INTEGRITY ASSESMENT OF HVAC AND SYSTEM SUPPORT USE IN COMMERCIAL BUILDING AND OFFSHORE PLATFORM

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BACHELOR OF MECHANICAL ENGINEERING TECHNOLOGY (MAINTENANCE TECHNOLOGY) WITH HONOURS

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Faculty of Mechanical and Manufacturing Engineering Technology

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A thesis submitted
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DECLARATION

I declare that this thesis entitled Integrity Assesment of Hvac and System Support Used In Commercial Building and Offshore Platform is the result of my own research except as cited in the references. The Choose an item. has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Name : KHAIRUNNISA BINTI BADRUL HISHAM

Date : 17 JAN 2022

APPROVAL

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of Mechanical Engineering Technology (Maintenenace Technology) with Honours.

Signature :

Supervisor Name : TS. DR. AHMAD FUAD BIN AB GHANI

Date : 18 JAN 2022

DEDICATION

I am dedicating this thesis to my parents Hayati binti Mohamad Nazir and Badrul Hisham bin Mohamed Ramli who give their full support through my ups and down and also to my siblings Danial Haqim bin Badrul Hisham, Danial Haiqal bin Badrul Hisham that always there help builds my motivation up and cheer me up when i felt lost. Also, a big thanks to my project supervisor Ts. Dr. Ahmad Fuad bin Ab. Ghani and Ir. Mohd Azhar bin Shah Rizam for the guidance throughout completing this thesis and to all other UTeM lecturers. Without their dedication in teaching, I wouldn't reach until this far. Lastly, to my all good friends, classmates and teammates through bittersweet four years' journey. Thank you I appreciate all the support and good vibe through the process.

ABSTRACT

Heating, Ventilation, Air Conditioning (HVAC) is a system keeps people healthy by filtering clean indoor air that and maintained the humidity levels at optimal comfort levels. The failure of the compressor results in the breakdown of the entire system. Multi criteria decision making (MCDM) focused with constructing and addressing multi criteria decisions and planning issues on to failure that occur on the compressor. In this reports, Failure Mode Effect Analysis (FMEA) was applied in order to identify the most significant failure mode using the Risk Priority Number (RPN) score. Then, the highest risk priority number score was compared between the compressor used in oil and gas platform in Terengganu with other failure occur in other wide industry application. The information identified of compressor was gathered on the maintenance reports HVAC Experts Sdn. Bhd. The highest failure modes occur in offshore analysis is crankshaft with 17% due to chlorine from the sea water caused a moderately acidic at the base component while other application was the pistons and bearing. Additionally, the highest failure mode with risk priority number score above 120. As a recommendation, Risk Based condition maintenance is suggested as it reduce the risk according from higher likelihood breakdown to lowest and are cost-saving.

Keyword: Semi- hermetic compressor, Hermetic compressor, FMEA Method, RPN score

ABSTRAK

Pemanasan, Pengudaraan, Penyaman Udara (HVAC) ialah sistem memastikan orang ramai sihat dengan menapis udara dalaman yang bersih dan mengekalkan tahap kelembapan pada tahap keselesaan optimum. Kegagalan pemampat mengakibatkan kerosakan keseluruhan sistem. Pembuatan keputusan pelbagai kriteria (MCDM) tertumpu dengan membina dan menangani keputusan pelbagai kriteria dan merancang isu kepada kegagalan yang berlaku pada pemampat. Dalam laporan ini, Analisis Kesan Mod Kegagalan (FMEA) telah digunakan untuk mengenal pasti mod kegagalan yang paling ketara menggunakan skor Nombor Keutamaan Risiko (RPN). Kemudian, skor nombor keutamaan risiko tertinggi dibandingkan antara pemampat yang digunakan dalam platform minyak dan gas di Terengganu dengan kegagalan lain berlaku dalam aplikasi industri yang luas. Maklumat yang dikenal pasti mengenai pemampat telah dikumpul pada laporan penyelenggaraan HVAC Experts Sdn. Bhd. Mod kegagalan yang paling tinggi berlaku dalam analisis luar pesisir ialah aci engkol dengan 17% disebabkan oleh klorin dari air laut menyebabkan komponen asas berasid sederhana manakala aplikasi lain adalah omboh dan galas. Selain itu, mod kegagalan tertinggi dengan skor nombor keutamaan risiko melebihi 120. Sebagai cadangan, penyelenggaraan keadaan Berdasarkan Risiko dicadangkan kerana ia mengurangkan risiko mengikut pecahan kemungkinan lebih tinggi kepada terendah dan menjimatkan kos.

