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Effect of Ambience Temperature and Electric Current Leakage on Vibration of High-Pressure Pump

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Abstract

In this paper, we make a brief overview of the maintenance procedures and condition monitoring methods. The WKL32 model high pressure pump made in Iran Pump Co, be evaluated by the vibration analysis and sound tests, based on the proactive maintenance procedure. We study the effect of electric current leakage which is made of using the pump chassis as the welding connection cable (NULL) and check the effect of the ambience temperature on the grease lubricant viscosity and on the corrosion of the pump's bearings. Finally, we make appropriate cures according to the proactive maintenance procedure.

Keywords: High Pressure Pump, Corrosion, Electric current leakage, Air temperature, Proactive Maintenance.

1- Introduction

The industrial maintenance is a set of technical and managerial actions that are done to create a favorable condition at production. The maintenance cost is one of the main problems at every production unit which depend to a large extent of modern strategies [1-2]. The human beings have used the several periods of the maintenance procedures until they could achieve to the proactive maintenance technique. The first generation of these procedures is, make repairs after the failure, or Emergency Maintenance(EM). in this procedure, the repairs always are carried out when the machine has a failure and the main purpose is continuing the machines operation only. So that the repairs, in order to continue the machine operation, have an emergency and compulsory aspect. The second generation called Preventive Maintenance (PM). The PM was considered, but the cost of the repairs and the number of unexpected stops at systems, led to begin a great opposition against to this procedure in the early 1980s [3-4].

Due to these problems the third generation of the maintenance procedures created which become known as Pre-dictive Maintenance(PdM). In this procedure by control the machines condition and identify the signs of the system failure, a suitable solution be offerd [5]. The weakness of this procedure, is loss of attention to the root and reason of the machine failures. So, the failure repeats in the near future again.

The Root Cause Failure Analysis (RCFA), made the fourth generation of the maintenance cultures that titled as the Pro-active Maintenance (PaM). This procedure can be considered as the improved scheme of the PdM procedure. In the PaM, the maintenance process is incomplete until we find the root of failure and solve it [6].

2- Condition Monitoring systems (CM)

Condition monitoring is the process of monitoring a parameter of condition in machinery, in order to identify a significant change which is indicative a developing fault. It is a major component of the predictive maintenance.

The CM systems are a set of operations as receiving, studying and processing of physical and chemical parameters such as vibrations, sounds, lubricants, temperature and etc, in industrial equipment.

The CM systems reduce unexpected failures, the cost of repair, spare parts and the repair time, by analyzing the machinery condition. On the other hand, these systems increase the products quality, reliability, interest and the better understanding of technical skills.

The most important CM techniques are Vibration Analysis (VA), Acoustic Emission (AE), Lubricant Analysis (LA), Thermography, Ultrasonic, Electrical Signature Analysis (ESA) and other techniques such as Visual Testing, Performance Analysis and etc. We show the plan of the most important CM techniques in the Fig. 1, [7].

We give a brief overview of the vibration analysis, because it has a broad application in troubleshooting process of the engine-pump system, which is analyzed in this paper.

2-1-Vibration Analysis (VA)

The machines, even in the best operating conditions, will have some vibration, because of the minor defects. Each machine has a level of the vibrations which may be regarded as normal. However, sometimes the machine vibration level, increases or becomes excessive. The vibration level of the machine is measured with the help of the sensors. These are: proximity sensors, velocity transducers and accelerometers. The accelerometers are mostly used for the vibration analysis. The vibration signals are often contaminated by the noise signals. These contaminated signals can be unfit for fault diagnosis. The vibration features or signatures can’t be detected without the assistance of some certain techniques. Feature extraction techniques can locate certain components in signals to help detection of machine faults [1].

