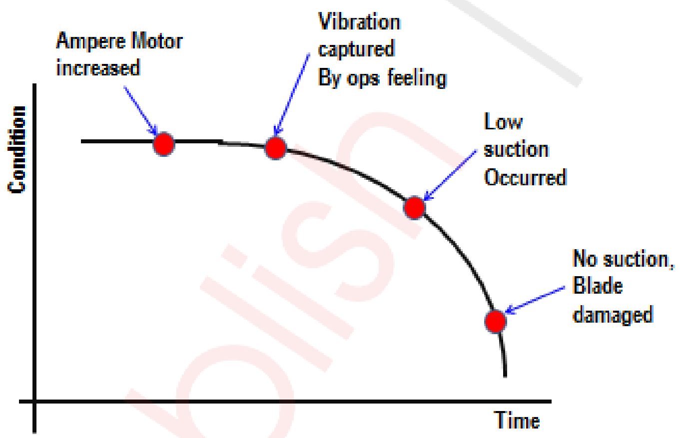


Figure 36. IDF deterioration curve

The types of damage caused by combustion dust that is not captured are abrasion and perforation. In **Figure 37**, 2 types of damage occur to the fan blade. The perforation on the blade surface occurs after the abrasive content contained in the flue gas causes abrasion on the fan blade surface.

Figure 37a. IDF abrasion blade

Figure 37b. IDF perforated blade

Abrasion occurs because fly ash containing 12.6-14.2% Fe2O3 collides with the fan blade surface. Also, fly ash also does not undergo a reduction process due to a non-functioning ESP.

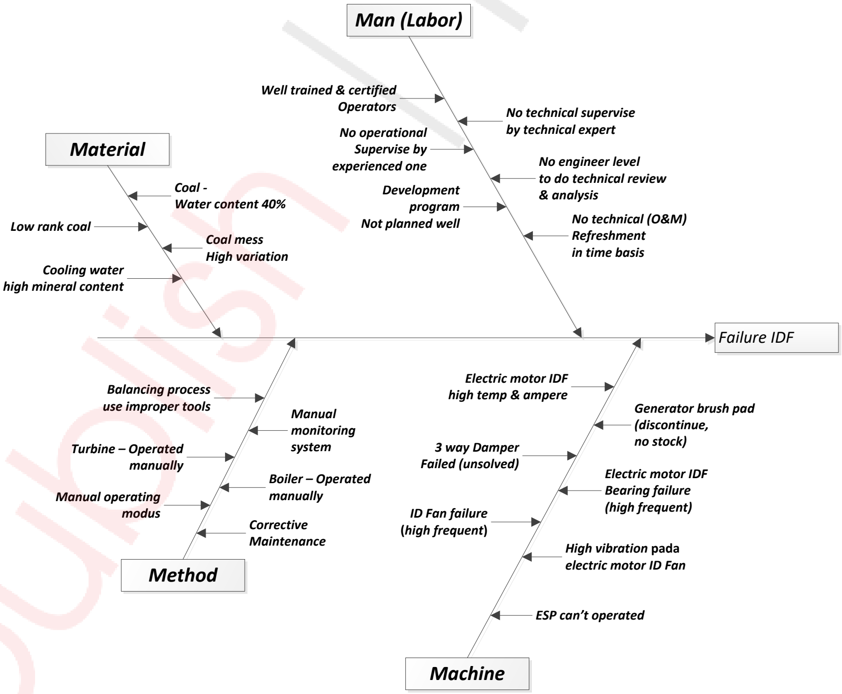


Figure 38. Fishbone diagram

The coal specification used is lignite with Fe_2O_3 content which has met the chemical composition limit (4-15%). 8.23% of ash content does not cause damage to the IDF but the grate bar. IDF damage occurs due to a malfunction of the ESP which causes the abrasive material (Fe_2O_3) in the flue gas to flow towards the IDF and the fan blade is in direct contact with the abrasive material, resulting in abrasion and perforation on the IDF fan blade.

THE DAMAGE OF ELECTRIC GENERATOR DIESEL ENGINE CONNECTING ROD

The diesel engine power plant experienced damage to a number of engine components after being operated for a long time. The damage began with a loud sound then followed by a very large vibration. Due to this incident, the operator on duty then carried out an emergency stop. Visually, it can be seen that the engine components that were damaged include broken engine blocks and cylinder liners, broken piston rods, and broken engine crankcase covers. A number of engine components appear to be out of position. From the visual observations obtained, the damage that occurred to the diesel engine most likely started from damage to the piston rod. Therefore, the damage analysis carried out is only aimed at finding out the type and factors that cause damage to the piston rod. A number of laboratory tests have been carried out, including macroscopic analysis of fracture surfaces, metallographic tests. From the results of the analysis carried out, it was found that damage to the diesel engine piston rod was likely caused by wear that occurred on the small end of the piston rod, causing loosening of the bushing and causing an enlargement of the gap between the rod eye and the bushing. This condition causes a very large increase in stress on the bushing and rod eye so that the bushing becomes overloaded and can ultimately cause damage (cracks/breaks) to the bushing

A. Damaged Diesel Engine Components

Operators who are monitoring the operating unit and the unit next to them hear a rough sound (knocking) and then check the sound source. Shortly thereafter the unit experiences over vibrations accompanied by rough sound (knocking), then the operator performs an emergency stop on the unit. After the engine stopped the operator did a visual check and found damage to the engine block, liner, broken piston rod, broken crankcase cover and some components were out of position.

Figure 39. Condition of engine block and crankcase cover

B. Connecting Rod

The connecting rod is divided into several regions namely the top is the pin-end, the middle area is called the shank, and the bottom is the crank-end / big-end (Figure 40). The pin-end and crank-end holes are each equipped with a very high accuracy bearing. When connected to the piston the pin-end hole must be equipped with a solid bearing (bushings), while the crank-end part that besides getting the compressive force and thrust from the piston movement also gets a high temperature due to the rotational motion of the crankshaft so the presence of the bushing is also very important[10]. The parts of the connecting rod[36], 1. Fillet, 2. Seat for the nut, 3. Seat for the bolt, 4. Piston pin bushings, 5. Shank, 6. Bolt, 7. Parting line, 8. Connecting rod cap, 9. Bolt (nut), 10. Thrust bearing surface, 11. Piston pin bore, 12. Crankshaft hole.

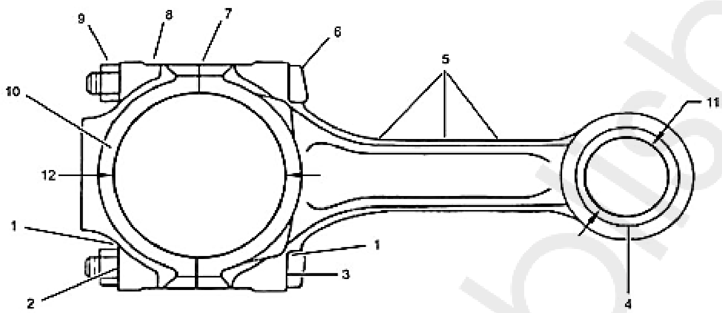


Figure 40. Parts of the connecting rod [36]

The connecting rod damage based on findings often results in major failure in the diesel engine, it was found that any casting defects might be developed depending on the cyclic loading behavior of the connecting rod[37].

C. Exploration of Connecting Rod Problems

Analysis of connecting rods using the method of visual inspection and some laboratory testing metallography and microstructure.

The purpose of this analysis connecting rod piston:

- To clearing procedure failure analysis connecting rod.
- Visual observation of connecting rod damage.
- Associate visual observation after laboratory testing.

In the failure analysis of the connecting rod piston to determine the root cause of the damage.

D. What Causes the Failure of Diesel Engine Connecting Rod

Observations were before damage of connecting rod[10] recording was carried out as follows: 1. Normal of exhaust temperature, 2. Supply fuel to system combustion normal, 3. Pressure oil normal, 4.

Cylinder block

Figure 41. Broken cylinder engine block

Engine Components

The broken engine component is in the oil pan (oil pan), after checking the components found according to the picture attached:

1. Broken piston rod.
2. Oil cooling jet
3. Close the crankcase.
4. Bushing flakes.

The material below is not a cause but an effect.

Figure 42. Broken engine components

Oil filter

To identify the particles that are in the oil filter of the engine components, checking the oil filter is carried out. Because the oil filter functions to filter particles under 2 microns, if the particles are smaller than 2 microns, the particles will be carried to the lubrication system.