Kata kunci: Pemampat separa hermetik, Pemampat hermetik, analisis FMEA, skor RPN

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LIST OF SYMBOLS AND ABBREVIATIONS

HVAC	-	Heating Ventilation and Air Conditioning
FMEA	-	Failure Mode Effect Analysis
Sdn. Bhd	-	Sendirian Berhad (Company)

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CHAPTER 1

INTRODUCTION

1.1 Background

HVAC stand for Heating Ventilation and Air Conditioning or in the simple way system that are used to make people feel cosy warm and cool in any residential and commercial buildings. It is called heating ventilation and air conditioning, which it keeps cooling and cosy to people like Malaysia country which is the weather mostly hot and humid. Because of the systems used air particle moving freely in both residential and commercial buildings, the system also keeps people healthy by filtering clean indoor air that and maintained the humidity levels at optimal comfort levels. One of the most intricate and comprehensive system in building is heating and air conditioning system, if one part in the system broken it can affect the whole system (Brennan Heating & Air Conditioning, 2019). As the air conditioning main role is to reduce adverse temperature. It also to increase the comforts to the environment indoor, there a process of removing heat and moisture from interior of closed room. Moreover, there is a process called ventilation it takes source from fresh outside air intake then exchange it to replenish oxygen and remove the unwanted such as bad odours, carbon dioxide and excessive moisture. There are several part in the system that keep the system working, the air returns for ventilation, ducting, electrical elements, compressor, condenser, expansion valve, outdoor unit and blower.

Before, there are many gaps between the ventilation process into the building caused from the open and closed door system. But nowadays, the modern construction tightly focused on the sealed so ventilation process can be improving. After the outdoor air is brought in the HVAC system itself will works to filtered the air, remove dirt, excessive moisture, dust and other particles to keeps people inside breathes clean air. When the process is done, the air will direct into the space provided such as home living rooms, cars, classes, laboratory and factories. So taking care from the earlier stage is crucial and support as mentioned by researchers (Haberschill et al., n.d.) in designing the system, it crucial to study and investigate the performance of each component as there are wide variety of operating circumstances also the interactions between the component in the system. It is to prevent excessive failure, experimenting to determine performance may costly and be time-consuming.

An air conditioning having an air conditioning system inspection is important to improve efficiency, reduce energy consumption, operating costs and the carbon emissions of its system. Person in charge to taking control of the whole operation of the system, such as building owner, operator, engineer, manager and other has legislative requirement and care duties in the operation and maintenance of air conditioning systems. The system's capacity to create healthy and comfortable settings must be checked and maintained on regular basis. The ability of the system to provide healthy and comfortable conditions for building occupants in the same time minimising refrigerant gas leakage must be emphasis of the inspection and maintenance routine.

Compressor is like the heart to the HVAC system. The failure of the compressor results in the breakdown of the entire system. Usually it is the source of many system problems. The primary component of the system was identified based on the maintenance report Hvac Experts Sdn. Bhd and Failure Mode Effect Analysis (FMEA) was applied in order to identify the most significant failure mode influencing parameter first. The FMEA examine various failure modes and their impacts on the system, then ranks the degree of severity based on failure rate and occurrence of failure effect (Jomde et al., 2017). The analysis information should be updated it will benefit to the system in long term. By overcome the failure through analysis it will results in lower total cost to run and maintain the facility as well as improved the system performance. The FMEA method are chosen according to standard by American Bureau of Shipping (ABS), Incorporated by Act of Legislature of the State of New York 1862 updated version in 2015.

As continuation in this report, the performance of maintenance report of HVAC support system produced by HVAC experts Sdn.Bhd such as blower, compressor, refrigerant data in industrial facilities has been compiled into this report to be studied the failure mode through Failure Mode Effect Analysis (FMEA) analysis. The file database compiled are gathered from year 2015 to the latest year 2020 are used to identify probable failure mechanism and undesirable conditions that might result affecting the system. Due to that, as a response maintenance of each component over the system is required throughout its lifecycle. Significantly, due to compliance with safety regulations and the standard followed the cost of new HVAC system is rather expensive compared to the existing HVAC system. The HVAC system on the oil and gas platform was scheduled for maintenance in accordance with standard procedure (Preventive maintenance, Corrective maintenance, and Risk-based inspection). These would be common options for the maintenance department while running a maintenance programme.