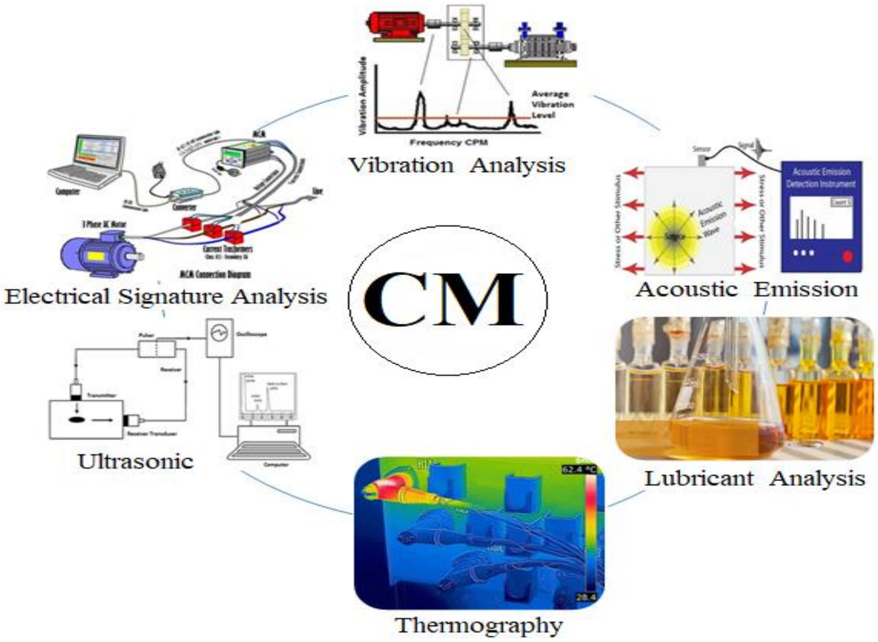


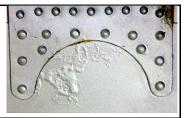
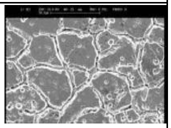
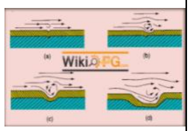
Figure 1- The Schematic of The most important CM techniques.

3- Classification of industrial faults

In our opinion, the faults of industrial machinery are divided into two categories;
1-Iner Structural Faults(ISF). 2- Outer Structural faults (OSF).
The ISF are the faults which created by generated forces inside the components used in the machine's structure, such as corrosion, fatigue, electrical faults in the machine's electronic parts and etc.
The OSF are the faults which are consequence of an outside force such as the faults which are made by impact, coupling, machine installation, fire, natural disasters, outside electric current leakage, air temperature and etc.
One of the most important reasons for the mechanical systems failure and industrial challenges is the corrosion phenomenon. The consumption of the corrosive materials has led to increasing the financial and systemic losses. So, it is important and essential to know the ways that cope these damaging factors. The various corrosions, their causes and a picture of their effects are summarized in table 1.

Table 1- Corrosions and Their Properties

Corrosion		Reason	Damage	Sample
General		Chemical or electrochemical reaction of a metal and its environment	Gradual destruction of a metal or alloy	Corrosion of the steel structures and iron parts 
Localized	**Pitting**	Loss of the protective coating	Creating a small hole on the metal surface and penetrating of corrosion into it	Oil and gas drilling industry 
	Crevice	Corrosive liquid penetration in a static position which isn't in contact with the surroundings	Development of corrosion in grooves	Gaskets and seals 

Filiform	Coating defects on a metal surface	Corrosion penetration in the uncoated and weak parts	Surfaces of the galvanized and imperfect coated sheets 
Galvanic	Contact of two different metals in a corrosive electrolyte	One metal acts as anode and the other as cathode. Anode becomes corroded and cathode is protected	A common example is galvanized iron, a sheet of iron or steel covered with a zinc coating which are exposed to water 
Environmental Cracking	Environmental effects such as chemical corrosives, heat, tension, and etc.	1- Stress corrosion cracking 2- Corrosion fatigue 3-Hydrogen stress cracking and etc.	The couplings, welded parts and etc. 
Granular	Chemical or electrochemical corrosion in the grains boundary at a polycrystalline metal	Grain boundaries are the main location of dislocations. Dislocations inside the grains, accelerate the corrosion rate	Effect of chrome carbide in austenitic stainless steel 
Alloy Defeat	Alloying elements with the favorable electrochemical property (such as zinc and copper in brass)which are in an electrolyte environment	Galvanic corrosion in alloying elements	Zinc makes porosity as the anode in Brass 
Fretting	The permanent flow of a corrosive liquid on the surface of metals	Creating the slots and grooves on the surface of metals.	Valves, blower and centrifugal pumps, heat exchangers such as oilers and condensers, turbine blades and etc. 
High Temperature	Reaction of vanadium compounds or sulfates in some fuels at high temperatures in a combustion chamber.	Forming a corrosive salt on the stainless steel and other alloys.	All machinery which are in contact with a hot fuel containing a certain contaminant 

