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Bearing Failure Analysis on Gearbox Forced Draft Fan at LNG Plant

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A B S T R A C T

Boilers Forced Draft Fan has a gearbox reducer to reduce speed from steam turbine as a driver and fan as the driven. Based on Predictive Maintenance Group at Machinery and Heavy Equipment Section, it was found that gearbox has high vibration and noise when boilers load on 195 Ton/Hr (Max Load 295 Ton/hr). Vibration Analysis indicates that the source of vibration comes from bearings with peak value 0.572 in/sec at gearbox high speed outboard vertical and 0.593 in/sec at gearbox high speed outboard horizontal (Max Allowance 0.50 in/sec). Lubrication analysis using X-ray Flourescence method, to see wear particle on lubricating oil showed that Tin(Sn) content is very high 203.62 mg/L (maximum allowance for Tin(Sn) at gearbox is 20mg/L), but wear debris are not found in lubricating oil. Gearbox disassembly found that high speed and low speed bearings suffered severe corrosion. Corrosion at bearings are caused by water contamination on lubrication oil, it comes from steam leak due to carbon ring failure at steam turbine, which is steam turbine bearing lubrication and gearbox lubrication get into one lubrication system. After Bearings replaced with a new one, vibration analysis shown improvement in vibration due to several reasons.

A R T I C L E I N F O

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1. INTRODUCTION

All rotating machines produce vibrations that are a function of the machine dynamics, such as the alignment and balance of the rotating parts (Muszynska, 1995). Measuring the amplitude of vibration at certain frequencies can provide valuable information about the accuracy of shaft alignment and balance, the condition of bearings or gears, and the effect on the machine due to resonance from the housings, piping and other structures (Harrison, 1963). Vibration analysis can identify improper maintenance or repair practices. These can include improper bearing installation and replacement, inaccurate shaft alignment or imprecise rotor balancing (Nurprasetio *et al.*, 2017). As almost 80% of common rotating equipment problems are related to misalignment and unbalance, vibration analysis is an important tool that can be used to reduce or eliminate recurring machine problems (Hameed et al., 2009).

For example, there was an interesting case and described in several reports (Kjer, 1981; Peng *et al.*, 2005; van Zyl & Al-Sahli, 2013)). On September 26, 2016, gearbox vibration is in normal condition, then on November 17, 2016, gearbox vibration began to increase and exceed maximum allowance value, which is 0.52 in/sec (Max allowance 0.50 in/sec) where the data are taken on the high load. After the workload is lowered on Desember 13, 2016, the data are taken on the low load where there is a decrease in vibration to 0.46 in/sec. On Februari 13, 2017, the data are taken on the high load and found the vibrations become higher 0.59 in/sec followed by the noise on the gearbox. On March 2, 2017, Maintenance Department issued a recommendation to replace Bearings, because bearing purchase takes six months and due to operational needs then Boilers Forced Draft Fan is recommended to operate with no more load than 150 Ton/hr (see **Figure 1**).