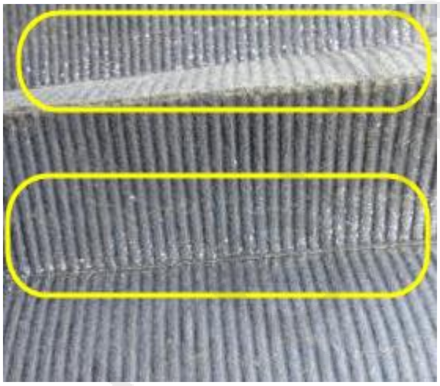


Figure 43. Large particles at oil filter

Valve, cylinder head, and top crown piston

Suction valves and exhaust valves collide with the piston top crown due to piston movement, when the bushing and rod eye distances are enlarged causing the piston to collide with the valve during the TDC step (top dead spot). If you look at the picture below traces of collision between the valve and piston top crown [38].

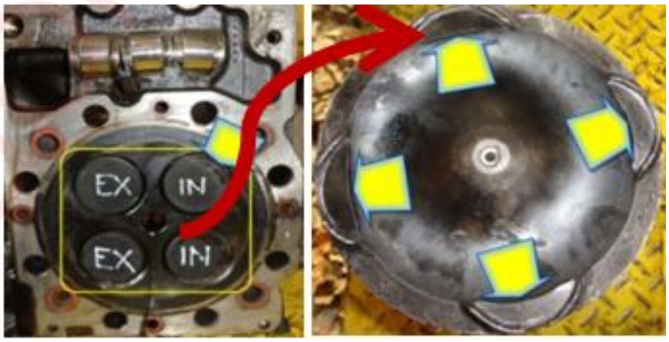


Figure 44. Top crown piston damage

Figure 45. Normal piston [38]

Liner dan under top crown

The piston position is still in the cylinder liner, which is caused when the rod eye is detached from the piston pin, the piston rod movement becomes abnormal and the piston bottom is damaged due to the movement of the piston rod. After the piston is released from its position the piston pin is still in position, this indicates that damage does not occur to the piston itself and the piston pin. It should be noted from damage to the damaged part, that the right and left sides of the piston body are damaged.

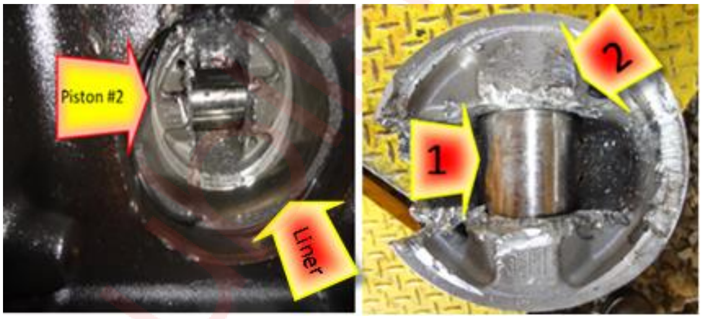


Figure 46. Broken Pistons and Liners

Connecting rod.

Broken connecting rod into 3 parts and in the position of the broken eye rod into 4 parts of them (A, B, C, D) according to the label listed.

Figure 47. Connecting rod faults

The fracture in Figure 48 position A is about the shape of the rough surface, where during the rise and fall of the large load piston it is in position A.

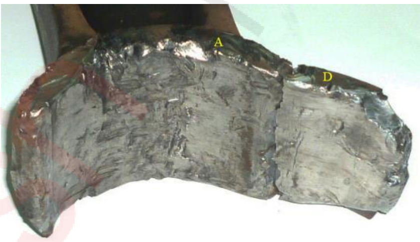


Figure 48. Fault in position A & D.

Figure 49. Small end (rod eye) fracture shape in position B

Figure 50. Fault position of C small end (rod eye).

Microstructure Examination

The microlocation structure of 3 fracture samples 2 in the fault area is bainite-ferrite and cracks occur due to impact loads.

Figure 51. Micro structure of the rod eye fracture

When the unit operates the bushing spins and starts to exit the bore. A little part of the bushing is released into debris and this splinter is found in the oil pan. The remaining bushings that are still inside the bore are overloaded so that damage occurs to the rod eye. The results of a visual examination showed that the damage began in the rod in the rod eye area. The occurrence of fatigue is caused by an enlarged bushing chamber due to wear or friction that is significant enough to the distance between the bushing and the surface of the loose rod eye diameter. After cracking propagates large enough the cross section of the rest cannot withstand the load so that it occurs broken. When the piston rod is not in the piston pin and the piston rod is released and collides with the engine block. The failure was followed by a broken piston rod colliding with the engine block

THE QUALITY OF THE WATER PUMP ENGINE TYPE SAA6D170E-5

At the Plant Rebuild Center Workshop PT Data from 2020 shows that water seal leaks occurred on the SAA6D170E-5 type water pump machine seven times. The aim of this examination is to determine the cause of leaks in the water seal on the water pump. Next, repairs are carried out to prevent further damage. By using the flow method, damage analysis can be carried out on the water pump. From the results of this analysis, several findings were obtained which were the causes of frequent leaks in the water seal, namely the presence of dust particles entering the surface of the water seal, the installation of the bearing shaft not according to standards, and the wrong way of installing the seal. Corrective action in the assembly process starts from adding a transparent hose to the indicator hole, replacing the bearing installation tool and changing the water seal lubricant from oil to soap. After conducting an evaluation from May to September 2021, it was found that the water pump components were not damaged

A. Engine Type SAA6D170E-5

PT. X is the largest coal mining company in Indonesia. PT. X uses heavy equipment and sophisticated mining equipment. In 2009, PT. X established the Plant Rebuild Center (PRC) which functions as a support center for the operation of PT's heavy equipment. X [1].

To serve job site needs, the Plant Rebuild Center (PRC) produces several components, including engines and powertrains. PRC is required to satisfy customer satisfaction, by improving quality. Problems with machine parts need to be reduced or eliminated completely [2].

The engine which is one of the main driving forces of a unit produces power which is used not only to move the unit but also to run the work equipment [1]. Many systems, including fuel, cooling, lubricant, air, and electrical systems, are included in the engine [2] [3]. The main parts of the machine must function well so that all systems can operate properly [4]. Compared to other components, engine parts that support the cooling system often experience damage [5].

The cooling system is a system component that helps cooling and functions to absorb heat and reduce explosions due to combustion [1][6][7]. The SAA6D170E-5 engine cooling system is shown in Figure 52. Every engine, as we know, needs to operate at peak efficiency [3]. Heat is generated during combustion in the combustion chamber and transferred through the cylinder liner and cylinder block [8]. One type of energy that can migrate or flow from one substance to another is heat transfer [9].

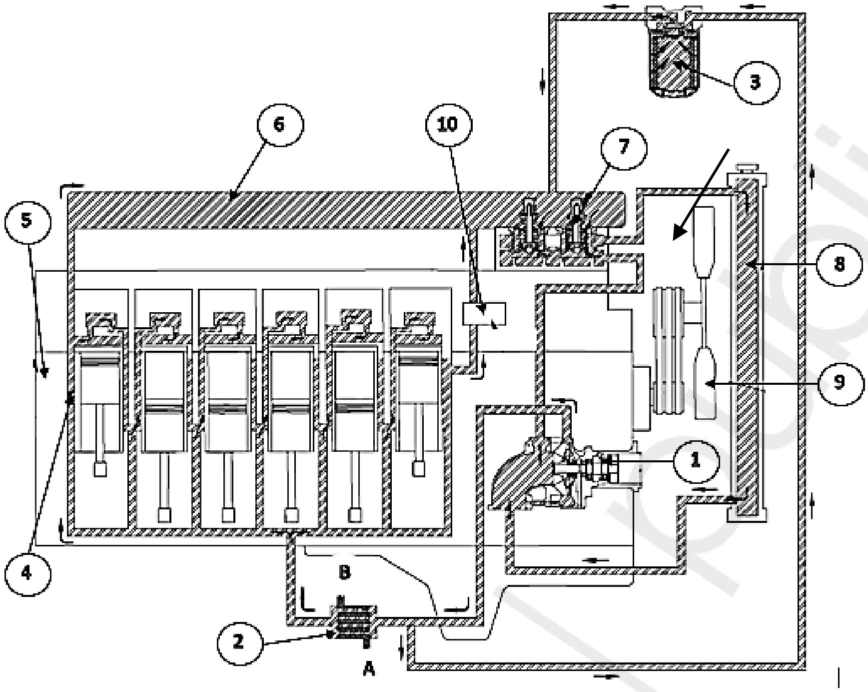


Figure 52. Cooling system on engine type SAA6D170E-5

The following is a description of the component names in Figure 52: (1) Water pump; (2) Oil cooler: (a) Engine oil flow from the oil pump; (b) Engine oil flow toward the engine oil gallery from the oil cooler. (i) Water manifold (within the engine cylinder block); (ii) Corrosion resistor; (iii) Cylinder liner; (iv) Cylinder block; (v) Fan; (vi) Thermostat; and (vi) Exhaust Gas Regulation (EGR) cooler. Engine component issues must be minor since the Plant Rebuild Center (PRC) division aims to provide high-quality components. Nonetheless, based on the SAA6D17E-5 engine problem component database. Installed in the field on HD 465-7R, PC 1250-8, and D375-6R units between January and December 2020, it was discovered that, out of the 18 engine components with type SAA6D170E-5 that had issues, the water pump component had the largest percentage, with seven damage events. This is shown in Figure 53.