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1.2 Problem Statement

Semi hermetic compressor are known as sealed type compressor. Marine refrigeration, residential buildings, petrochemical, pharmaceutical and chemical processes, industrial refrigeration, high temperature ammonia heat pumps are the examples of common application that uses semi hermetic screw compressor type. Oil and gas failures may have a wide range of consequences, affecting both business and safety. As a result, it's critical to evaluate failures in order to avoid them from happening again. most compressors fail as a result of system flaws, which must be addressed to avoid recurrence failures. Symptoms of system faults are frequently revealed during a field inspection of a failed compressor. The inspection and maintenance routine should focus on the system's capacity to provide healthy and comfortable conditions for building occupants while reducing

In this research, an assessment for HVAC support system approached for failure mode of compressor. As compressor are one of the component that keeps the HVAC system running. According to Jomde et al. 2017, when the compressor fails, the entire system fails. Current type of maintenance widely applied is the corrective maintenance and preventive maintenance. It is requiring high cost. Semi hermetic and hermetic compressor is widely used in wide application; it aims for maintenance that are cost- effective at the same time keeps the compressor in maximum performance.

1.3 Research Objective

The main aim of this research is to find integrity assessment to be applied of HVAC support system. Specifically, the objectives are as follows:

a) To study and listed several type of integrity assesment in optimize HVAC component maintenenace selections for HVAC support systems.

b) To apply the Failure Mode and Effect Analysis (FMEA) to the actual maintenance report case study by listing the severity to the failure modes occur in the system.

c) To analyze and provide a defined method for identiofy potential dangerous situations, adressing gaps and improving safety, environmental performance and operational downtime of HVAC system.

1.4 Scope of Research

The scope of this research are as follows:

- Mainly focused on the brainstorming to FMEA method to be applied to the case study maintenance report by Hvac Experts Sdn.Bhd.
- The analysis to ensure that the maintenace sugeestion suitable with the occurs failure mode in the case study to the other jurnal follow Standard International Maritime Organizatioonal .
- To compared type integrity assesment for HVAC system using FMEA method examined preventive maintenance, corrective maintenance, risk-based maintenance and replacement to determine which option the most effective for specified HVAC maintenance type and dependability.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In today's modern society, energy efficiency is identified as key strategies to address growing issues in increasing electricity cost, utility cost, unexpected and high cost of equipment repairs, climate change and energy crisis without commissioning and good installation it can harm and give impacts on the building management. Due to increasing in the energy bill by unexpected costs through years it forced many company throughout the worlds towards energy saving in building so that the operating cost can be reduced also lead to green company as many existing commercial buildings are built with low carbon emission features. It is because with the features it helps enhanced the building environmental performance. But it is different now days, energy efficiency in commercial buildings can be achieved throughout redevelopment of energy efficiency of buildings heating, ventilation and air conditioning (HVAC) system.

One of the support system in HVAC/R is compressor. Also in basic system of HVAC there are compressor, condenser, expansion valve and evaporator. In industry there are many listed type of compressor. One widely used type compressor is semi-hermetic refrigeration compressor due to their benefits which is has stable operation, reliability, has high efficiency also compact structure.

2.2 Background of HVAC system

HVAC are stand for Heating Ventilation and Air Conditioning. Refrigeration "R" is sometimes added, resulting in "HVACR." HVAC refers to the process of controlling the temperature of a restricted place in order to meet the needs of the people or items there. HVAC systems are responsible for not just heating and cooling air, but also for managing interior air quality (IAQ). In the winter, heating the air is done, and in the summer, cooling the air is done. Thermodynamics, fluid mechanics, and heat transfer are all used in HVAC systems. All of these fields are used in various HVAC components. IAQ (Indoor Air Quality) Indoor air quality refers to the air quality inside a building or structure as it relates to the health and safety of its occupants. Inclusion or contamination with gases, as well as uncontrolled mass and energy transfer, alter IAQ. HVAC systems are utilized for heating, cooling, and air conditioning in a variety of applications, including homes, buildings, industry, cars, aquariums, and more. HVAC applications are growing in popularity, and more research is being conducted in this space. The HVAC industry is growing at the same time that the field of application is expanding. A heating and cooling system, as well as indoor climate control, is essentially an assemblage of many types of equipment connected together. Mechanical and electrical components are used in HVAC systems to give comfort to building/space occupants or to maintain goods, products, or anything placed in space.

Depending on the HVAC architecture, HVAC cooling systems can be combined with HVAC heating systems or installed independently. On an industrial scale, HVAC systems keep machines working by maintaining the temperature of the space/hall/room where they are installed. For a variety of reasons, HVAC water chillers have become indispensable in any sector. A HVAC water chiller creates chilled water in the background of the HVAC system, which is then circulated throughout the building or area up to cooling coils in air handling units. Blowers move air across cooling coils, which is subsequently distributed throughout the room or building for comfort or to preserve goods/items according to HVAC design. Air is delivered by supply ducts, while return air is collected via return ducts in air handling systems. Energy is provided by chilled water and cooling water pumps to keep the chilled and cooling water circulating. HVAC Valves are also put at various points in pipe to make HVAC system maintenance easier or to manage the system. Heating the air can be accomplished using an HVAC heat pump, a hot water generator, or a furnace. During the winter, certain industrial chillers can also be used as heaters. In the heating mode, heated coils take the place of cooling coils. The cost of an HVAC system varies depending on the use, as does the cost of heating and cooling an area or environment.