4- The Condition Monitoring of the WKL32 High Pressure Pump

In this paper presents the condition monitoring process of the WKL 32 high-pressure gear pump, made in the Pump Iran Co. The duty of this pump is provide the water of a chiller from an industrial unit in the South Pars Petrochemical Co. In the initial study of this pump, abnormal noises, high temperatures and increased vibrations were clearly seen. We found the exact location of the pump's failures with the vibration analysis and sound processing by the Easy Viber System, made in VMI CO of Swedish, and the STD 270System, made in USA. The Engine-Pump system scheme and directions of vibrations measurement are shown in Fig. 2.

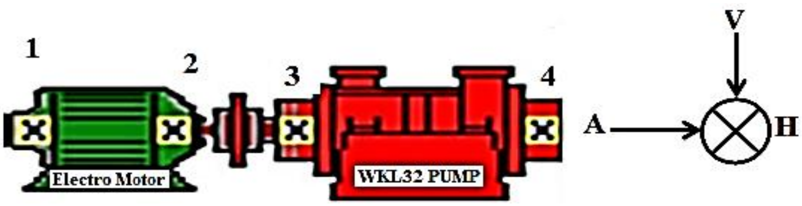


Figure 2- The Scheme of the motor- pump system and the points of vibration measurement

We can see in the Table 2 and 3 that the maximum vibrations recorded from the Engine-Pump system are related to the non-drive end in horizontal direction(NDE-H-12.2mm⁄s) and vertical direction (NDE-V-10.7mm⁄s) of the pump. Note that according to the ISO10816 standard the maximum acceptable vibration for this pump, is $5^{mm}/_{s}$, So, the vibration frequency in H and V directions are at risk [8].

Table 2- Vibrations of the engine- Pump system before repairs

SYSTEM	Motor		Pump	
Point	1	2	3	4
H($\frac{mm}{s}$)	1	1.4	3.5	12.2
V($\frac{mm}{s}$)	1.3	2.3	3.2	10.7
A($\frac{mm}{s}$)	-----	-----	4	3.2

Table 3- Vibrations of the engine- Pump system after repairs

SYSTEM	Motor		Pump	
Point	1	2	3	4
H($\frac{mm}{s}$)	۰.۸۵	۱.۴۳	۲.۹	۱.۱
V($\frac{mm}{s}$)	۱.۱	2.3	۲.۵	۰.۹۴
A($\frac{mm}{s}$)	-----	-----	۰.۶۶	۰.۳۵

According to the unusual vibrations and sounds from the ball bearings in the NDE side of the pump and the spectrum curve which is shown in figure 3, we can say that the ball bearings in the NDE side of the pump are damaged. You can find that the corrosion phenomena are one of the main causes of damage in the bearings. See Fig. 4.

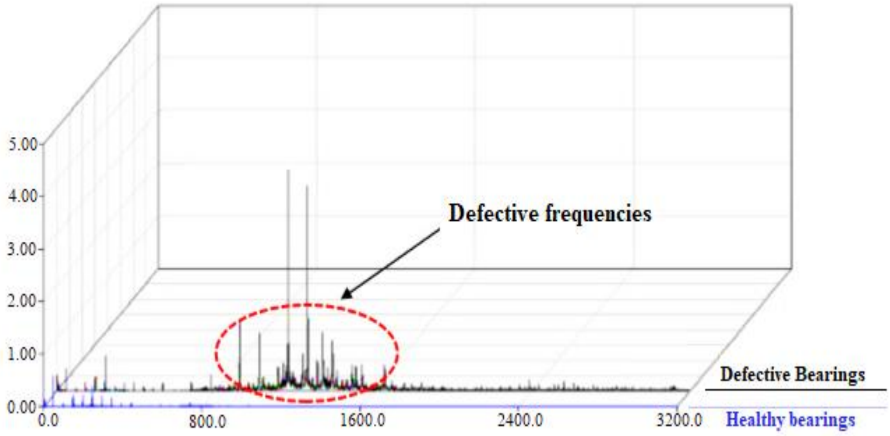


Figure 3- Spectroscopy of the defective ball bearings in the non-drive end in horizontal direction NDE-H), before and after repair