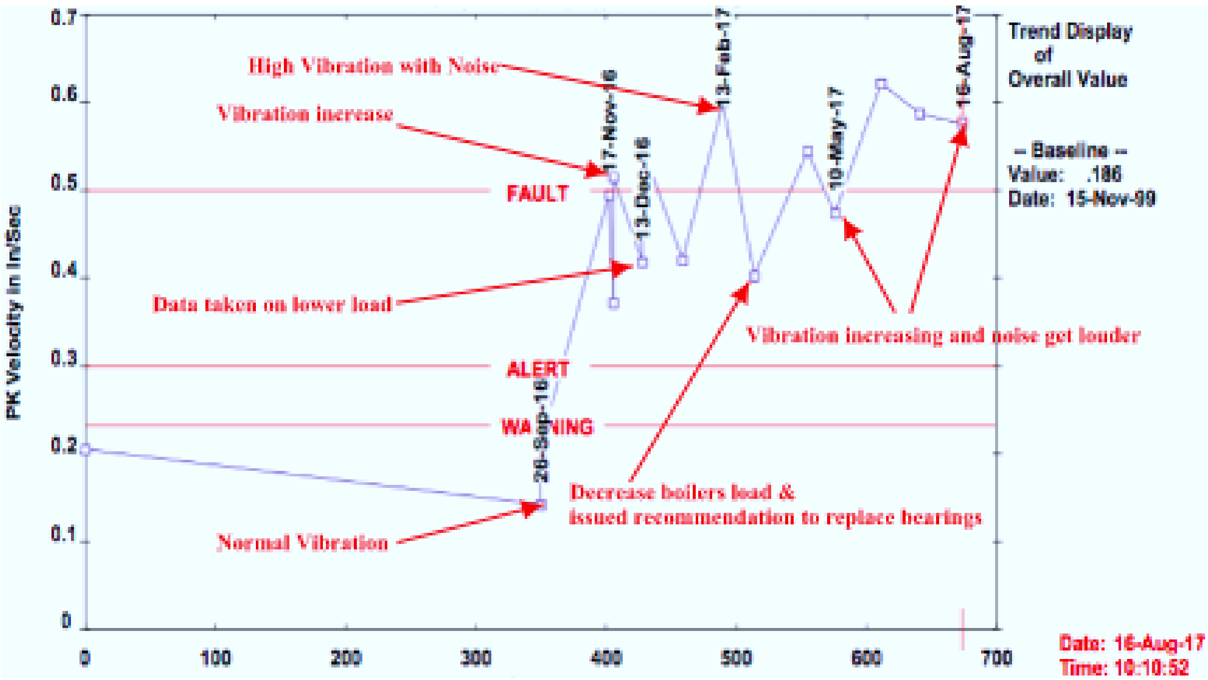

Figure 1. Overall Vibration Trending History

In this paper, analysis of failure mechanism of the broken gearbox bearing is presented. Vibration Analysis is performed to find out which gearbox components are the main cause of high vibration. Data were taken using CSI 2130: Machinery Health Analyzer and Analyzed using AMS suite: Machinery Health Manager software. Lubricant analysis was carried out to determine the presence of metal debris and metal particle on the gearbox lubricant system during operation, analysis was carried out using the filtration method and X-Ray Flourescence (XRF) method. Then after the gearbox dismantling stage is carried out to replace the bearings, Visual and metallographic analysis is done to find the cause of bearing damage using a visual inspection method and scanning electron microscope (SEM) method to determine the condition of the bearing metal surface that is damaged and compare it to the surface conditions of the bearing which is not damaged. Finally failure mechanism of the broken bearing is comprehensively discussed.

2. MATERIALS AND METHOD

2.1. Mechanism of Boiler Force Draft Fan Gearbox and Its Failure

Figure 2a shows schematic figure of Boiler Force Draft Fan Units. A 1350 HP Steam Turbine with a nominal speed of 3600 Rpm at maximum conditions is used to generate torque. A Gearbox reducer with a transmission ratio of 3.671:1 which is used to rotate the Boiler Force Draft Fan with a speed of 977 Rpm as shown in **Figure 2b.** Gearbox data can be seen in **Table 1.**

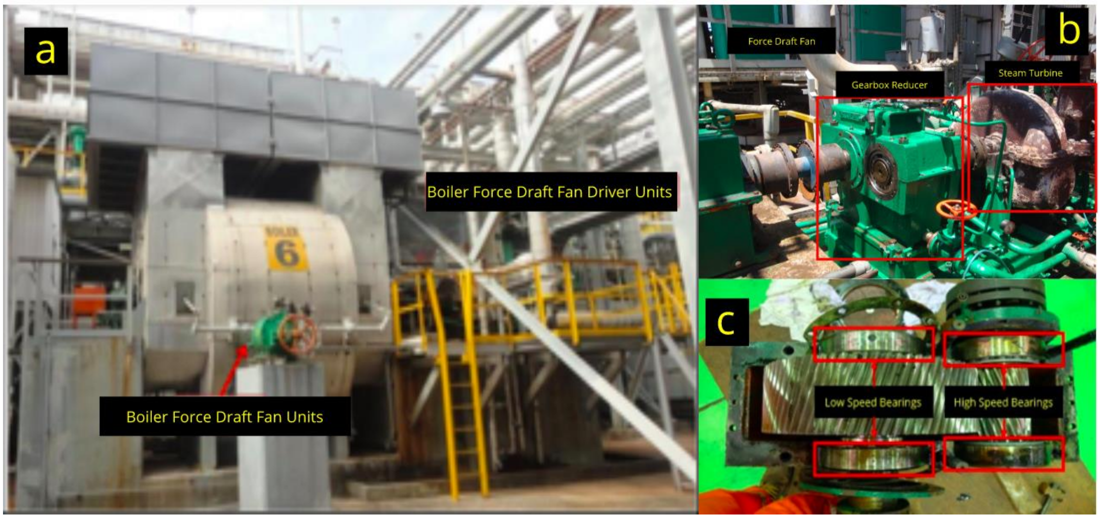

Figure 2. Schematic figure of Boiler Force Draft Fan (a) Gearbox reducer location (b) and Its broken bearing (c)