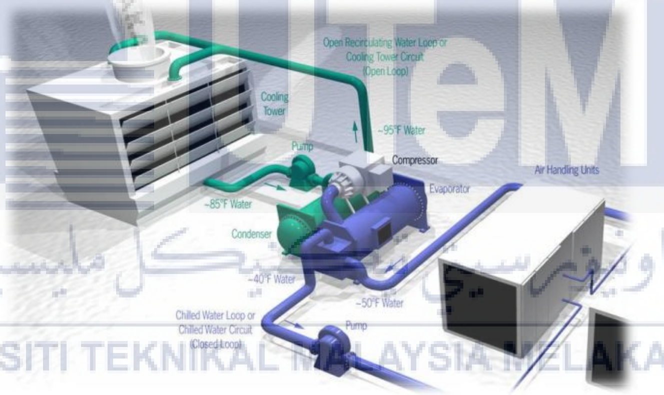


Figure 2-1 Basic System of HVAC

There are 4 types of HVAC system which is heating and air conditioning split system, Hybrid, Ductless mini split, and Packaged System. HVAC systems rely on the distribution system to supply the necessary volume of air while maintaining the ideal environmental conditions. The distribution system differs mostly according on the refrigerant type and the manner of delivery, such as air handling equipment, fan coils, air ducts, and water pipes.

2.2.1 Basic Refrigerant Cycles.

The purpose of a refrigeration cycle is to absorb and reject heat. The refrigeration cycle, also known as a heat pump cycle, is a method of transferring heat away from the area that has to be cooled. This is performed by adjusting the working refrigerant's pressure through a compression and expansion cycle.

The cycle list as below:

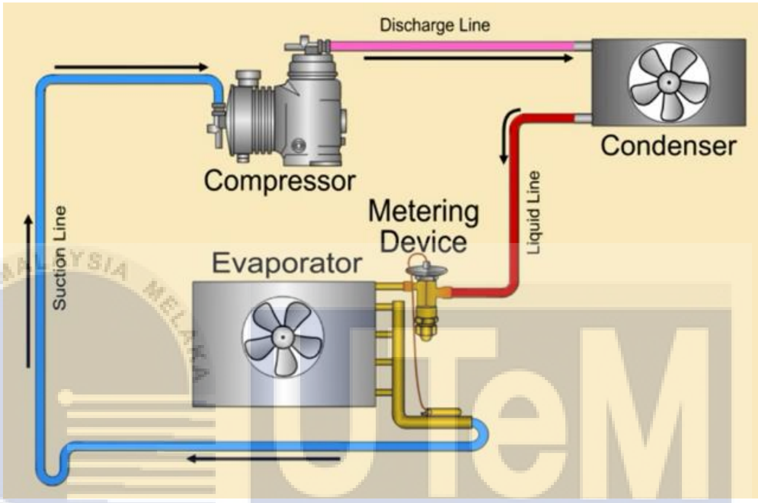


Figure 2-2 Basic Refrigerant Cycle

Compressor

Compressor is like a heart part of the air conditioner. Low-pressure, low-temperature refrigerant enters the compressor as a low-pressure, low-temperature gas and exits as a high-pressure, high-temperature gas. The conventional central air conditioning system found in most homes is a split air conditioning system. In the outdoor unit, the compressor is located. Its job is to circulate the refrigerant required for heat exchange via the indoor and outdoor unit's coils, as well as to apply energy to the refrigerant. The compressor is driven by a motor, which is built similarly to a motor with a cylinder and piston. The compressor compresses the gaseous refrigerant, increasing its temperature and converting it to a high-pressure gas.

The refrigerant is forced through a line to the outdoor coil, where it releases its heat and condenses into a liquid due to the high pressure.

Condenser

In a basic refrigeration loop, the condenser, also known as the condenser coil, is one of two types of heat exchangers. This component receives vaporized, high-temperature, high-pressure refrigerant from the compressor. The condenser cools the heated refrigerant vapour gas vapour until it condenses into a saturated liquid condition. A condenser (or AC condenser) is the exterior portion of an air conditioner or heat pump that, depending on the season, either releases or gathers heat. The essential components of both split air conditioner and heat pump condensers are the same. The condenser coil, a compressor, a fan, and other controls are all housed in the condenser cabinet. To transfer heat quickly, the condenser coil might be composed of copper tubing with aluminium fins or all aluminium tubing. The condenser fan is an important part that pumps air across the coil to help with heat transfer. Because it compresses the refrigerant and pumps it to a coil as a hot gas, the compressor is the system's heart. In heat pumps, the hot gas is pumped directly to the evaporator coil to provide heat.