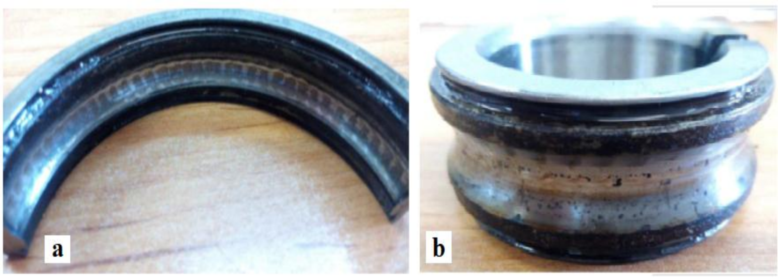


Figure 4- Images of the defective ball bearings. a) External ring. b) Internal ring

After diagnosing the system problems, repairs and corrections were made and the defective bearings were replaced with a new one. With pay attention to the spectroscopy diagram and vibrating trend shown in Figures 4 and 5, we see that the system operation after the repairs become stable and properly.

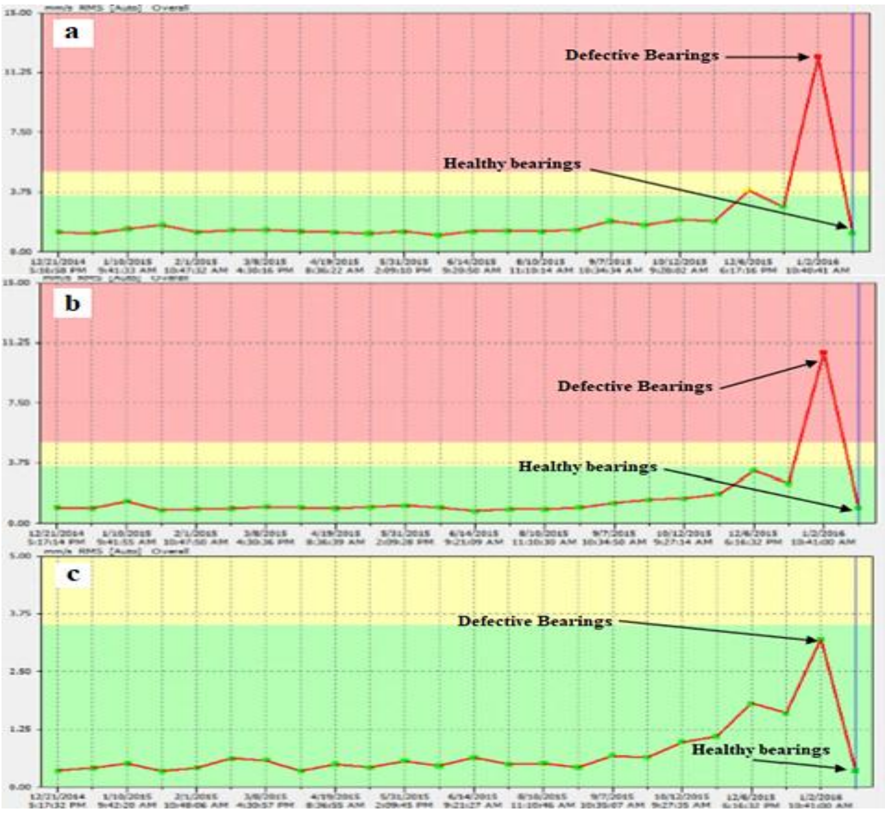


Figure 5- Vibration trends of the system, before and after the repairs. a) Horizontal direction (H). b) vertical direction (V). c) Axial direction (A).

The results of the statistical comparison of the system, before and after the repairs, is shown in the bar chart in Fig.6.