Table 1. Gearbox Data Sheet (Philagear, 2018)

Size Type	Hp Rating	Service factor	Input RPM	Ratio	output RPM
12 MHPS	1350	19	3600	3.681-1	977.77

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Figure 2c shows the detailed conditions of the inside of the gearbox that experience high vibration consisting of gearbox housing, high speed gear, low speed gear, shafts, high speed bearings, and low speed bearings. The gear condition is still good and shows no signs of failure while bearing conditions indicate the condition of corrosion damage. Therefore, further analysis is needed to prove that high vibration in the gearbox reducer is due to bearing failure.

2.2. Vibration check Method

Vibration data retrieval is carried out using CSI2130: Machinery Health Analyzer as shown in **Figure 3a.** It is a measuring instrument used to measure the frequency of vibrations that a rise. This measuring instrument can be used for a variety of vibration-related tests such as spectrum, waveform, bump tests, and others. While for analyzing the results of reading the measuring instrument, AMS Suite: Machinery Helath Manager software is used as shown in **Figure 3b.** From the results of processing the vibration spectrum and waveform data on the gearbox using AMS Suite software shows that there is damage to the Rooling Element or Bearing, and also the reading results show that the vibration value for the inboard and outboard horizontal gearbox has a value above the permissible threshold of 0.5 in/Sec.

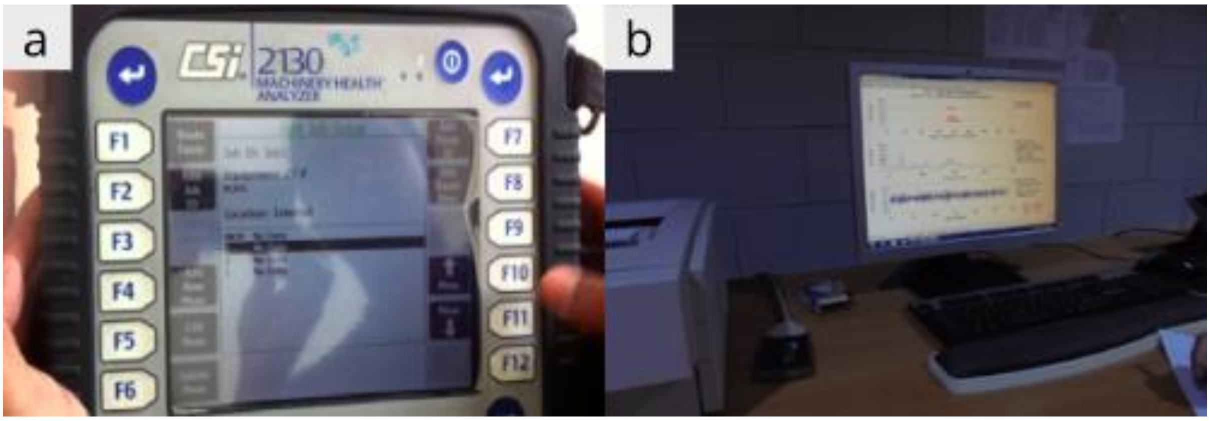

Figure 3. CSI2130: Machinery Health Analyzer (a) and AMS Suite: Machinery Health Manager (b)

2.3. Filtration and X-Ray Flourescence (XRF)

Lubrication analysis is done by taking the lubricant sample on the gearbox to be tested for water content, metal debris, and metal particle. **Figures 4a and b** show the position where the sample was taken. Filtration method is carried out to find out if there are metal flakes in the lubrication system with a visible size, if there is one then it is certain that the components in the gearbox have suffered severe damage resulting in high vibration and noise. And to determine the content of metal particles in the lubricant, energy dispersive device X-Ray Flourescence Spectrometer Shimadzu EDX-720/800HS are used. An EDX fluorescence spectrometer irradiates a sample with X-rays, and then measures the energy of the generated fluorescent X-rays to determine the type and amount of elements comprising the sample. The lubricant used for the gearbox lubricant system is an ISO VG 68 DTE HEAVY MEDIUM MOBIL shown in **Figure 4c**.

2.4. Visual and Metallographic Inspection

Visual and metallographic analysis is done by visually seeing the condition of the damaged bearing and determining the cause of damage from the bearing and micro-scale analysis is carried out using a scanning electron microscope (SEM) method to get a more detailed magnification of the bearing surface with damaged conditions.

