

# Development of air compressor lubrication

[Environment](#), [Air](#)



In this project, the mission which needs to be accomplished is to investigate the relentless root cause of such failure and to give useful recommendations which can help to avoid such failures in the reciprocating compressor under study in the future. An engine driven auxiliary air compressor failed, the air compressor is located in the Hawke workshop. The first stage will be to establish details about the compressor, the manufacturer and how the compressor works. Classification of compressors and types will be also discussed and of course the theory of operation. Collecting components failed in order to be examined subsequently for the failure cause or causes this will be held using a variety of methods. NDE (non-destructive examination) or NDT (non-destructive testing) is valuable way to use for preliminary inspection of the failed parts without damaging it. DT (destructive test) is another way to check and inspect parts but this inspection method appears from its name it lead do destructive damage the tested parts which will be no longer able to be used. Fatigue principles also will be showed. Studying all the above will gave a clear idea about the cause of the damage.

Discussion of the probable causes for the failure well be performed in the following chapters as well as the conclusion obtained from study conducted.

## **1. 1 Introduction**

Air compressor producing is return for long time ago. The main idea of compressing air and discharge it used by the ancient in deferent ways. The first usage for the air compressor is increasing the combustion of furnace.

The air compressor is raising the heat of the furnace by bellowed compressed air to it. Moreover, the main products got from these furnaces are metals and weapons.

Muscles were the main power source for the air compressor. The below figure shows the old air compressor. That kind of old air compressors still used in different productions.

This project will investigate and analysis a failure happened in an air compressor. This investigation will be done in several ways to figure out the cause of the failure. Air compressor is a machine has the ability to compress the air and release it to convert the electrical power to kinetic energy to use it in several industrials and usages. Air compressor is consisting of many components. These components are electrical motor, pistons, air pump, air receiver, air drier, filters, air pressure regulator and pressure switch.

All of these components will be discussed in details in the next chapters. There are also types of air compressor will be discussed later.

## **1. 2 Background**

The case which had here is a failure in an air compressor. From the first sight on the damage happened in it, it seems to be that the failure happened in the connecting rod and it's obvious from the below figure number 3. This figure shows that the failure happened in the connecting rod from the ring part which connected to a crank shaft. But the reason for this failure is unknown as there are several scenarios could be adopted. The first scenario is the fatigue is the reason for this failure. The second scenario is a very

heavy pressure loaded to the compressor which led to that failure. These are the most expected scenarios which will be investigated later in this project to figure out the reason of the failure.

### **1.3 Aims and objectives**

Aims:

The main aim of this graduation project is to investigate and discover the cause or the causes of failure of diesel engine driven auxiliary reciprocating air compressor made by Knorr-Bremse, model number is LP 4865. This will be achieved by carrying out the below objectives, once its achieved, the main aim of the project will be achieved.

Project objectives:

Collecting valuable information about, model number is LP 4, this will include: design of compressor, design of each part, construction materials of each part, operation principles, working theory, production range.. etc. collecting data will help to recognize main failure cause, and accordingly to prepare new procedure to eliminate the problem, to decrease the opportunity of failure occurrence in the future, use greater safety factor and to recognize the person or the entity responsible for failure and to make mistake proofing for future avoidance of the failure. Collecting this background information is not limited to numbers only but it is should be extended to everything such as pictures, charts and graphs and samples.

Investigating operational parameters, history of operation, nature of operation.. etc in order to be able to determine precisely the root cause of such failure and which failure mode it follows.

Physical investigation or macroscopic inspection should be carried out. This mission includes photo capturing, code of the product, model number, lot number, batch number and serial number.

Perform compressor disassembly in order to dismantle each component, part, assemblies and sub-assemblies to perform through investigation and inspection of each. It's should be mentioned that necessary tests and analyses should be performed; mainly the manufacturer usually has his own procedures and tests for test and inspection.

## **2. 0 Air Compressor**

### **What is the air compressor?**

Air compressor is a machine that converts electric power to kinetic energy (motion). This energy comes from pressurizing and compressing air. After that, the compressed air goes into a chamber, and the air kept in the chamber by unidirectional valve. There are many types of compressors these types are: reciprocating compressor, rotary screw compressor and centrifugal compressor. These types will be explained in details below.