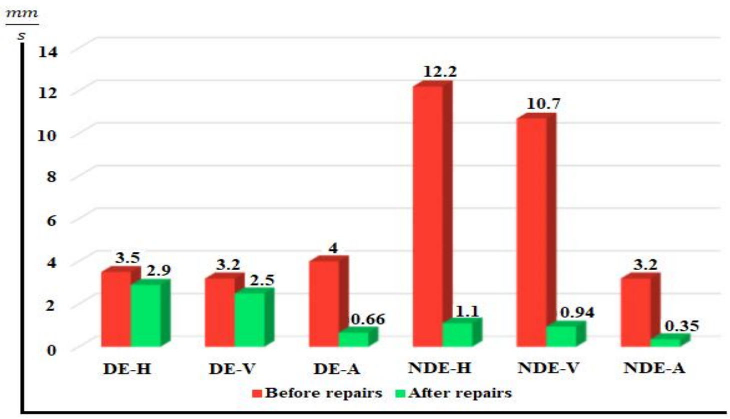


Figure 6- Statistical comparison of the pump vibrations, before and after the repairs

5-The Pro-active maintenance implementation

What we have mentioned up to now, is based on the pre-dictive maintenance procedure. We found the defects and repaired the engine-pump system. But we didn't specify the reason of defects and can't be sure that the system works with confidence and standard condition. So, it is necessary for us to specify the causes and cures of the failures, according to the pro-active maintenance procedure.

5-1- The bearings failures: The causes and cures

The first cause: According to the bearings and pump catalogs, bearings temperatures shouldn't be 50ºC more than the ambient temperature. But, due to operational conditions of the engine-pump system, the temperature of the bearing's external shell shouldn't be more than 90°C. Unfortunately, the ambient temperature increase to 70°C in the warm days. These data show that the bearings temperature climb to more than 120°C, which doesn't match to the bearings standard (90 C°). So, in these conditions, the chemical compounds of the bearings grease (lubricant additives), such as chlorine or sulfur, are decomposed and acidified, which causes the corrosion in the bearings. In addition, in this temperature, the main components of the pump may be failure, because, according to the pump's catalog, operational temperature of the pump, with the mechanical seals, is in the range of -50 to140 C°, and with the graphite strip seals, is in the range of -50 to110 C°.

The cure of the first cause: 1- Choose a high-temperature grease which has a good heat stability. The choice of a lithium-based grease can help us to prevent the extreme heat, at the ball bearings. Although this grease hasn't a good water resistance,
2- The bearing oil coolers sit within the bearing housing and removing the heat directly from the oil sat in the oil sump. The shape of the oil sump depends on the machine orientation and operating parameters. As a result, the geometry of the cooler varies widely from one application to the next. Cooling of a bearing on a vertical shaft may require a circular array of tubes to sit around the outside of the bearing while other arrangements may need a set of small cooling clusters in the bottom of the housing.
3- Using a fan on a bearing housing can be an acceptable cooling method for cooling a bearing in an alert or alarm condition. If the bearing is on a circulating oil system, increasing the oil flow may also cool the bearing. However, too much oil flow can cause oil churn and increased friction inside the bearing.
4- The bearings can be cooled with an oil easily. Use an oil lubricants vs the grease lubricants are a most common technique in the high speed and high-temperature situations that need the heat transfer away from the bearing surfaces. Mineral oils are the more common for cooling the bearings.
5- In order to reduce the ambience temperature that has a great role on increasing the temperature of the ball bearings, we can install the engine-pump system in a suitable place that is far from the ambience high temperature.

The second Cause: The pump chassis is made of a gray cast iron which by a structural steel, such as IPE, U channel (UNP), angle(L) and etc., is installed on the pump's base plate. We found that the chassis of the pump was used as the welding connection cable (Null) which this problem cause which it has been expose to the electric current leakage for a long time. Fig. 7, shows the connection point of the welding cable to the pump chassis.

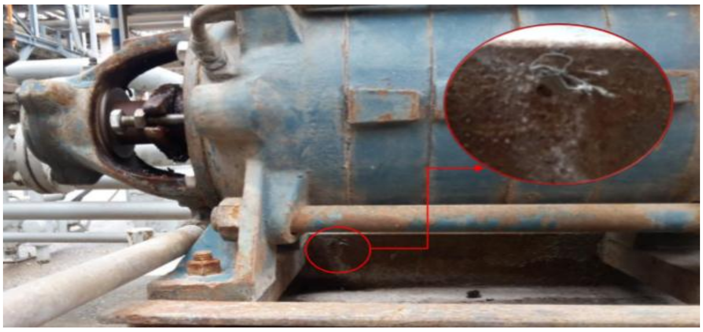


Figure 7- The point of the welding connection cable to the pump chassis

When the electric current passes through a bearing, arcing occur through the thin oil film at points of contact between the path of electric current and the rolling elements. The arcing can change the structure of the bearing's metal and the points of contact are melted locally which can be seen by the naked eye. The effects of this phenomenon on the pump's bearings are shown in Fig. 8.