3. RESULTS AND DISCUSSION

Figure 5 shows the results of filtering the lubricant on the gearbox. Based on the filtration results, there is no visible metal flakes with large size that can be seen by the eye, so that filtration data cannot be used to do damage analysis on gearbox components.

Another lubrication oil sample for gearbox was analyzed for metal particles using the XRF method. **Table 2** shows the content of the Tin in the lubricant is very high where the maximum limit of the Tin in the lubricant is **100mg/L**. Tin content in the new lubricant has a high enough value of **70.54 mg/L** but the value of the circulating lubricant reaches **203.62 mg/L** which indicates metal contamination in the lubricating system.

The metal composition on gearbox lubrication oil contains **high Tin(Sn) 203.62** and **99.11 mg/L**. This is in a good agreement with data according to Lubetrend oil analysis that showed Tin(Sn) sourced from Bronze/ PhosphorBronze (with cooper), white metal bearings, and Bushes derived from components on bearing (Wakelin, 1974).

Figure 4. Lube Oil Filter (a) Gearbox Drain (b) and lubricants used for gearboxes (c)

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Figure 5. Results of filtering gearbox lubricants

Table 2. XRF Result for Gearbox Lubrication Oil

Test Parameters	Unit	Method	Results		
			ISO VG 68	5-Sep-17	19-Sep-17
Kin. Viscocity @40 C	cst	ASTM D 445	63.76	61.76	62.04
Chromium (Cr)	mg/L	XRF	<9.6	<9.6	<9.6
Copper (Cu)	mg/L	XRF	26.74	32.94	35.35
Iron (Fe)	mg/L	XRF	6.93	9.16	5.85
Lead (Pb)	mg/L	XRF	<5.3	<5.3	<5.3
Tin (Sn)	mg/L	XRF	70.54	203.62	99.11
Zinc (Zn)	mg/L	XRF	55.49	80.37	71.94

Visual examination of the failed bearings revealed that it suffered severe corrosion. **Figure 6** shows bearings location inside gearbox housing. The condition of bearing is covered by sludge, this sludge is formed because of the mixture of water and oil inside gearbox housing. And **Figure 4** shows the remaining water deposits in the bottom of the gearbox housing. This Indicates that there has been contamination of water in the lubricant system.

Visual appearance of the corroded bearings (shown in **Figure 8**) is clearly visible that the damage is caused by the corrosion. Based on literature and references from bearing manufactures "TIMKEN" corrosion of the observed bearing is Etching or Corrosion (Ellis, 1970). Bearing cups have heavy corrosion on the race, cage, and roller. The stain on bearing cannot be cleaned with a fine emery cloth or crocus cloth and there is a pits that cannot be cleaned with light polishing.

Figure 8 shows the condition of the components in the corroded bearing, such as corroded rollers, corroded raceways, and corroded roller cages. This condition causes the bearing cannot be used and repaired so it is recommended to be replaced with a new bearing.

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Figure 6. Sludge on the bearing