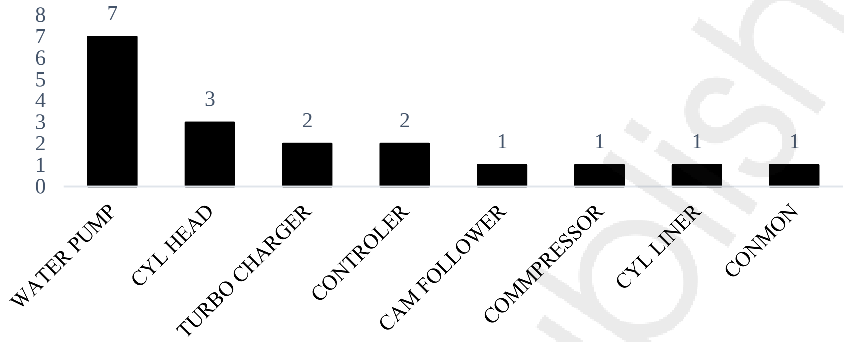


Figure 53. Component engine problem in January-December 2020

It can be concluded from the data in Figure 53 that the low quality of component products is the main cause of various problems that arise with water pump components. The aim of this examination is to identify the main causes of damage to water pump components which is expected to improve the quality of water pump components [9].

A diesel engine is defined as a device that produces power through a specific process. The thermal process is converted into mechanical energy, and the air entering the cylinder is compressed to a temperature of around 300–400ºC and a pressure of 30–40 kg/cm^2 [10]–[13]

Diesel Engine Specifications**.**

Engine type SAA 6D 170E-5. SA code 6D 170E-5 shows:

- S : Boost (use turbo)
- AA : Air-to-air aftercooler type.
- 6 : Number of cylinders.
- D: Four stroke diesel.
- 170 : Cylinder diameter.
- E : Environment (environmental protection).
- 5 : Change [9].

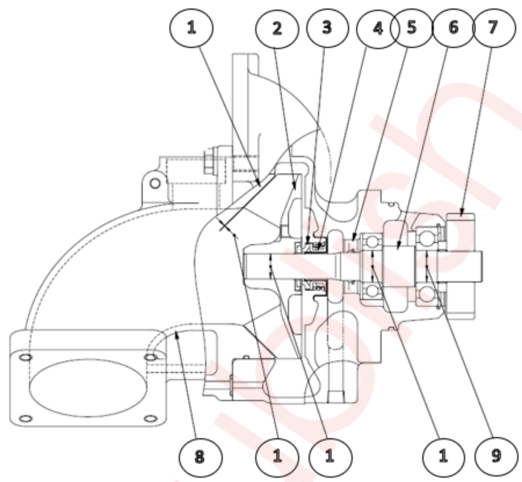
Engine Type and Application to the Unit

The type of engine used consists of several engine models, as follows.:

A. Engine model SAA12V140E-3 for unit: HD 785-7.
B. Engine model SA12V140-1 3 for units: HD785-5, WA800-3
C. Engine model SAA6D170E-5 for units: HD4657R, PC1250-8, D375-6.
D. Engine model SAA6D140E- for unit: D155-6.
E. Engine model SA6D140-2 for unit: GD825-2.

Understanding Water Pump (Cooling Water Pump).

The purpose of a water pump, which is a centrifugal pump assembly, is to move water through the cooling system. A gear mechanism that has an impeller and drives the pump releases water into the cooling system [39]. The component designations for the water pump are displayed in Figure 54 and are taken from the shop manual for the engine type SAA6D170E-5 [40], [41], [42], [43].



Part number:

1. Pump body
2. Impellers
3. Floating seal
4. Water seal
5. Oil seals
6. Pump shaft
7. Water pump drive gear (number of teeth on gear: 31)
8. Inlet housing

Figure 54. Water pump components

B. The Repair Process of Water Pump Components

This examination uses the flow method to analyze the causes of recurring problems in water pump components.

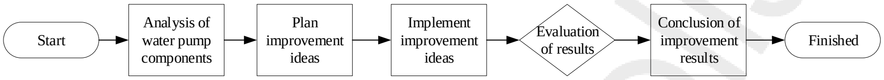


Figure 55. Flow diagram of the repair process for water pump components

The following is an explanation of the examination flow in Figure 55: (a) beginning: A water pump component needs to be disassembled due to damage. (b) Component analysis of water pumps: Disassembling the water pump component in order to inspect the damaged sections, (c) Arranging potential repairs: Once broken water pump parts have been identified, keep gathering references and supporting information to develop repair strategies. (d) Put fix thoughts into practice. Fix water pump parts in accordance with the repair schedule; (e) Assess the outcomes of the water pump part repairs: If so, move on to summarizing the water pump repair's outcomes; if not, Go back to the planning stage and evaluate improved suggestions once more. Moreover, (f) Finish: Complete the examination report; (g) Conclusion: Recap the issues raised by the water pump and the advancements that have been made.

C. What Causes the Leak and How to Improve the Quality of The Water Pump Engine

The Problem of Water Pump Component

From observations in the field, it was found that water was found flowing through the water pump check hole, which is also known as the indicator hole. This indicates that one of the water pump components is damaged. It is known that damage to the water pump results in damage to the water and oil seal so that the water and oil cannot be sealed [19], as shown in Figure 56.

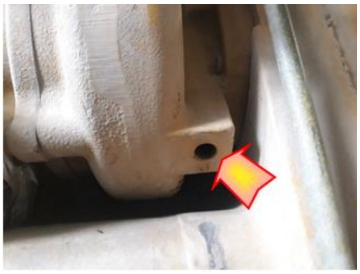


Figure 56. Water pump leak

It was found that there was a cooling water leak at the hole indication when the water pump components were disassembled and dismounted. This leak was caused by abnormal wear on the water pump shaft, damaged water pump shaft bearings, and damage to the ceramic water seal. As indicated in Table 7.

How to Improve the Water Pump Component

After the water pump's components were disassembled, a number of damages were discovered, investigation and analysis were done to demonstrate that the damages comprised:

a) Ceramic water seals sustain damage frequently due to their high susceptibility to dust contamination. When the water pump shaft spins, the wind speed from the radiator fan pushes dust or other particles into the indicator hole where they adhere to the seal and shaft gap, trapping the dust. This arrangement of the water pump on the engine's front side near the radiator fan creates this phenomenon is abrasive and wears down the ceramic seal's surface between the seal and shaft.

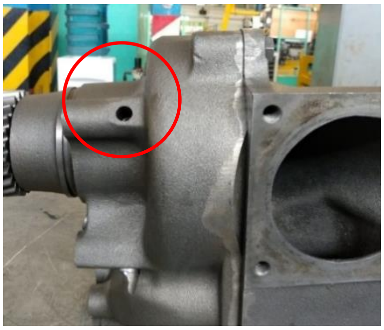
Table 7. Wear on the water pump shaft

No.	Visualization	Remarks
1	 	Because of deterioration, the ceramic water seal was unable to completely seal the water.
2		The outer edge of the water pump shaft bearing detached from its seat due to deterioration.
3		Between the ceramic contact region, seal, and water pump shaft, there is significant wear on the water pump shaft.