Expansion valve

These parts are available in a variety of styles. Fixed orifices, thermostatic expansion valves or thermal expansion valves, and more modern electronic expansion valves are all popular types. The job of a system's expansion device, regardless of arrangement, is to cause a drop in pressure when the refrigerant leaves the condenser. Because of the pressure reduction, some of the refrigerant will boil quickly, resulting in a two-phase mixture. This rapid phase change is known as flashing, and it aids the evaporator, the next piece of equipment in the circuit, in doing its role. Thermal expansion valves are sometimes referred to as "metering devices," however this term can also refer to any other device that releases liquid refrigerant into the low-pressure portion but is unaffected by temperature, such as a capillary tube or a pressure-controlled valve.

Evaporator

In a conventional refrigeration circuit, the evaporator is the second heat exchanger, and it, like the condenser, is named after its primary function. Given that it accomplishes what we anticipate air conditioning to do absorb heat it acts as the “business end” of a refrigeration cycle. When refrigerant enters the evaporator as a low-temperature, low-pressure liquid, and a fan drives air through the evaporator's fins, the air is cooled by the refrigerant absorbing heat from the place in question. The refrigerant is then returned to the compressor, where the process begins again.

2.3 Research Gap

This research analyzes a review of the study in the maintenance area of HVAC components support system in general, with the study focused on the HVAC maintenance reports at a selected firm, the findings of which may be used as a reference and applied to other companies. Those working in maintenance in the sector frequently struggle with prioritizing maintenance concerns in order to build an appropriate approach. One of the way used to prioritize the concern is through the FMEA approach. The FMEA approach is used to trace the effect of each failure mode in the reciprocating compressor until the cause is discovered, allowing the appropriate remedial action to be decided (Qosim, n.d.).

Table 2-1 List of potential gaps in the area of maintenance and Multi Criteria Decision Making

No.	Authors	Year	Study method	Topics/ Focus	Description	Gap
1	Amit Jomde et al.	2017	FMECA (Failure Mode Effects and Criticality Analysis)	FMECA on linear compressor	Applied FMECA on linear compressor. Studied effect of the failure mode of refrigerator powers in the vapor compression	Different type of compressor. Duration of the maintenance should be applying not clear.

					refrigeration system (VCRS).	
2	Qosim, n.d.	2017	RCFA (Root Cause Failure Analysis) & FMEA (Failure Mode and Effect Analysis)	The goal of this research is to uncover problems that cause failures in compressor performance	The effect of each failure mode in a reciprocating compressor is tracked in order to decide remedial action. So that maintenance costs and improvements can be reduced.	Piston Compressor PK 60- 150. Different type of compressor not semi hermetic compressor. Author expects using Taguchi analysis as verification comparison.
3	Dwianda	2021	FMEA	FMEA of Pneumatic System of CNC Milling Machine	FMEA method to define priority failure for pneumatic system in CNC milling machine.	Applied preventive maintenance instead of corrective maintenance and the journal applied FMEA on CNC Milling Machine. Also,

						repair action is not assigned to each failure mode.
4	Dyah Lintang et al.	2021	Fuzzy-FMEA & Fuzzy – AHP (Analytical Hierarchy Process)	Proposed Action of Supply Chain Risk Mitigation Air Compressor Type L Unloading ¼ HP Using Fuzzy – FMEA and Fuzzy – AHP Method in PT. XYZ	To provide a risk mitigation strategy for risks event occurred in supply chain of air compressor type L Unloading ¼ HP using FFMEA & FAHP approaches.	Fuzzy type of method approached. Lack of maintenance activities on the engine.
5	Dilbagh Panchal et al.	2018	Fuzzy FMEA and GRA (Grey Relation Analysis)	Carry out risk analysis for clean and sustainable urea fertilizer	To provide a framework based on fuzzy methodological techniques for carrying out risk	The Fuzzy FMEA method applied in centrifugal compressor. Compressor

				manufacturing.	analysis on a real industrial system of a urea fertiliser business in northern India	application not HVAC system. subsystem different from HVAC system.
6	Fengyuan Jiang & Dong, 2020	2020	Nonlinear finite element analysis, quantitative analysis	The elements that contribute to the risk of falling debris on offshore pipelines were investigated.	The effects of relevant parameters on failure risk are investigated, including seabed flexibility, burial depth, acceptable criteria, and fundamental variable sensitivity.	No mentioned type of maintenance should be applied; the risk is not prioritized clearly. The method uses show lower percentage of failure risk.
7	Pisut Koomsap & Thuangp	2016	FMEA	Customer dissatisfaction using improved customer	Customer complaint been included into new risk assessment	A research that demonstrates the effectiveness of a certain