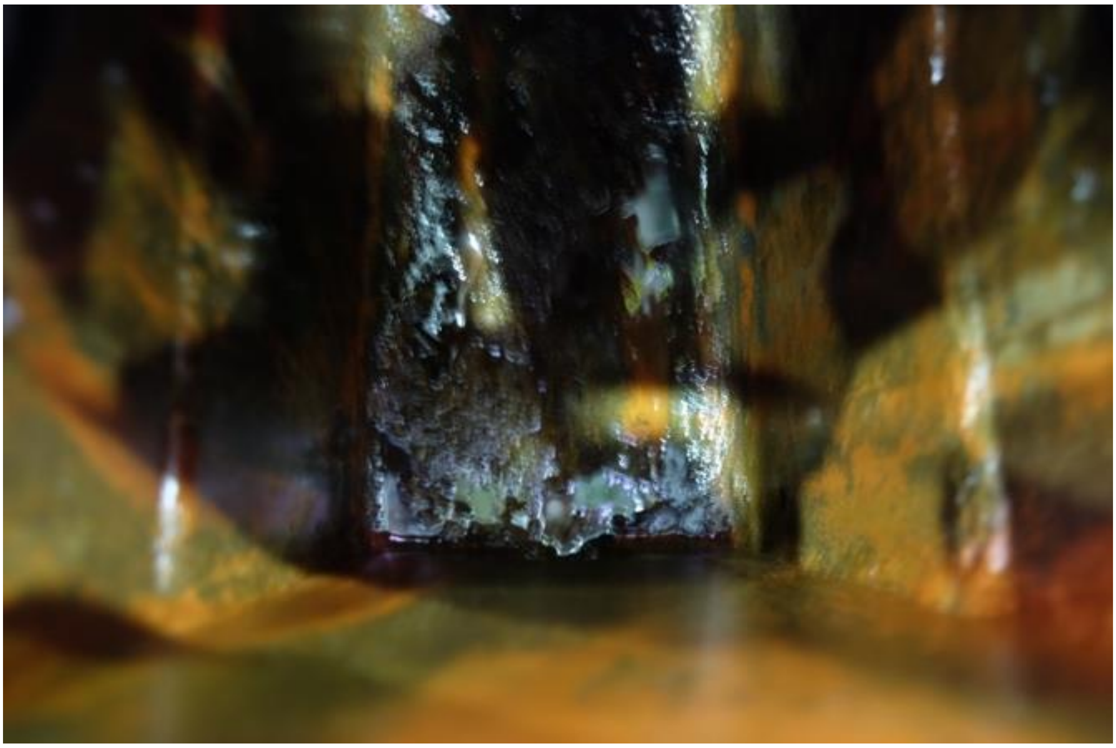

Figure 7. The Remaining water at the bottom of the housing Gearbox

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Figure 8. Bearing Cage, Roller, and Raceway Conditions

A sample was cut from the bearing Corrosion zone. This sample was metallographically prepared and observed in an optical microscope, in corroded and non-corroded conditions.

Figure 9 shows the condition of the metal that has been corroded. It is clear that the rust crust formed has changed the condition of the metal surface. Metal surfaces become rough and deformed this causes the metal to become brittle , as well as the appearance of stress concentration points which can be a source of failure in metals.

Figure 10 showed analysis that is carried out on non-corroded metals, the condition of the metal surface is smoother and free of rust crust.

The microstructure, with corroded, revealed high quantity of rust crust compared to non-corroded metals as shown in **Figure 9** and **10.** Through magnification of x500 rust crust are clearly visible, in which the crust result in deformation of the metal. No visible deformation due to rust on non-corroded metals as shown in **Figure 10.** Rust affects changes in the composition of metal structures which result in metal conditions becoming brittle and susceptible to failure.

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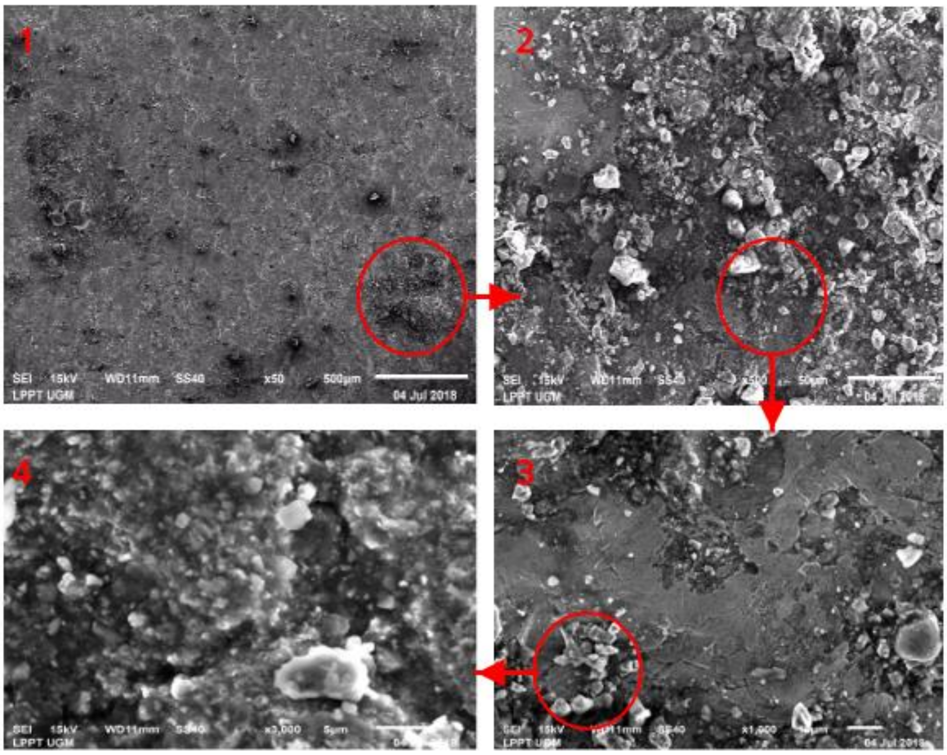