To prevent dust from entering through the indicator hole, it is necessary to install a hole protection adapter in the form of a transparent hose and facing the rear of the engine. So that dust cannot enter the indicator hole, due to the push from the radiator fan. This is shown in Table 8.

b) The water pump shaft bearing is damaged, this is due to looseness in the water pump shaft and the inner side of the bearing, as explained in the round sign in Figure 57. The picture explains that the cause of the bearing not sitting perfectly and causing it to slip and rotate is that the bearing is not on the axis of symmetry and the tightness between the bearing and shaft of the water pump is small [20].

Table 8. Water pump condition

Condition before repair	Condition after repair
	
There is no barrier preventing foreign objects from getting inside the water pump indication hole.	There is a hose attached to shield the water pump indication hole from extraneous particles.

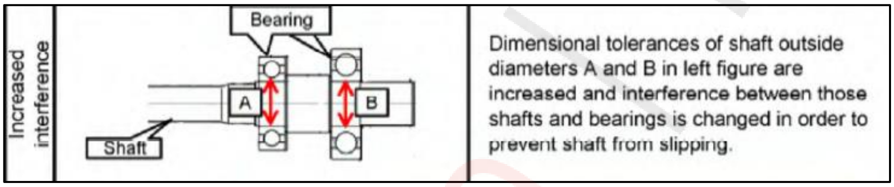
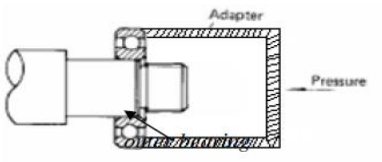
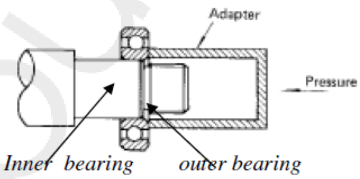


Figure 57. Bulletin for upgrading water pump components type SAA6D170e-5

During the inspection, it was found that the bearing pressing tool used by the Workshop Plant Rebuild Center only pushed the outer bearing side, even though based on manual bearing failure analysis, the bearing installation process had to be done on two sides, namely from the inner bearing and outer bearing side to avoid damage to the ball bearing. One of the consequences is that when the bearing is installed and the shaft rotates, the bearing and shaft are not symmetrical in their mounts, so that over time the interference causes loosening, and causes the water pump to not function normally. Therefore, improvements must be made to the standard bearing installation tool for the shaft water pump [21], which is explained in Table 9.

Table 9. Bearing condition

<table>
<tr><th>Condition before repair</th><th>Condition after repair</th></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td>On the outside of the bearing is the contact area of the bearing press tool</td><td>On the interior of the bearing is the contact area of the bearing press tool</td></tr>
</table>

Because there is no lubrication at the point where the mating ring and shaft

c) Because there is no lubrication at the point where the mating ring and shaft meet, the water pump shaft suffers anomalous wear between the ceramic seal and the water pump shaft. This state is seen in Figure 58.

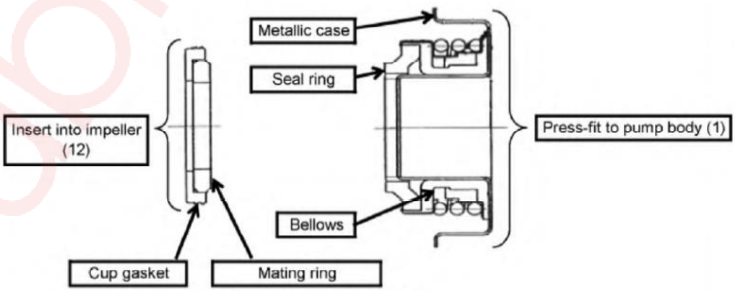
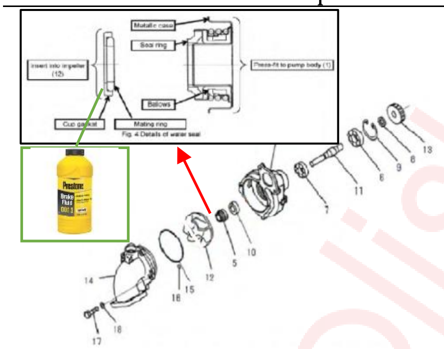
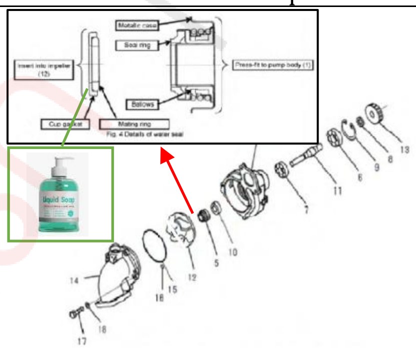


Figure 58. Details of the water pump ceramic baffle

DOT type lubricant is already used throughout the water pump component assembly process at the Narogong Plant Rebuild Center Workshop when the mating ring and cup gasket are installed on the impeller. The water pump shaft still sustains aberrant wear, nevertheless. During the analysis, a water-based lubricant (Water Soluble Lubricant) must be used when installing the matting ring and cup gasket onto the impeller. This is because an oil-based lubricant will evaporate when the seal is submerged in water because it is not a compound. Is varied or contains water. In the meantime, if you apply a water-based lubricant, it will keep lubricating the cup gasket and mating ring, preventing abnormal wear on the water pump shaft. Soap, or water soluble lubricant, is used during the installation of the mating ring and cup gasket [44]. This circumstance is displayed in Table 10.

Table 10. Seal parts comparison

Condition before repair	Condition after repair
	
Apply DOT 3 lubricant to the impeller when installing the water seal.	Using a water-soluble lubricant, install the water seal onto the impeller.

The Improvement of the Quality of the Water Pump Engine Type SAA6D170E-5

After repairs have been carried out, the quality of the water pump components can be evaluated using sample data from problem engine type SAA6D170E-5 before repairs were carried out in the assembly process in January-December 2020. The water pump components experienced problems 7 times and after repairs were made to the water pump components there was no damage. in May-September 2021. This condition is shown in **Table 11**.

Table 11. The outcome of component improvement.

NO	Component	Before Improvement Redo Based Process Jan-Dec 2020		After Improvement Redo Based Process May - Sept 2021	
		Internal	External	Internal	External
1	Fuel Pump		7		1
2	*Water Pump*	7		0	
3	Cyl Head	3		0	
4	Starting Motor		3		0
5	Turbocharger	2		0	
6	Controller	2		0	
7	Cam Follower	1		0	
8	Compressor	1		0	
9	Cylinder Liner	1		0	
10	Fip		1	0	
11	Cyl Head	1		0	
12	Hpi Pump			1	
13	Rear Seal			1	
14	*Oil* Cooler			1	
	TOTAL	18	11	3	1

Table 11 indicates that once process and assembly method improvements have been implemented, the quality of the water pump components will be higher and the improvement objective will be met.

Based on component problem data at the Plant Rebuild Center Narogong workshop, problems often occur with engine components due to lack of quality of the water pump. The damage to the water pump that occurs is leakage of coolant water from the water seal which can be seen from the indicator hole. After conducting field analysis, several findings were obtained regarding the causes of frequent leaks in the water seal. After improving the assembly process by carrying out engineering techniques by adding transparent hoses, replacing bearing installation tools and changing the water seal lubricant from oil to soap, the quality of the water pump components has improved. So, by improving the water pump component assembly process on the SAA6D170E-5 engine type and putting it into procedures (Work Instructions) that are in accordance with the latest SOP manual, the performance results of the water pump components are good and of very high quality, as evidenced by the data taken that the components. The water pump did not leak from May-September 2021.