	orn Charoenchokdilok, 2016			oriented in FMEA	technique using Kano model to determine customer perceive failure mode the customer oriented RPN was created and compared to traditional approaches.	strategy. However, more research and testing are necessary before using customer-oriented FMEA in other sectors, as the outcomes would differ from standard FMEA.
8	Braaksma et al.,	2012	FMEA	FMEA in Asset maintenance through comparation between case study and industry process.		

9	J. Mateus, et al.	2019	FMEA	Finding of the fundamental reason resulted in the crankshaft collapsing of turbo diesel engine.	Explain the crankshaft failure mode and its mechanical processes, fractographic,metallographic and numeric analyses carried out.	The study show combined FMEA with numerical analyses helps finding the real reason of the collapsing but through estimation of the researcher.
1	Bassetto & Hernandez	2007	FMEA	Refrigeration system reciprocating compressors	Using bathtub curve to define reliability distributions for refrigeration semi hermetic compressor for failure rate and then applied FMEA to the failure mode based on 600 reports of	This study stated that the design and operation of such compressor have significant impact on the behaviour of reliability metrics. Mentioned maintenance

					occurrence of failures.	could help maintaining the life cycle but no maintenance action is suggested in the research.

2.4 Types of compressor

2.4.1 Scroll Compressor.

Scroll compressors are positive displacement compressors used in air conditioning, refrigeration, and heat pump applications in both residential and commercial settings. Gas is accepted on the perimeter and released in the centre are of a mechanical compressing element in these compressors. This element is made up of two spiral- shaped metallic bits that are identical (scrolls). One scroll remains stable, while the other travels in an orbital pattern that causes gas to migrate from the scrolls' peripheral to the inside. The capacity of the gas chambers is continually lowered throughout this migration. As a result, both the pressure and temperature of the gas rise. In scroll compressors, the major irreversibility is usually assumed to be leakage between chambers with differing pressures. The thermodynamic efficiency is also influenced by heat transfer within the compressor. The gas temperature inside the suction pockets (suction temperature), which is greater than the input temperature due to refrigerant contact with heated compressor elements, and the temperature profile along the scroll wraps are essential for heat transfer characterisation. Many authors have created models to forecast suction temperature in scroll compressors, which are generally used in conjunction with numerical simulations of the compression process.

The gas temperature increase and scroll temperature profile might be focused on when it comes to heat transmission throughout the compression process. A linear temperature profile in respect to the scroll involute angle is an appropriate assumption, according to most research.

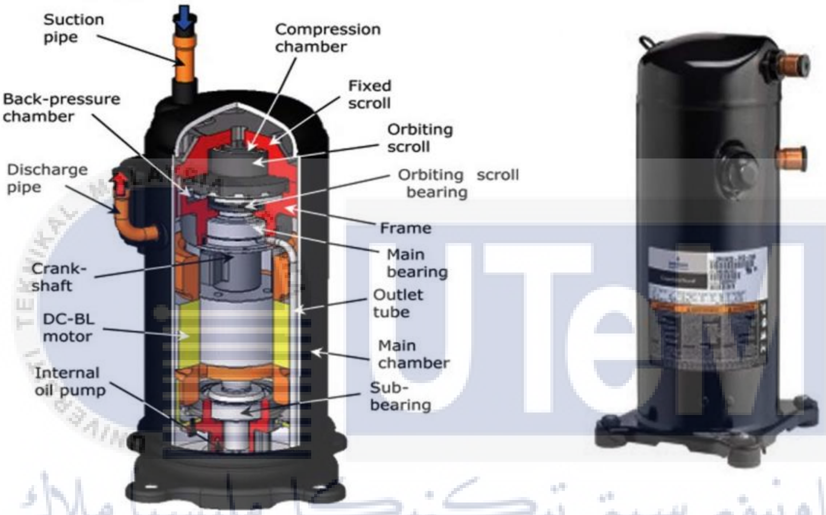


Figure 2-3 A) Scroll compressor with fixed B) Orbiting scrolls enclosed in hermetic shell

Suction temperature is a key beginning condition when differential models are used to simulate the compression process, with the scroll temperature profile serving as the needed boundary condition. Heat conduction and temperature distribution in the scrolls were predicted using a steady state one-dimensional model in this work. A thermodynamic model of the compression process produced by Pereira and a reduced thermal model given by Diniz et al. were combined with the conduction model. As a result, the simulation was run repeatedly, providing for thorough compressor thermodynamic characterisation.