Figure 9. Scanning Electron Microscope result for corroded metals

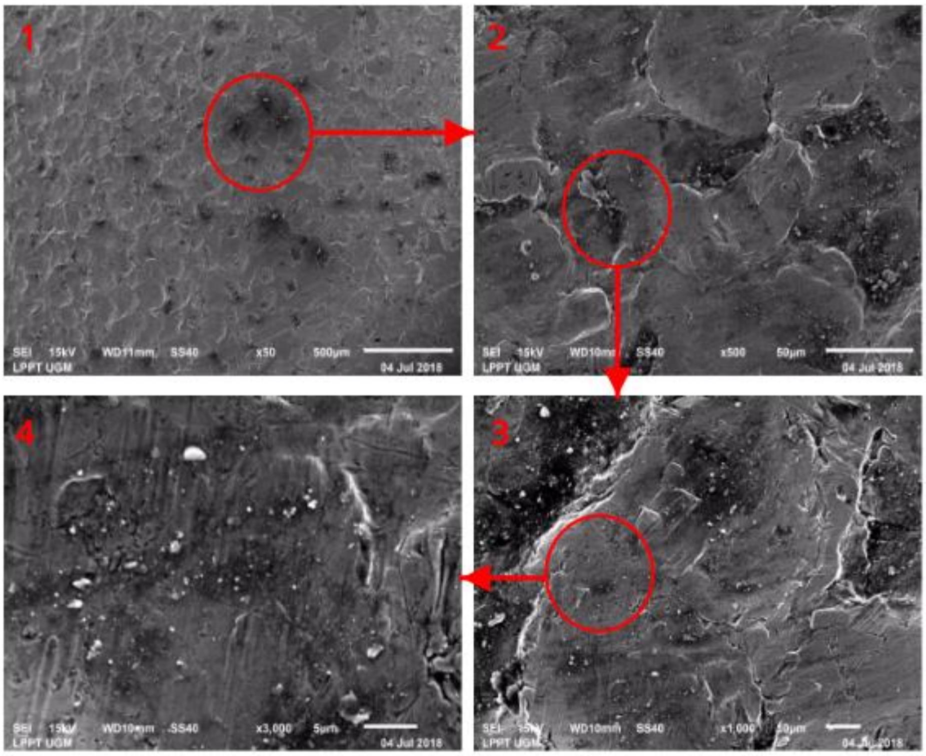

Figure 10. Scanning Electron Microscope result for non-corroded metals

After replacing the broken bearing with the new one, vibration data retrieval is done on March 8, 2018, to compare with data before repair. Vibration data can be seen after repairmen for high speed and low speed bearings tend to improve.

Table 3 shows the vibration value in the gearbox (in/Sec) after bearing replacement, data collection is carried out at 25%, 50%, and 75% load of the boiler. The value is much lower than the vibration value in the gearbox before repairs are made on August 16, 2017. With the maximum limit of the vibration value allowed on the gearbox is 0.500 in/sec then the vibration value after repair is below that threshold.

Figure 11 shows a curve of vibration measurement data before and after repair. The Chart shows the average vibration value after bearing replacement is below 0.2 in/Sec far from the maximum permissible limit of 0.5 in/Sec.

Tabel 3. Comparison Vibration Data Gearbox

	After Repair (March 8, 2018) Boilers Load				Before Repair	
	25%	50%	75%	75%	16-Aug-17	
HIV(Gear Box High Speed I/B Vertical)	0.072	0.112	0.112	0.068	0.576	0.597
HIH(Gear Box High Speed I/B Horizontal)	0.097	0.098	0.14	0.081	0.501	0.524
HOV(Gear Box High Speed O/B Vertical)	0.084	0.089	0.091	0.123	0.572	0.48
HOH(Gear Box High Speed O/B Horizontal)	0.066	0.087	0.082	0.07	0.593	0.397
HAX(Gear Box High Speed O/B Axial)	0.081	0.117	0.118	0.12	0.609	0.663
LIV(Gear Box Low Speed I/B Vertical)	0.021	0.029	0.023	34	0.374	0.269
LIH(Gear Box Low Speed I/B Horizontal)	0.029	0.031	0.031	0.039	0.454	0.251
LOV(Gear Box Low Speed O/B Vertical)	0.027	0.03	0.028	0.031	0.468	0.31
LOH(Gear Box Low Speed O/B Horizontal)	0.035	0.035	0.035	0.039	0.375	0.345
LAX(Gear Box Low Speed O/B Axial)	0.109	0.115	0.049	0.062	0.674	0.501