RADIATOR CAP DAMAGE TO CAR ENGINE TEMPERATURE

Lack of radiator water in the Kijang 5K car cooling system, which is often caused by leaks, has an impact on reducing vehicle performance. This can also trigger high engine cooling system temperatures (overheating). One cause is damage to the radiator cap. The aim of this examination is to find out the root cause of engine temperature and radiator cap damage. The radiator cap test was carried out by observing the Toyota Kijang 5K car by testing the radiator cap pressure using a radiator cap pressure test measuring tool and visualization of the radiator cap components. After the inspection, there was damage to the radiator cap seal and the radiator cap test results were 0.6 kgf/cm2 which caused the radiator cap pressure to be low, while the standard pressure was 0.9 kgf/cm2 - 1.03 kgf/cm2 and there was damage to the radiator cap seal. So, it can cause the engine to overheat. The corrective step is to replace the radiator cap component with a new one, efforts that need to be taken into account to prevent losses due to damage to cooling system components by checking the height of the radiator regularly and ensuring that everything is done properly and correctly

A. The Role of Radiator Cap in Car's Cooling System

The performance of the Kijang 5K car decreased due to a lack of radiator water. When driving, the radiator water temperature was high, so the vehicle often stopped to cool the engine temperature. There are many causes for reduced radiator water. Damage to the seal on the radiator cap, damage to the hose/water pipe, dead end tube, broken fan belt, loose fan belt, loose clamps. The thrust of the radiator fan also influences the increase in radiator water temperature [1]. This factor is caused by the fan design not being suitable for its intended purpose. It is necessary to pay attention to the condition of the fan rotation, damage to the vee belt. The radiator water circulation in the engine functions to absorb heat generated from the combustion system [2] or friction of moving components, as well as cooling the lubrication system. The combustion process creates a high temperature, but does not cause excess heat. Meanwhile, the rotating engine components receive lubrication from oil, so that the moving components are not damaged. Hot oil flows to the oil cooler for the cooling process [3], where in the oil cooler there is a tube that flows cooling water to absorb the heat of the oil. Figure 59. Cooling system parts (1. Water Pump, 2. Oil Cooler, 3. Engine Block, 4. Regulator, 5. Radiator, 6. Radiator Cap, 7, Hose/radiator pipe.

The cooling system has several components which function as follows: 1) The water pump functions to move water from the radiator to the engine. 2) The lubricating oil cooler (Oil Cooler) functions to cool the engine oil. 3) The engine block functions as a holder for engine components such as liners, pistons, crankshaft, connecting rods and others. The radiator water circulation system in the engine block functions to reduce explosions during the combustion process and absorb heat from the movement of engine components carried by oil. [4]. 4) The regulator functions as a regulator of cooling water circulation to the radiator or back to the engine. This regulator has a temperature limit so that cooling water circulation is not hampered. 5) The radiator functions to absorb the heat of the water [4] The coolant is cooled by means of water flowing through the upper radiator tank to the tube and the hot water flowing through the radiator fins and then the water to the lower radiator tank. The function of the radiator cap is as a cover to keep the cooling water temperature stable [5] and so that it does not boil at a temperature of 100 ^{o}C. Then the hose or pipe functions to drain the radiator water to the engine and back to the radiator.

Radiator components, from the radiator cap, upper radiator tank, radiator core, radiator tube, lower radiator tank, radiator hose/pipe, radiator hose/pipe clamps, of several radiator components that will be used as examination on radiator water shortages are the radiator cap.

This radiator cap functions to maintain or control the water pressure in the car's cooling system [6]. Damage to the radiator cap can be determined by testing the radiator cup tester with a standard pressure of 0.9 kgf/cm^2 - 1.03 kgf/cm^2.

Figure 59. Radiator cap

The aim of this examination is to find out the root cause of damage to the radiator cap on engine temperature on Kijang cars, in order to minimize damage to Kijang car engines.

B. Exploring Radiator Cap Damage

In testing the radiator cap, use the examination flow in Figure 60.

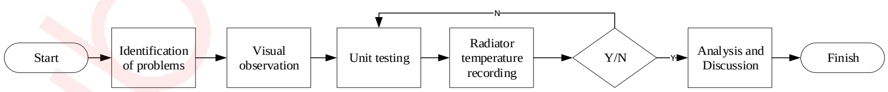


Figure 60. Exploration scheme of radiator cap damage.

Tools and materials

1. Tool

   Equipment used in the process of identifying damage to the radiator cap on engine temperature includes, among others: Radiator Cup Tester.

   For leak testing on radiators [7] when the engine is operating or not operating for a certain time, if a leak occurs, it can be read on the cup tester and the pressure will tend to decrease. Changes in materials to minimize water leaks in the cooling system will also have an impact on damage to hose, cap and tube components [8].

Figure 61. Radiator cup tester

2. Material

   Materials used in the process of identifying damage to the radiator cap on the engine radiator temperature of the Kijang 5K car.

Figure 62. Radiator condition

Radiator cap testing examination procedure:

1. Open the radiator cap using your hands (it is prohibited to open using tools).
2. Check the seal on the inside of the radiator cap and check for flexibility on the inside and outside.
3. Check the spring on the radiator cap, by pressing it, whether the spring returns to normal, if not the damage could be caused by the spring.
4. Check the radiator cap with a tester.
5. Install the radiator cap according to shape and size.
6. Then install the tester pump on the radiator cap holder.
7. After completion of installation, pump using a tester. And check the pressure on the radiator cap, and pay attention to the pressure should not be less than 0.6 kg/cm^2.
8. To keep work tools safe and reusable, after work, clean them and return them to their place.

C. The Root Cause of Engine to Overheat

After observing and checking the cooling system of the Toyota Kijang 5K car, what causes overheating.

Radiator cap pressure measurement results [9] 0.6 kgf/cm^2

Figure 63. Radiator cap measurements

Data from examination results after replacing the radiator cap.

Table 12. After replacing radiator cap

Time	Pressure	Unit
08.00	9	psi
08.05	8	psi
08.10	8	psi
08.15	8	psi
08.20	8	psi
08.25	8	psi

The condition of the seal on the radiator cap can affect the lack of cooling water. An incorrect closing position causes radiator water to come out when the engine is running at normal or abnormal temperatures. [10]. If the air pressure in the radiator gets higher, the radiator water will form a crust which can inhibit the flow rate of water in the radiator tube [6].

Figure 64. Damaged radiator cap seal and whitish color

The results of observation and inspection of the radiator cap found damage to the radiator cap seal and the radiator cap pressure was below the manufacturer's minimum standard size. Table 13 shows the test results before repairing the radiator cap.

Table 13. Before replacing radiator cap

Time	Pressure	Unit
08.00	5	psi
08.05	2	psi
08.10	1	psi
08.15	0	psi

Based on the pressure test on the radiator cap before replacement, the pressure decreased quickly, from 5 psi – 2 psi within 5 minutes. After replacing it with a new radiator cap, the pressure remained stable at 8 psi. From the results of the analysis, the cause of the decreased pressure was caused by damage to the radiator cap.

IMPROVING THE AVAILABILITY PERFORMANCE OF TYPE 150 EXTRUDER ENGINES

The insulation process, also known as the conductor coating process, is the final step in cable production. This procedure uses a type 150 extruder machine to coat the conductor with a material consisting of polyvinyl chloride (PVC) or cross-linked polyethylene (XLPE). Observational data showed the Mean Time to Repair (MTTR) was 175 minutes, and the mean time between failures (MTBF) was 3458 minutes. Availability Performance (AP) was only 95.1% at the same time. This causes disruption to the production process and less than optimal operation of the Type 150 Extruder machine. The problem that often arises is leakage of pneumatic components. This examination aims to reduce the damage that occurs by increasing the availability of pneumatic components. The process involves repairing damaged pneumatic parts and, most importantly, carrying out routine maintenance. Furthermore, as an effort to stop the release of water entering the pneumatic system, a Regulator Lubricator Filter (FRL) is installed. After repairs were carried out, the Availability Performance (AP) of the type 150 Extruder machine increased to 99.00%, Mean Time Between Failures (MTBF) increased to 9400 minutes, and Mean Time to Repair (MTTR) decreased by 90 minutes

A. Availability Performance of Type 150 Extruder Engine

Electrical energy is distributed by the use of electrical wires as a medium. electrical wires that facilitate the movement of electric current between locations. Humans can do a lot of things, including getting lights, with cables [45]. The insulation process is the most important step in the production of cables. The insulation process, also known as the conductor coating process, coats the outside of the conductor with material consisting of cross-linked polyethylene (XLPE) or polyvinyl chloride (PVC) using a type 150 extruder machine. This procedure completes a sequence of steps involved in the production of cables. Should there be an issue with the conductor coating, the cable may leak and put people in danger [45][46]. The unit must function dependably and not sustain damage frequently when conductor cable coating is applied. The truth is that conductor coating units get damaged frequently and take a while to fix in the field.