Figure 8- Destructive effects of the electric current leakage on the bearings

The cure of the second cause: When a bearing damage from the electrical corrosion has begun, increased the noise levels, reduced the lubricant effect and excessive the vibration will decrease the bearings life drastically.
To overcome this problem, we can use a special ceramic coating that is designed by the bearings manufacturers and called electrical insulate or BMI. This coat is applied using plasma spraying technology and can be applied on the inner or outer ring of the bearings depending upon the application. This coat protects the bearings completely and can tolerate 7000 watts of electricity.
To prevent the electrical erosion of the bearings and other components, generator manufacturers incorporate a slip ring and brush system to provide a low resistance path to ground for any charge that may build on the rotor shaft. This grounding system may degrade over time if the ground ring becomes oxidized, the brushes become worn or the brush holder spring does not have enough pressure to hold the brush firmly against the ring.
3- The bearings surface be covered by a layer of reinforced fiberglass. This layer protects the ball bearings against surroundings damages such as the electric current leakage and the ambience high temperature
According to the table 1, the Probability of galvanic corrosion, alloy defeat and intergranular corrosion can be considered as options for corrosion in the ball bearings.

6-The corrosions analysis at the pump's bearings

The bearings industry uses different materials for production the various bearing components. The most common material which use for produce a load carrying component is 52100 chrome-steel alloy. The bearings commonly are made of high carbon-chrome alloy steels (AISI 440C: 0.95~ 1.2% C, 1% Si, 1% Mn, 0.04% P, 0.03% S, 16~18% Cr, 0.75% Mo). The bearings inner and outer rings, balls and rollers are made of a hard alloy steels (1% carbon, 15% silicon, 3% manganese) and in some cases from alloys such as cementation steels, non-magnetic steels or bronze. The shelves in the large bearings and roller bearings are made of coinage steels or light metals.
Using controlled processing and heat-treating methods, the bearing components achieve to high strength (resist cracking) and a hard surface (resist fatigue).

6-1-The Galvanic Corrosion

Galvanic corrosion is based on the three following conditions which must be simultaneously met:
– Different types of metals,
– Presence of an electrolyte,
– Electrical connectivity between the two metals.
Experience shows that the galvanic corrosion only occurs when two metals have a potential difference at least 100mv. Note that the galvanic corrosion intensity is not related to the potential difference between the two metals.
According to the electrochemical series and potential difference ranking of metals (see Fig. 9.), and due to the materials of external and internal rings, balls and shelves which are the same and made of alloy steel, Probability of the galvanic corrosion in the pump's bearings is canceled.

Electrode	E^0
Li^+/Li	-3.045
Rb^+/Rb	-2.925
K^+/K	-2.925
Cs^+/Cs	-2.923
Ba^{2+}/Ba	-2.905
Ca^{2+}/Ca	-2.866
Na^+/Na	-2.714
Mg^{2+}/Mg	-2.37
Al^{3+}/Al	-1.66
Ti^{2+}/Ti	-1.630
Zr^{4+}/Zr	-1.539
Mn^{2+}/Mn	-1.179
V^{2+}/V	-1.175
Cr^{2+}/Cr	-0.913
Fe^{2+}/Fe	-0.44
Cd^{2+}/Cd	-0.403
Co^{2+}/Co	-0.277
Ni^{2+}/Ni	-0.250
Sn^{2+}/Sn	-0.136
Pb^{2+}/Pb	-0.126
Fe^{3+}/Fe	-0.037
H^+/H_2	0.000
Cu^{2+}/Cu	+0.337
Cu^+/Cu	+0.521
Ag^+/Ag	+0.799
Hg^{2+}/Hg	+0.851
Pd^{2+}/Pd	+0.987
Pt^{2+}/Pt	+1.188
Au^{3+}/Au	+1.50
Au^+/Au	+1.692

Figure 9- Electrochemical series of metals

6-2-The Intergranular Corrosion

The element which has a positive effect on the corrosion resistance of steel is the chrome. However, to use this effect, the steel must contain at least 13% chromium.
The nickel is another important element for improving the corrosion resistance of the bearings alloy steel. But the presence of the elements such as carbon, silicon and manganese used in the bearings alloy steel, reduce the corrosion resistance.
So, due to produce the acidic environment by the decomposed grease lubricant, the intergranular corrosion and the sediment of chromium carbide may occur in the bearings components. We can consider these phenomena as a factor for damage the bearings. Figure 10, shows the affected zone from these phenomena.