2.4.2 Screw Compressor

The majority of screw compressors are oil-lubricated. The semi hermetic and open-drive kinds are the two types. The motor is housed in the same housing as the compressor in the former, but the motor is housed outside the compressor housing in the latter, necessitating the use of a shaft seal. Screw compressors have only two moving parts: two intermeshing helical rotors. The rotors are made up of a male lobe that serves as a rolling piston and a female flute that serves as a cylinder. There are no surges in the system since rotary screw compression is a constant positive-displacement operation. Because the rotors rotate at slow speeds and are adequately lubricated with cooling oil, screw compressors require little maintenance. Fortunately, with screw compressors, the majority of the oil can be easily separated from the gas.

Figure 2-4 MAS oil injected screw compressor for marine.

2.4.3 Semi- Hermetic Compressor

Semi hermetic compressors have a two-piece shell that houses the motor and compressor housing. The coverings are bolted together and can be opened for maintenance. Semi hermetic compressor are frequently more expensive than hermetic compressors due to the bolts and O-rings required to connect the covers. The ease with which this compressor failure or for normal maintenance is its key benefit over the hermetic kind. It was conceived by Abbe Audiffren, a French priest and was built by SIngrun in Epinal, France in 1905.

Figure 2-5 Semi Hermetic Compressor (Calyle)

Semi-hermetic compressors increase gas pressure and transfer it via a pipe system to meet system distribution requirements. The refrigerant is supplied in a continually decreasing volume from low pressure to high pressure side. It mechanical working principle started form the motor is energised by electricity, which causes the compressor crankshaft to revolve. During the down stroke, the compressor pump has a piston that provides a low pressure rear between the piston top and the cylinder head. Gas rushes through the entrance of a suction valve and into the low pressure compartment. The suction valve closes during the piston upstroke, forcing the exhaust valve to open owing to increased pressure. The gas is compressed and driven through the system's discharge, or high pressure side. The discharge valve closes when the semi-hermetic compressor piston reaches the top of the cylinder. As the piston begins to descend, the suction valve opens, pulling in gas to complete the cycle. Additionally, screw compressor doesn't even have suction or pressure valves, merely a non- return valve to guarantee that there is no refrigerant return flow when the compressor is turned off. Screw compressors can operate at high compression ratios because the oil absorbs compression and friction heat during the process in addition to lubrication and sealing. Proper oil cooling is therefore essential in a screw compressor, and can be achieved either through refrigerant injection into the compressor or through a separate oil cooling system. BPHEs are commonly utilised in oil coolers.

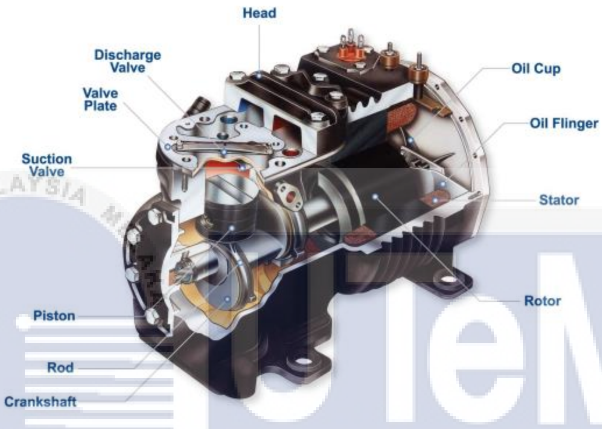


Figure 2-6 semi hermetic (Couplant Compressor) Emerson's brand

Semi hermetic compressor common faults

i. Oil leakage causes insufficient lubrication.
ii. Inadequate oil in the system.
iii. Slugging oil happen in the compressor.
iv. Overheated compressor.
v. Due to contaminant inside system degrade valve and seal.

2.4.4 Hermetic Compressor

Hermetic compressors are hermetically sealed and inaccessible. It has a shell that holds the motor and compressor housing together. The steel shell is welded to provide seal hermetic from the surroundings. As the shell is welded, it complicates to access the welded shell in form to do maintenance work progress. For maintenance work to be done the compressor must be discarded if there is damaged on the motor or compressor. While, Semi-hermetic compressors have a metal shell with covers that allowed be opened by the user to replace any damaged or malfunctioning elements, such as pump components or the motor. In term to differentiate between hermetic and semi hermetic compressor can be observing from its size where the hermetic compressor is compact than the semi hermetic compressor. For maintenance purpose, the cost for maintenance and repair for hermetic is costlier due to its size. Both compressor has been widely used in many sector as domestic refrigeration, small commercial refrigeration and air conditioning systems.