The results of the observation data collection indicate that the pneumatic components suffered damage, which resulted in a mean time between failure (MTBF) of 3458 minutes and a Mean Time to Repair (MTTR) of 175 minutes. Availability Performance (AP) was just 95.1% at the same time. This results in suboptimal performance from the type 150 Extruder machine and disrupts the production process[47][48]. Equation (1) is used to calculate Availability Performance (AP), Mean Time Between Failures (MTBF), and Mean Time to Repair (MTTR).

$$MTBF = \frac{\sum WP}{\sum TUP} = \frac{WP1+WP2+WP3+WP4+WP5+WP6+WP7}{7} \quad \text{.........................} (1)$$

Regarding the MTTR computation using Equation (2).

$$MTTR = \frac{\sum DT}{\sum FRM} = \frac{DT1+DT2+DT3+DT4+DT5+DT6}{6} \quad \text{.......................................} (2)$$

Equations (3) and (4) can be used to determine processing time and downtime.

$$MTBF = \frac{\sum WP}{\sum TUP} = \frac{WP1+WP2+WP3}{3} \quad \ldots\ldots (3)$$

$$MTTR = \frac{\sum DT}{\sum FRM} = \frac{DT1+DT2}{2} \quad \ldots\ldots (4)$$

As a result, the type 150 Extruder machine needs to undergo maintenance. The type 150 Extruder machine must first be observed in person when it is in operation. so that you can determine which unit parts require maintenance[49], [50], [51]. The purpose of this study is to enhance the type 150 Extruder machine's performance [52], [53], [54].

B. Strategy to Enhance Type 150 Extruder Machine's Performance

The study was conducted from October 1 through December 31, 2021, with data collected within this time frame[42], [43], [55]. Given that the author is employed by this organization, this site was carefully picked [56]. Figure 65 displays the examination flowchart.

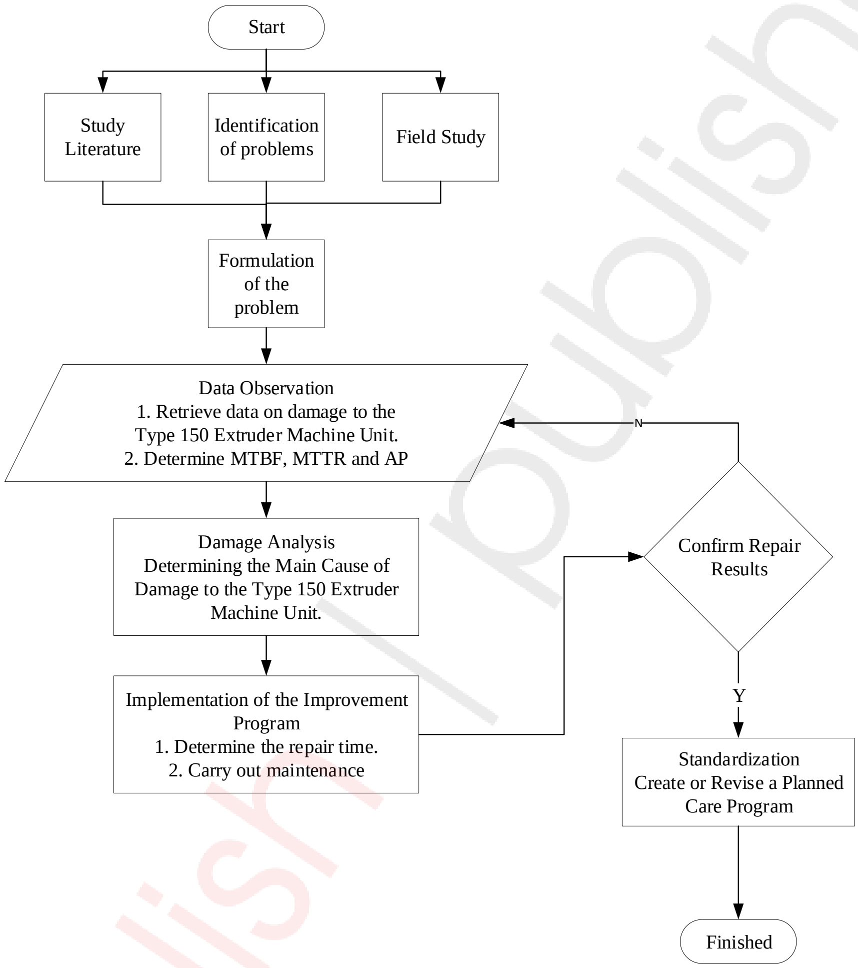


Figure 65. Enhancement scheme of type 150 extruder machine's performance [48].

This study was conducted in a number of steps that were completed in order. Studying literature is stage I. The purpose of this step is to identify potential examination questions, provide a theoretical foundation, establish a conceptual framework, and identify working assumptions of examination hypotheses. by looking through existing examination on the subject, obtained from scientists who have looked into cases comparable to yours. Stage II is field study after that.

The goal of this stage is to observe and analyze everything that takes place in the field, including observations and data collecting. The objective is to comprehend and investigate the issues that arise in the type 150 Extruder machine during operation. Following that, the units that require maintenance are visible, and the production team must then decide when to schedule a repair and maintenance program. This process requires time [57]**.** The third step, known as "damage data observation," consists of the following: (a) production-side machine damage observation data, such as production output data and production disruptions on the type 150 extruder machine in October 2021; and (b) after the data is obtained, compute the machine's total downtime using the formulas Mean Time Between Failure (MTBF), Mean Performance (AP), and Mean Time to Repair (MTTR). As a gauge for assessing engine performance [47]**.** The investigation of damage that frequently happens and the variables producing it are covered in Stage IV, or damage analysis. Additionally, step V, the repair program's implementation stage, entails the following: (a) After the parts are obtained, production must allot repair time in order to identify when it is appropriate to perform repairs. Repairs will be performed in November 2021 following approval by the manufacturing party, and (b) upon the completion of all repairs. The type 150 extruder machine's maintenance was initiated by the mechanical team. Because regular, timely maintenance is what makes a component or part durable**.** Stage VI is the phase that follows the completion of maintenance and repairs. The next action is to advise the production party to verify, by means of production output data and production disruptions in December 2021, the outcomes of the repairs and maintenance. as a means of comparison between December and October. Has the Pneumatic Caterpillar's Availability Performance increased as a result of the maintenance method steps implemented? [58]**.**The last stage, known as maintenance standardization, entails the following: (a) the maintenance party must update the preventive check sheet and add the necessary maintenance since some of the methods used for maintenance are not listed there; and (b) the maintenance team must receive feedback in order to improve maintenance actions. Due to the fact that up until now, maintenance was only done when an equipment broke or was not scheduled [59][60][61].

C. The Improvement of Type 150 Extruder Machine's Availability Performance

Table 14 and Table 15 present observation data from October indicating that Caterpillar pneumatic components sustained the most damage to the Type 150 extrusion machine.

Table 14. Type 150 extruder machine production output and disruptions[62].

No	Date	T. Up A/ processing time without problems (minutes)	Downtime (minutes)	Constraint	Cable Process Type
1	1/10/21 s/d 4/10/21	2820	√	√	NYY (Cu/PVC/PVC) Sect 4 x 185 mm^2 0.6/1 kV Rope/Pet
2	4/10/21	X	180	Caterpillar was unable to draw the conductor due to four pneumatic leaks	NYY (Cu/PVC/PVC) Sect 4 x 185 mm^2 0.6/1 kV Rope/Pet
3	5/10/21 s/d 7/10/21	3300	√	√	NYY (Cu/PVC/PVC) Sect 4 x 185 mm^2 0.6/1 kV Rope/Pet
4	7/10/21	X	120	The primary take-up motor's blower is dead	NYY (Cu/PVC/PVC) Sect 4 x 185 mm^2 0.6/1 kV Rope/Pet
5	8/10/21 s/d 12/10/21	4020	√	√	NYY (Cu/PVC/PVC) Sect 4 x 185 mm^2 0.6/1 kV Rope/Pet
6	12/10/21	X	120	Short Barrel Heater	NYY (Cu/PVC/PVC) Sect 4 x 185