### **2. 1 Reciprocating compressor:**

Reciprocating air compressor is positive displacement compressor. This compressor sucks a volume of air and presses it with high pressure. This pressure done by using a piston and cylinder as movement part and

displacement part. The compressor could be single acting or double acting according to its accomplish by using one side or both side. When the pressure difference between the cylinder and the receiver became proper, the valves open. Inlet valves open when the pressure in the cylinder is slightly below the intake pressure. Discharge valves open when the pressure in the cylinder is slightly above the discharge pressure. The compressor could be a single stage when the compression process done parallel.

Advantages:

- Simple design.
- Lower initial cost.
- Easy to install.
- High efficiency with 2 stages.
- No need for lubrication.
- Large range of horsepower.

Disadvantages:

- Maintenance cost is high.
- Many moving parts.
- Vibration problems.
- Foundation maybe required.
- Not running at full capacity all the time.

2. 2 Rotary screw compressor:

Also Rotary air compressor is a positive displacement compressor. Single stage helical or spiral lobe oil flooded screw is the most common in rotary air

compressor. This compressor is consisting of 2 rotors located in a case where the air is compressed internally without any valves. The cooling for these compressors done by oil. As the cooling for the working parts happened inside the compressor, this type of compressor will not experience over heat due to operation, so it could operate without stop. Due to the simple design of the rotary screw compressor and it's parts it can be maintained easily and installed any where could handle its static weight. The 2 stages rotary air compressor uses 2 rotors with a combined air end. This 2 rotors installed in series to share the compression. This raise up the efficiency with 50%. This 2 stage rotary compressor combined the maximum profit from the rotary screw with its simplicity and flexibility and the reciprocating compressor with its effective energy when it works 2 stages with double acting. The 2 stages of this compressor could be cooled by water, air or oil. The cooling system for this compressor could be oil, air and water.

#### Advantages:

- Simple design.
- Low initial cost.
- Low maintenance cost.
- Good efficiency at 2 stages.
- Easy to install.
- Few moving parts.
- Common in use.

#### Disadvantages:

- Limited life for airend.

- Service for air end couldn't be done at field.
- High rotational speeds.
- Must be oil lubricated.
- Single stage has low efficiency.

### **2.3 Centrifugal compressor:**

The centrifugal air compressor is a dynamic compressor that depends on transfer of energy from a rotating impeller to the air. This is done by changing the air's momentum and pressure. By slowing the air in stationary diffuser the momentum is converted to pressure. This compressor is oil free. There is a separation between the lubricated oil and air by shaft seals and atmospheric vents. Where the high volume of dry air is required a centrifugal compressor is the proper compressor as it has a few moving parts and could operate continuously.

### **2.4 Rotary Sliding Vane Compressors:**

Rotary sliding Vane Compressor is also a positive displacement compressor. This type of compressor is consisting of rotor and stator and eight blades. Between the intake and exhaust valves a crescent shape is formed by the location of the rotor and stator. The compression is achieved by one complete rotation as the volume changes from the maximum to minimum. Vanes are pushed outward against the stator walls. Injecting oil from the intake valve and along the stator wall to cool the air and make a sealing between the stator wall and vanes and also to lubricate bearings. So that a filtration system must be installed to separate the oil from the compressed air.

Advantages:



- Simple design.
- Easy to install.
- Low cost.
- Maintenance cost is low.
- Reliable.
- Few moving parts.

Disadvantages:

- Single stage.
- Low efficiency.
- Must lubricate with oil.
- Difficult with over pressure.

## **2. 5 Main Component of Air compressor in general:**

The system could be installed in 2 methods. The first method is where air drier before receiver tank. The second method is where the air drier after the receiver tank. These components will explained in details in the below paragraph.

Receiver tank: From its name receiver tank is a tank that receives the discharged air. It helps to prevent rapid compressor cycling by providing a storage capacity. The advantage for the receiver tank is reducing the wear and tear in motor, inlet control system and compression module. It also eliminate the flow pulsing.

Air Dryers: there are 3 types of air dryer. The main objective for air dryers is to dry the air to prevent rust and wearing in the air compressor components and discharge line. These types are:

Refrigerated air dryers: This dryer used a mechanical technique to remove moisture from compressed air and cooling it and condense water.