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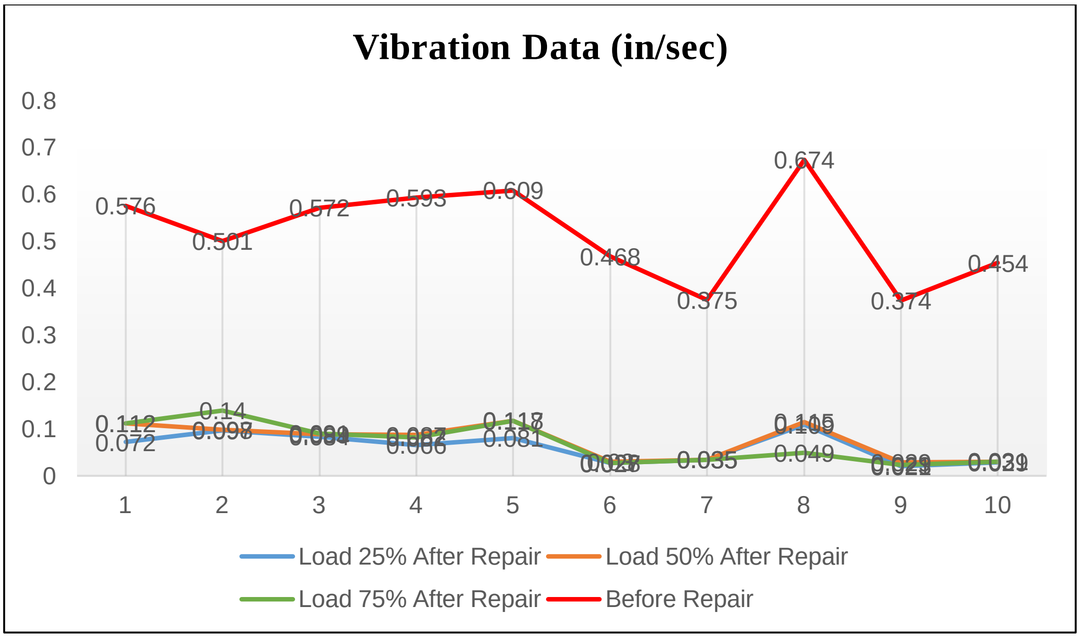