No	Date	T. Up A/ processing time without problems (minutes)	Downtime (minutes)	Constraint	Cable Process Type
					mm^2 0.6/1 kV Rope/Pet
7	13/10/21 s/d 22/10/21	7200	√	√	NYY (Cu/PVC/PVC) Sect 4 x 185 mm^2 0.6/1 kV Rope/Pet
8	22/10/21	X	360	Caterpillar is unable to draw the conductor due to five pneumatic leaks	NYY (Cu/PVC/PVC) Sect 4 x 185 mm^2 0.6/1 kV Rope/Pet
9	23/10/21 s/d 25/10/21	1710	√	√	NYY (Cu/PVC/PVC) Sect 4 x 185 mm^2 0.6/1 kV Rope/Pet
10	25/10/21	X	150	The stiff Caterpillar transmission gears	NYY (Cu/PVC/PVC) Sect 4 x 185 mm^2 0.6/1 kV Rope/Pet
11	26/10/21 s/d 28/10/21	3300	√	√	NYY (Cu/PVC/PVC) Sect 4 x 185 mm^2 0.6/1 kV Rope/Pet
12	28/10/21	X	120	Caterpillar was unable to remove the conductor due to three pneumatic leaks	NYY (Cu/PVC/PVC) Sect 4 x 185 mm^2 0.6/1 kV Rope/Pet
13	29/10/21 s/d 31/10/21	1860	√	√	NYY (Cu/PVC/PVC) Sect 4 x 185 mm^2 0.6/1 kV Rope/Pet
	TOTAL	24210	1050		

Table 15. Type 150 extruder machine outage[62]

Problem	Downtime
Caterpillar's pneumatic leak prevents it from pulling the conductor. 4 Items	180
The primary take-up motor's blower is dead	120
Short Barrel Heater	120
Caterpillar's pneumatic leak prevents it from pulling the conductor. Five Pieces	360
Caterpillar's pneumatic leak prevents it from pulling the conductor. Three pieces	120
Caterpillar transmission gears hard	150

Calculation of Availability Performance (AP), Mean Time Between Failures (MTBF) and Mean Time to Repair (MTTR), October 2021

Total Processing Time (WP)	=	24210 minute
Total Down Time (DT)	=	1050 minute
Frequency of Faulty Machines (FRM)	=	6 machine failure times
(T.UP)	=	7 machine process times are normal

The value that is generated from the MTBF calculation is 3450 minutes, however the MTTR value is 175 minutes. In the meantime, 95.1% was the result of the Availability Performance calculation [48][47].October 2021: Pareto chart problem [46][63].The Caterpillar Pneumatic unit component sustained the most damage to the type 150 extruder machine, according to Figure 66's Pareto chart of October's issues

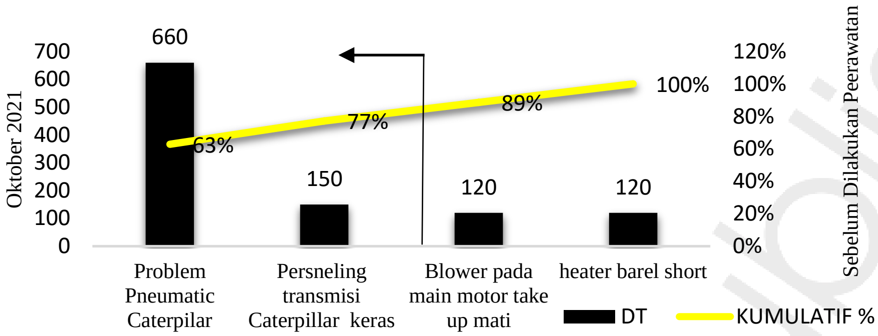


Figure 66. Pareto chart showing issues with the type 150 extruder machine.

Table 16. Total percentage of type 150 extruder machine downtime[62]

Problem	*DT*	Kumulatif %	%
Pneumatic Problems Caterpillars	660	63%	63%
Transmission Gear Caterpillar Hard	150	77%	14%
The blower on the Main Motor Take Up is Dead	120	89%	11%
Short Barrel Heater	120	100%	11%
TOTAL	1050		

Table 16 demonstrates that the observation results and report above indicate that damage to Caterpillar pneumatic components was the cause of the highest number of downtimes for type 150 extruder machines, amounting to 660 minutes. This resulted in a 95.1% Availability Performance (AP) for type 150 extruder machines, 3450 minutes for Mean Time Between Failures (MTBF), and 175 minutes for Mean Time to Repair (MTTR). Corrective action is necessary, but upkeep is even more crucial in order to reduce similar harm[62].

The Damage of Pneumatic Caterpillar

Pneumatic leaks, which are described in Table 16, are the main issue with the type 150 extruder machine, according to the data in the Pareto chart graphic. The Filter Regulator (FR) does not filter the wind that is so full of water that comes from the portable compressor and goes through the hose. There was still a lot of water entering the pneumatic system, making the installation of a Filter Regulator (FR) less successful.

Figure 67. Filter regulator (FR)

Figure 67 illustrates how ineffectively the Regulator Filter (FR) in the pneumatic system of the Caterpillar unit separates air from water. A Filter Regulator Lubricator (FRL) must be installed in place of the pneumatic system in order to improve the air quality. Because the Filter Regulator (FR) component is less successful in reducing the amount of water that enters the pneumatic system, the pneumatic piston frequently corrodes.

Figure 68. Pneumatic piston corrosion

Figure 68 illustrates how water entering the pneumatic system can lead to corrosion on the pneumatic piston.

Figure 69. Damaged pneumatic seal

Figure 69 shows how the presence of moist, water-containing air can damage the pneumatic seal and produce air leaks from the pneumatic system. Due to the variable wind inflow, this situation will prevent the pneumatic pressure from operating as intended. Tensile conductor failure is the result of instability.

Improvements to pneumatics

The procedures for fixing pneumatic leaks are executed in accordance with **Figure 70**. Following the selection of the pneumatics that will be repaired, the pneumatics are disassembled and the source of the damage is examined. **Figure 71**. The water from the portable compressor caused the pneumatic piston to corrode and weather the seal, and the filter regulator (FR) was unable to reduce the water. To reduce the amount of water that enters the pneumatic system, this part—the Filter Regulator Lubricator—needs to be replaced (FRL).

Figure 70. Damaged pneumatic

Figure 71. Pneumatic piston

Once the source of the damage has been identified, use type 320 coarse sandpaper and type 1000 finishing sandpaper to clean the corrosion-affected piston and pneumatic tube. To facilitate the installation of the pneumatic seal, the pneumatic components must first be sanded and then lubricated with ISO VG 32 oil. To facilitate installation, Figure 72's pneumatic components are lubricated with ISO VG 32 type oil. Figure 73 shows that the damaged seal is replaced with a new one after the pneumatic components have been cleaned.

Figure 72. Wetted pneumatic parts with ISO VG 32 oil

Figure 73. Seal pneumatic

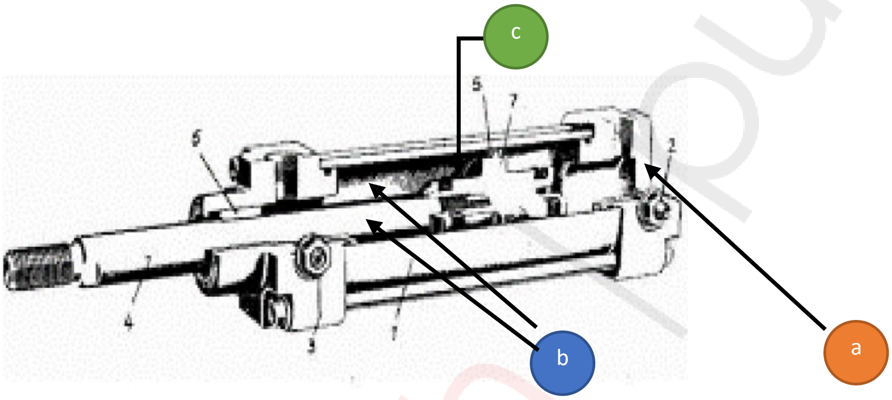


Figure 74. Seal installation on pneumatic components [64]

The positioning of seals on pneumatic components is shown in Figure 74: (A) The piston seal, also known as the Nok seal, is situated in the middle piston. Its job is to keep the wind out of the way so the piston can move. There are two seals: the (b) Rod Seal blocks the wind at the bottom and the other blocks it at the top. It is housed in the pneumatic housing and serves to (c) seal the 0-ring and stop leaks in the rod and piston axle. In essence, the o-ring found in pneumatic cylinders falls under the seal category and serves to prevent air leaks. The o-ring on the pneumatic cylinder is fitted at the point where the cylinder rod end cover and cylinder tube connect. There are two o-ring seals on the pneumatic at the connection between the cylinder tube and the cylinder head end cap to stop air at the top and bottom.