Desiccant dryers: This dryer is absorbing water vapour by using utilizes chemical drops called desiccant. The common desiccants used in this dryer are silica gel, molecular sieve and activated alumina.

Deliquescent air dryers: This type of dryer using desiccant to dry compressed air. The wetness in the compressed air reacted with the absorption material and turned into liquid which drained from the dryer. This process could be corrosive so the corrosion check has to be done.

Filters: Filters are installed to remove the lubricants and water from the compressed air. It could be installed downstream at refrigerated air dryer or upstream at desiccant dryer. The most common in filters is coalescing filter.

But this filter it only can remove liquid and water which have been previously condensed.

Piping Distribution systems: Piping distribution system is controlling in how the compressed air go out to the tools and also determined the required energy for the air compressor.

## **2. 6 The reciprocating air compressor (knorr-bremse, model lp 4865)**

The main study object in this project as said before is to study the reciprocating air compressor (knorr-bremse lp 4865). By searching the internet and try to get information about the air compressor which needed to complete this study but unfortunately the required information couldn't be found except its maximum pressure 12 bar and volume 460 . So the general information about the reciprocating air compressor will be mentioned instead of the specific air compressor.

There are 9 main parts for the reciprocating air compressor these parts are:

**Crank case:** Crank case is a close rigid body where the crank shaft and the bearing house where located. This body could by rectangular or square shape. Mainly crank case formed by using cast iron.

**Crank Shaft:** Crank shaft in one of the most important parts in air compressor. It is a motion transferor. It designed as one piece has balance in its dynamics and tries to avoid any twisting. To ensure a long life for bearings, the polishing and crank pin will be done. Generally crank shafts have a fly wheel. This crank shaft manufactured mainly of high grade S. G iron.

**Connecting rod:** This part is responsible of transfer the motion from the crank shaft to the piston and changing the direction from the rotating motion come from the crank shaft into reciprocating motion in piston. This part is mainly forged of alloy steel.

**Bearings:** Bearings are made to provide the rotating gear with rigidity. It's mainly manufactured of copper lead alloy.

**Cross slide:** to get a perfect running for cross head, this part is responsible for reduce the inertia. This part is commonly manufactured of high grade S. G. iron.

**Cylinder:** This part is where the air flow passes and compressed. Cylinders are manufactured with water jacket to reduce the generated heat from the compression process. This cylinder mainly made of cast iron.

**Pistons:** Piston is the main part in the compression process, which move forward to compress the air and backward to intake a new air amount to compress. There are 2 types of piston according to its lubrication system, the first type is non-lubricated which made from aluminium alloy, and the second type which is lubricated is made from cast iron. Due to moving of piston in the cylinder, so there must a space exist between them, to ensure there is no leak happened for air a piston rings located on piston.

**Piston rod:** Piston rod is this rod which connects the piston to the connecting rod. The piston rod is manufactured of alloy steel.

**Intake and discharge valves:** These valves are responsible for the amount of air sucked or discharged. When the piston in the retraction position the suction valve open to allow the air to get in. when the piston move forward and reach the maximum pressure the discharge valve open. These 2 valves are adjusted to be opened and closed according to the pressure difference

between inside the cylinder and the outside. These valves are made from stainless steel even a plate type or spring type.

## **2. 7 Air Compressor Lubrication**

Due to the operation of the air compressors which have different moving parts, a friction must be occurring. This friction generates heat and not just that it leads to part wearing which probably lead to a failure. And some time a kind of sealing need to be installed to prevent the compressed air from leaking. All of these reasons lead to using lubrication. Oil lubrication is a must in air compressors to overcome all above problems. The lubrication method could be different from type to another, but the main idea is to prevent the friction between moving parts like lubricate the bearings, or at the same time in some cases like reciprocating air compressor it also works like sealing between the cylinder wall and the piston. The problem in lubricate the air compressor is the selection of the proper oil. The selected oil must be industrial oil with high quality and matching the operation requirements. The environment of where the compressor will be installed is one of the parameter of selecting the lubrication oil, if the environment is too cold and the temperature is low the frizzling point, an anti-frizz oil must be use. If the environment is too hot oil with high viscosity and ability to heat resistance must be used. All of these restrictions must be considered while selecting the lubricant.