Figure 11. Comparison Chart Before and After Repair

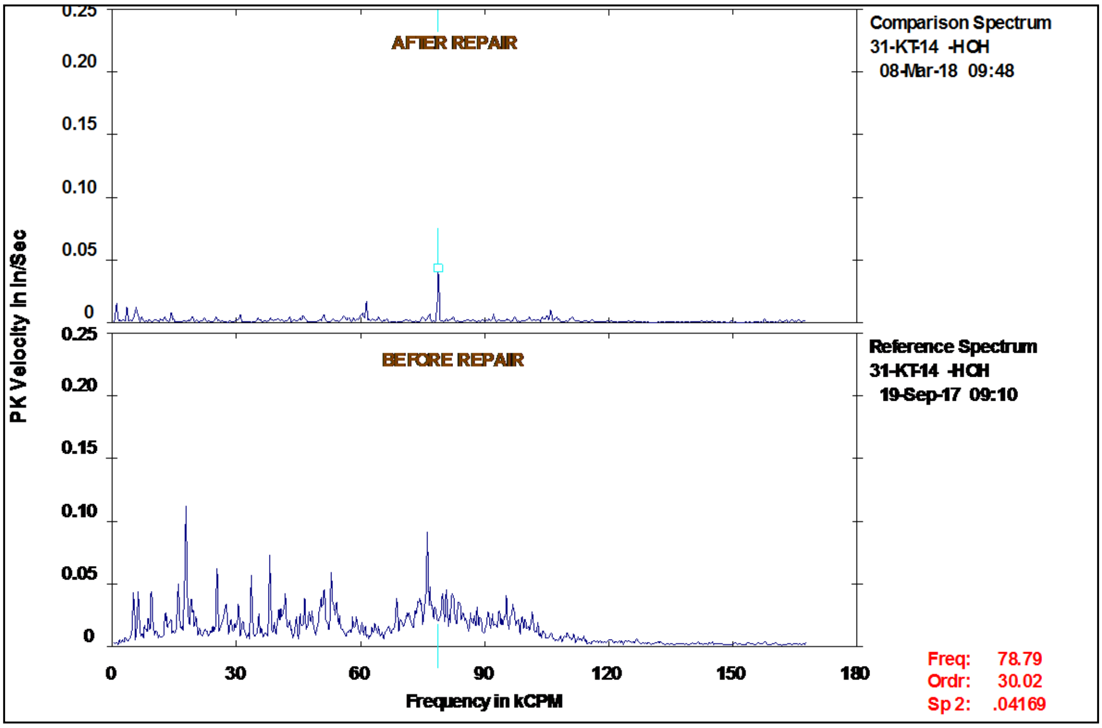

Figure 12. High Speed O/B Horizontal Spectrum Before and After Repair

Figure 12 shows the average spectrum of vibrations that occur in the gearbox before and after repair. It can be seen that before the repair there were many peaks which showed vibration in the gearbox, and after repairing it appeared that the peak formed was much reduced.

The Investigation performed on the failed bearings refers to how corrosion in bearings can occur. The possibility of water

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contamination on gearbox lubrication oil divided into two possibilities. Firstly, water contamination caused by leakage at lube oil cooler, the cooling medium used for oil cooler

Tabel 4. Water Content Data for Gearbox Lubrication Oil

	Date	wt%	Type
ISO VG 68	08/03/2018	0.01	
Before Repair	17/10/2017	27	Fresh water
	18/10/2017	1.5	Fresh water
After Repair	8/03/2018	0.45	Fresh water
	9/03/2018	1.8	Fresh water

is sea water with Pressure 2.8 Kg/cm^2 which is higher than pressure lubrication oil 1.8 Kg/cm^2. The lubricant sample is taken and checked the content the results can be seen in **Table 4.** The maximum limit of water content in the lubricant is 0.05 wt%, seen in the **Table 4** that the average water content in the lubricant exceeds this limit while the water content in the new lubricant (ISO VG68) is only 0.01 wt%.

Based on the type of water content in the lubricant it can be concluded that water content on lubrication oil are fresh water. Possible causes of fresh water contamination are through Seal Bearing or steam turbine carbon ring failure because the seal bearing found in a good condition then the most likely failure is in the steam turbine carbon ring. This can happen because if the carbon ring is damaged and water vapor enters the lubricating system through the steam turbine bearing will cause the lubricant to be contaminated by fresh water. The accumulation of water in the lubricant becomes the cause of corrosion on gearbox bearing and such corrosion results in high vibration in the gearbox.

4. CONCLUSION

The result of visual inspection analysis shows that there is sludge and water in the bearings and gears, the bearing condition has been severely corroded but the gear condition is still very good.

On the analysis of lubricants using the X-Ray Flourescence (XRF) method the values of the Tin(Sn) content is quite high and is above the permissible threshold. Tin (Sn) based on literature sourced from Bronze/ Phosphor-Bronze (with cooper), white metal bearings, and Bushes derived from components on bearing. This reinforces the assumption that the high vibration that occurs in the gearbox is caused by failure of the gearbox.

Scanning Electrone Microscope analysis shows that the rust formed has changed the shape of the metal surface and made the metal become brittle so that metal debris can be included in the lubricating system this could be the cause of the high content of Tin (Sn) in the lubricant. Rough metal surfaces can cause vibration and sound due to the large number of pointed ends of metal touching each other and over a long period of time can cause wear.

Based on vibration data, it is shown that the vibration in the gearbox has exceeded the allowance limit maximum of 0.5 in/Sec. After replacing the bearing on the gearbox, there is a decrease in the average vibration value below 0.2 in/Sec.

Thus, it can be concluded that the cause of high vibration in the gearbox based on the analysis that has been carried out is the result of damage to the gearbox bearing caused by water contamination in the lubrication system.

High vibration on the gearbox reducer is caused by the corroded bearing. Corrosion will form pitch on the bearing surface. This pitch will make bearing surface uneven and cause wear to bearing. This results in high vibration and noise on gearbox reducer. If this

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is left then it can cause damage to other gearbox components.

To prevent the same failure to happen, it is necessary to check water content on lubrication oil as often as possible. Lubrication oil observation through level glass needs to be improved. If possible, separating lubrication system between steam turbine bearing and gearbox reducer to minimize water contamination on lubrication oil needs to be carried out as well.

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6. AUTHORS' NOTE

The author(s) declare(s) that there is no conflict of interest regarding the publication of this article. Authors confirmed that the data and the paper are free of plagiarism.

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