Following assembly, the pneumatic is tested to identify any leaks by delivering 4 bar of air pressure. When the Caterpillar unit has finished testing, replace the pneumatic. Maintenance procedures are required to ensure that damage to the pneumatic does not recur once the pneumatic has been fixed and the Caterpillar is back in service. Water getting into the pneumatic system is a common issue. Installation of the Filter Regulator Lubricator (FRL), a pneumatic maintenance technique on Caterpillar**.** While the Regulator Filter (FR) lacks a lubricator tube, the FRL component is supplied with one. To lubricate moving pneumatic parts, such as pistons on solenoids and pistons on air cylinders, ISO VG 32-ISO VG 68 oil is utilized.

Installation of the Regulator Lubricator (FRL) Filter

First, the Filter Regulator (FR) components that were originally installed in the Caterpillar unit's pneumatic system must be removed and replaced with the Filter Regulator Lubricator (FRL). Continue adding lubricating oil to the Lubricator tube following the Filter Regulator Lubricator (FRL) installation procedures. ISO VG 32 and ISO VG 68 (International Organization for Standardization) (Viscosity Grade and (FRL) oil) are the recommended oils**.** To reduce the amount of water, ISO VG 68 oil is put into the lubricator tube as shown in **Figure 75**. **Table 17**: Report on Type 150 Extruder Machine Production Output and Disruptions in December 2021.

Figure 75. Filling the lubricator tube with ISO VG 68 lubricating oil

Table 17. Type 150 extruder machine production output and disruptions [62].

No	Date	T.Up A/ processing time without problems (minutes)	Downtime (minutes)	Constraint	Cable Process Type
1	1/12/2021 S/D 14/12/2021	12780	√	√	NYY (Cu/PVC/PVC) Sect 4 x 185 mm^2 0.6/1 kV Rope/Pet
2	14/12/21	X	120	Short barrel heater	NYY (Cu/PVC/PVC) Sect 4 x 185 mm^2 0.6/1 kV Rope/Pet
3	15/12/21 S/D 23/12/21	8580	√	√	NYY (Cu/PVC/PVC) Sect 4 x 185 mm^2 0.6/1 kV Rope/Pet
4	23/12/21	X	60	Caterpillar's pneumatic leak prevents it from pulling the conductor. One piece	NYY (Cu/PVC/PVC) Sect 4 x 185 mm^2 0.6/1 kV Rope/Pet
5	24/12/21 S/D 31/12/21	6840	√	√	NYY (Cu/PVC/PVC) Sect 4 x 185 mm^2 0.6/1 kV Rope/Pet
	Total	28200	180		

Table 18 provides an explanation of the downtime % for December 2021. The AP, MTBF, and AP formulae are calculated as follows: Frequency of Machine Damage (FRM) = 2 times machine damage, Total Processing Time (WP) = 28200 minutes, Total Downtime (DT) = 180 minutes, and (T.UP) = 3 times normal machine process.

Table 18. Type 150 extruder machine downtime percentage in December 2021[62]

Problem	Downtime	Cumulative	%
Short Barrel Heater	120	67%	67%
Pneumatic Caterpillar leaking 1 pcs	60	100%	33%
TOTAL	180		

With an AP result of 99%, this computation yields an MTB value of 9400 minutes and an MTTR of 90 minutes[47][48]. Pareto diagram showing issues following maintenance in December 2021. Because the author's primary goal was achieved, Figure 76's Pareto chart shows a decrease in the number of damages to the type 150 Extruder machine in December 2021 and a decrease in damage to the Pneumatic with just 60 minutes of downtime[46][63]. Availability Performance (AP) for type 150 Extruder machines in October and December of 2021, represented as a Pareto comparison chart. Based on the graph in Figure 77, it can be inferred that the Availability Performance (AP) of type 150 Extruder machines increased to 99.00% in December from 95.10% in October. October and December serve as the study benchmarks as November is the month when maintenance and repairs are completed. Thus, it can be said that there has been a 3.90% gain in Availability Performance (AP), a 9400 minute rise in Mean Time Between Failures (MTBF), and a 90 minute decrease in Mean Time to Repair (MTTR)[46][63].

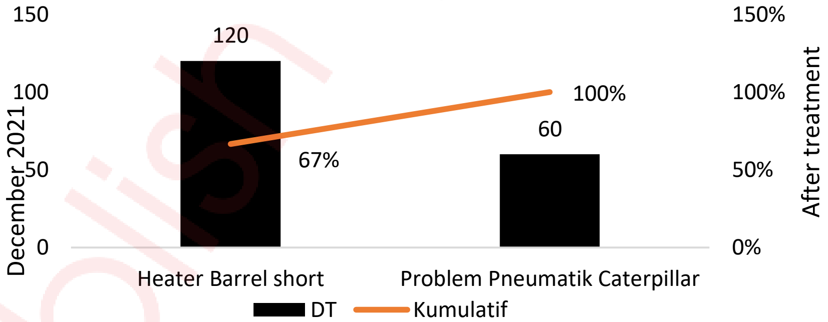


Figure 76. Pareto chart problem diagram for extrusion machine type 150

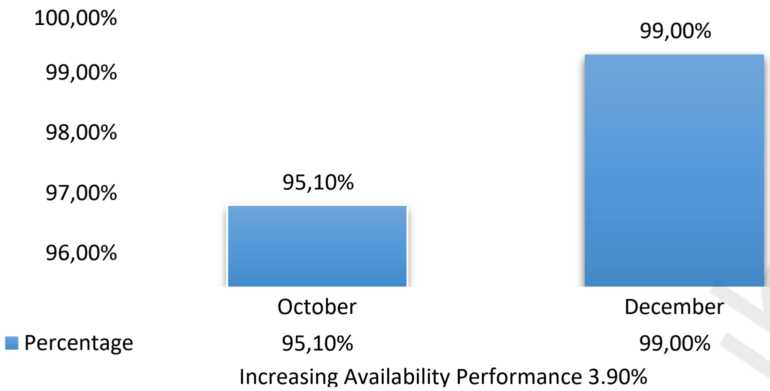


Figure 77. Pareto chart problem diagram for extrusion machine type 150

The preventive maintenance check sheet has been revised. The preventive maintenance check sheet has to be updated in order to add the following items in order to standardize maintenance on Caterpillar type 150 extruder machines: (1) Examine the Filter Regulator Lubricator (FRL) wind system's operation. (1) Monthly inspection of the transmission gearbox oil change; (2) Standard monthly examination of the air compressor drain; and (3) Every three days inspection of the air compressor.

The Filter Regulator Lubricator (FRL) installation, repairs, and seal replacements on pneumatic components resulted in an increase in Availability Performance (AP) on pneumatic components from 95.10% to 99%. According to the intended aim, MTBF increased from the previous 3450 minutes to 9400 minutes, and MTTR fell from the prior 175 minutes to 90 minutes. In other words, decreasing the MTTR raises the Mean Time Between Failures (MTBF) and the percentage of Availability Performance (AP). The Extruder type 150 machine's repair procedures are standardized.

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Ir. Awang Surya, M.M. adalah seorang pendidik, penulis, dan motivator yang memiliki latar belakang pendidikan di bidang Teknik Mesin serta Manajemen. Lahir di Lamongan, Jawa Timur, Awang Surya telah berkontribusi secara aktif dalam dunia pendidikan sebagai dosen di Program Studi Teknik Mesin di Sekolah Tinggi Teknologi Muhammadiyah Cileungsi. Selain menjadi pendidik, beliau juga memiliki minat yang besar dalam menulis dan memotivasi orang lain untuk meraih potensi terbaik mereka.

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Dia juga dikenal sebagai seorang penulis yang produktif. Melalui karya-karya tulisnya, beliau berbagi pengetahuan dan pengalaman dalam bidang Teknik Mesin serta Manajemen kepada masyarakat luas. Buku-buku dan artikel yang ditulisnya memberikan wawasan yang berharga bagi pembaca yang tertarik dengan topik-topik terkait.

Sebagai seorang motivator, Ir. Awang Surya, MM. telah menginspirasi banyak orang dengan ceramah dan kelas motivasinya. Dengan pengalamannya dan kepribadiannya yang menarik, beliau mendorong orang untuk mencapai potensi terbaik mereka, memotivasi mereka untuk mengatasi hambatan, dan menginspirasi mereka untuk meraih impian mereka. Saat ini, dengan pengalamannya yang luas dan minat yang mendalam dalam bidang pengembangan SDM, beliau terus berupaya untuk memberikan kontribusi yang berarti bagi masyarakat dan generasi mendatang.

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Aswin Domodite