These are the main idea of lubrications but the implementation is different according to each type of air compressor. The lubrication system changes

from one type of air compressor to another according to the operation theory of it.

### **3.0 Quality assurance for the manufacturing process**

Air compressors are designed to work in both the industrial and the private fields, it designed to press gas or pressured air. During the air compressor operations leak or failure maybe happened and this will lead to a serious damage. The quality assurance purpose is to guarantee if the production is safe and ready to use or if rejected and have defects. This operation done by two methods the first one is the destructive test which means that the tested object will be destructed and no longer could be used and this type used in the initial design and on the first production to be sure of it. The second test is called the non-destructive test (NDT) which means we can make our test and be sure if the production is good to use or not without destructing the production. This type (NDT) what we are going to focus on because it's the most common method in inspection.

The definition of the NDT is it's a test methods used to examine an object without impairing its future usefulness. There are a several methods in NDT used like:

Visual

Microwave

Thermograph

Tap testing

X-ray

Magnetic particles

Acoustic Microscopy

Acoustic emission

Magnetic measurements

Liquid penetrate

Ultrasonic

Flux Leakage

Eddy current

Replication

Laser interferometer

All of the above methods are used in NDT, but in our case we will go to use the common methods and try to clarify its operation and how to use.

Visual inspection: It the most common and basic inspection method. In this method we can use fiberscope, bore scopes, magnifying glasses and mirrors. Another technology could be used as electronic microscopes have the ability to enter the narrow places inside the air compressor.

Magnetic Particle Inspection: This inspection could be done by magnetize the inspection part. After that coloured particles of iron covered the inspection

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area. These particles of iron will spread to the magnetic flux and show the discontinuity area. By applying the proper light this inspection could be checked by visual. splinedflour

Radiography: To perform this check a shot waves with high energy is used. Radioactive source or X-ray machine could generate such waves. The part which will be tested will be located between the radiation source and a film. This part will prevent some of the radiation. Thick areas will stop more waves. This will lead to variation on the film darkness the thick part will be less dark and the thin or cracked part will be more darker. RAD1Casting

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Eddy Current Testing: This type of test is used to discover the crakes on the surfaces. It also could be used to test the thickness of coating of the surfaces. eddy. PNG

Ultrasonic Inspection: To use this test a high frequency sound wave is applied to the surface of the part. These waves are reflected waves which will be reflected from any crack inside the material. This sound wave are reflected into the device which will show the reflection time on a gage this gage could show the depth of the crack by time of reflection. It could also be connecting to a computer by using a computer program which will draw a diagram of the part and the crack location.

Liquid Penetrate Inspection: To apply this type of test a liquid with high moistening spread over the tested part and gave time to leak into the crakes. After that the rest of liquid is removed from the surface. After that a



special powder spread over the surface to get the stuck liquid out from the crack. The crack will appear and could be discovered by eye. To increase the sensitivity and accuracy of this test it could be done under ultra violet light.

For the above types of NDT there is some common application where they also could be used:

Inspection of Raw Products:

- Forgings.
- Castings.
- Extrusions.

Inspection Following Secondary Processing:

- Machining.
- Welding.
- Grinding.
- Heat treating.
- Plating.

In-Service Damage Inspection:

- Cracking.
- Corrosion.
- Erosion/Wear.
- Heat Damage.

### **3. 1 Fatigue**

The strength of the product is the most important safety factor. To be sure that the product will be safe and could stand the applied loads safety factor must be added to the design. During the operation, parts experience a non-constant loads which lead failure along with time.

Fatigue could be defined as a failure happened due to a rapid variation in loads, but without any of this load variations exceed the maximum load. This type of failure happened commonly in metallic materials not only but also in different materials. There are 3 stages for Fatigue, these stages are:

1. Initial crack.
2. Propagation of crack.
3. Final fracture.

### **3. 2 How to analysis fatigue to prevent it**

Component material and stress field are the main 2 principals that govern the amount of time needed for crack to start and spread accusing a failure.