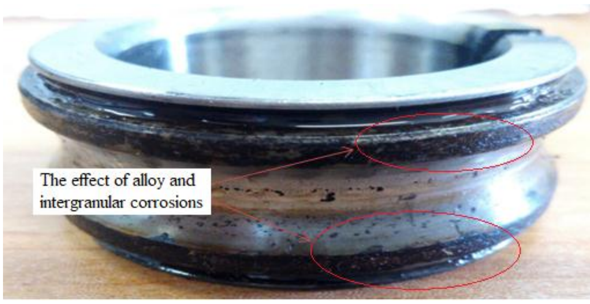


Figure 10- The effect of alloy defeat and intergranular corrosions on the defective bearing

6-3- The Alloy Defeat Corrosion

In our opinion, the alloy defeat is due to the effects of the intergranular corrosion. If the intergranular corrosion continues over a long time, it will lead to a localized alloy defeat corrosion. So, if a machine component, which has the intergranular corrosion, be repaired with great delay, the alloy defeat will occur at future.

7- Conclusion

Attempts to identify and eliminate a small mistake in the machinery of a manufacturing company can reduce the overall manufacturing cost, save time and money and provide an opportunity for the company to reallocate these saved resources to other profit generating activities.

A small mistake from the welding and machinery installation teams led to the electric current leakage and applying the high ambient temperature on the wkl32 pump. We investigated the causes of repeat damages in the pump with increasing the costs and waste the time and stopping production and even decrease the employee’s satisfaction.

The corrosions in the pump's bearings were identified by the VA and sound analysis. Degradation of the lubricating grease used in the bearings and high ambience temperature were the major causes of bearings failures.

At the end, we must say that finding and replacing or repairing the faulty components is a temporary effort in the maintenance of human industries. We must, by a perfect hegemony on our work, solve problems from the root and try to avoid the mistakes repeating.

This paper can be a small and painful hint to all the valuable engineers and experts who’s their powerful hands will make the future of us and our children’s.

8- References

1. Li Yanga, Yu Zhaoa, Rui Peng b, Xiaobing Maa, Opportunistic maintenance of production systems subject to random wait time and multiple control limits, Journal of Manufacturing Systems 47 (2018) 12–34.

2. Gerardo Pagaldaya, Patxi Zubizarretab, June Uribetxebarriac, Asier Erguidod, E. Castellanoe, Efficient development and management of after sale services, 6th International Conference on Through-life Engineering Services, TES Conf 2017, 7-8 November 2017, Bremen, Germany.

3. Abdullahi M. Salmana, Yue Lia, Emilio Bastidas-Arteagab, Maintenance optimization for power distribution systems subjected to hurricane hazard, timber decay and climate change, journal of Reliability Engineering & System Safety, Volume 168, December 2017, Pages 136-149.

4. Dong-Ping Song, Production and preventive maintenance control in a stochastic manufacturing system, Journal of International Journal of Production Economics, Volume 119, Issue 1, May 2009, Pages 101–111.

5. A.S. Nazmul Huda, Soib Taib, Application of infrared thermography for predictive/preventive maintenance of thermal defect in electrical equipment, Journal of Applied Thermal Engineering, Volume 61, Issue 2, 3 November 2013, Pages 220–227.

6. Kaican Kang, Velusamy Subramaniam, Integrated control policy of production and preventive maintenance for a deteriorating manufacturing system, Journal of Computers & Industrial Engineering, Volume 118, April 2018, Pages 266-277.

7. T. Touret, C. Changenet, F. Ville, M. Lalmi, S. Becquerelle, On the use of temperature for online condition monitoring of geared systems - A review, Mechanical Systems and Signal Processing - Volume 101, 15 February 2018, Pages 197-210.

8. F. Bogard, K. Debray, Y.Q. Guo, Determination of sensor positions for predictive maintenance of revolving machines, Journal of International Journal of Solids and Structures, Volume 39, Issue 12, June 2002, Pages 3159–3173.