There are 3 main methods to calculate the fatigue time, these method are:

1. SN Method: To predict a fatigue life for a part stress life approach could be used. This method gave the fatigue life for the object. This method is depending on the calculation of varying elastic strength so it couldn't be applied to low fatigue cycle. But this type of test is very accurate at high fatigue cycles.

2. EN Method: This method is using plastic stress to calculate not only the fatigue life but also the crack penetration. The advantage of this method is that it could be used for calculating the fatigue in low life cycle and plastic life cycle also.
3. LEFM Method: Linear Elastic Fracture Mechanics is used to calculate crack growth rates. This approach assumes that a crack is already present and predicts crack growth with respect to the stress intensity at the crack tip.

### **3.3 Fatigues in Aluminium**

From previous fatigue studies done on aluminium, it seems to be that aluminium is a very good material with high resistance to fatigue. These studies which done on a certain alloy of aluminium, but in general the heat treatment for aluminium lead to a significant in the fatigue life. Heat treatment also give aluminium high strength, excellent toughness and reasonable ductile. The crack initial behaviour of aluminium took place from the surface just like many metals and alloys.

### **3.4 Aluminium Properties**

To be familiar with Aluminium some properties must be considered and known, these properties are:

- Youngs Modulus: 70 GPa.
- Ductility & Malleability: High.
- Hardness: 420 MPa.
- Density: Low 2700 kg / cubic metre.
- Melting Point: 660. 32 °C Boiling Point: 2519 °C.

- Electrical Resistivity: Low  $2.65 \times 10^{-8}$  Ohm metres.
- Reflectivity: High 71% unpolished and when polished: 97% .

All of these properties gave a clue that Aluminium is the metal of the modern world. With its strong, lightweight, ductile and reflective it could be used for several industries and accomplish a great results.

#### **4.0 Problem Analysis**

The first problem in this study is that damage which happened in the connecting rod from ring which connected with crack shaft. As said in the background, there are 2 scenarios leads to this damage. The first scenario is a fatigue accrues in the connecting rod with lead to this damage as it couldn't stand the motion and the pressure any more. The second scenario is an excessive pressure more than the maximum pressure which could be hold by the compressor. At the same time a malfunction in the discharge happened, and this could be taken in consider as it must opened at slightly below the maximum pressure. In both scenarios, the damage in the connecting rod lead to another greater damage in the piston and the cylinder, as the piston start to move in non-liner motion and hitting the cylinder wall. This leads to a serious damage in the compressor's piston and cylinder.

The second problem is gathering the information about the air compressor Knorr-Bremse Lp 4865. This problem happened as the manufactured company keep the information about this compressor not listed and its material and properties to figure out the reason of the damage, maybe by knowing its maximum pressure or material type to check the fatigue on it.

## 4. 1 Problem Solution

After studying all sercomestances and what happened during the failure happened, it seems that the failure happened due to a serious fatigue which is not noticed in a previous time. This fatigue happened to the aluminium alloy which connecting rod made from. An analysis done for the particles and it shows that the particles is consist of 88% aluminium. This gave a thought about how serious was the fatigue in this movable part. As the connecting rod is responsible for transfer the power and motion from crank shaft to the piston, it experiences a load variation all the operation time. A crack must happened time ago on the surface of the connecting rod and it start to spread and choose the weakest area which is the ring where the crank shaft is hinged. This particular area is the weakest area in connecting rod as the thickness reduced to attach the crank shaft.

To overcome the second problem a deeply internet search is made with trying to contact with the manufactured company through their website [www.knorr-bremse.com](http://www.knorr-bremse.com), but with no result. So another technique implemented, which is gathering common information about reciprocating air compressor and its common parts and materials. This could be useful but not accoutre. There are 2 appendices attached to the project which have some data about the parts and how to maintain it gathered from the company itself.

## 4. 2 Results

As a final result of this project, the damage which happened in the connecting rod accusing damage on the rest of parts is happened due to a

fatigue. After the fatigue weak the connecting rod it reached a phase that the connecting rod couldn't stand any load. Just after the failure the piston starts to hit the cylinder wall, which accuses the obvious damage on the piston and the piston rings. To prevent such a failure in the future a regular check must be done for the concerning parts as scheduled in the producer's manual. A life time calculation for all parts must also be done and make the replacement in its time. These procedures are going to prevent such a failure to happen again.