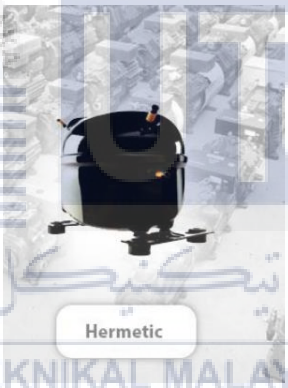


Figure 2-7 Hermetic compressor type

Advantages of hermetic system

i. Due to it sealed mechanical process it protected the system from pollution.

ii. Dust particles unable to enter and contaminate the lubricant.

iii. Simple design and small in size

2.5 Reciprocating compressor (Hermetic) characteristic

A hermetic or sealed compressor is one in which both the compressor and the motor are enclosed in a single welded steel casing for small compression while cast iron of the body compressor for high compression required. With the motor inside the refrigeration circuit, the motor and compressor are directly connected on the same shaft. And if a larger cooling capacity is required, this sort of compressor is typically used on the Offshore platform. It's usually placed in pairs and runs in duty and standby mode in that order.

Table 2-2 Main Components Of Reciprocating Compressor (Hermetic)

Name	Function	Failure Mode	Effect
Body of compressor	The body of the compressor is built of high-strength metals that can sustain high pressure compression and last for a long time. It also houses the essential components that allow it to function as a compressor.	The body compressor part can be damaged due to lack of lubrication at the surface. Then will cause the compressor to overheating	The compressor will increase in temperature and produce rattling sound until the compressor severely damage before it ends its life.
Piston	Internal combustion engines rely on pistons as a key component. It turns heat energy into mechanical power through a reciprocating	Worn pistons rings and cylinder, damage and also liquid slugging happens when the oil in the compressor head heats up to the point where it loses	This wears down the rings, piston and cylinder causing blow-by, leaky valves and metal debris in the oil. Punch hole top of piston will occur due

	motion. When the engine produces power, it goes up and down inside the cylinder. The piston's job is to stop gases from expanding and sending them to the crankshaft.	its capacity to lubricate effectively.	to overheat and other effect such as worn pistons scored cylinder walls & wear on wrist pin.
Connecting rod	The connecting rod joins the piston to the crankshaft, converting the crankshaft's rotating action into the piston's reciprocating motion.	Liquid Slugging	Connecting rods break & crankshaft break
Gasket, Piston Rings, Shaft Seals	Components guarantee that the compressor does not leak refrigerant, oil, or air.	Usually the failure mode that will occur in this part is wear & tear and because of that failure mode will cause to inadequate lubrication to the system.	Then due to inadequate lubrication effecting discharge valve failed, gasket plate blown effect pin hole to wear. Also cause discolored pistons and worn pistons because of the friction between the parts.

Cross Head	A crosshead is a mechanism used to alleviate sideways pressure on the piston in long reciprocating engines and reciprocating compressors as part of the slider-crank couplings. The crosshead also allows the connecting rod to move freely outside of the cylinder.		
Crankshaft	the reciprocating compressor's main shaft. The electric motor is connected to one side of the crankshaft, while the connecting rod is connected to the other.	If the crankcase oil level is low due to lack of oil in the crankcase to adequately lubricate the running gear. Then, overheat will occur.	The overheating in crankcase affect the crankshaft working continuously results to damage component.
Motor Winding	The power is usually supplied by an electric motor, which is constructed using either star or delta winding principles.	Many motors fail to function due to mechanical failure. Shorting windings and overheating happens due to exterior electrical	The whole winding gets overheats and burn, also causing voltage unbalance affects to electrical damages and system shutdown.

		components that are not working.	
Oil Sump	Oil pumps maintain the running gear elements adequately lubricated in order to prevent premature damage to the cylinder and other sections of the commercial compressor.	At the oil pumps part leaking will happen if the cover is not tightly closed. And cause of oil losses.	Low level of oil reading due to oil leaking then will cause to low refrigerant velocity as there not enough lubricants moving into the parts, such as broken fan belts, failed fan motors, dirty coil and unloaded compressor operation.
Bearings	Pistons, rotors, scrolls, and impellers all have shafts that need to be supported. These components are critical because they can sustain the varying loads that occur during compressor operation and prevent metal-to-metal contact between the rolling	If the bearing damage it will cause contaminants present in the oil of the compressor that will damaging. Another failure mode that will occur is overload as the bearing is continue to working excessive temperatures.	When bearing fails to achieve its performance requirements it causes bearing damage as the bearing failed to function and prevents proper lubrication (affect to short winding & fail motor) to the system causing totally system to breakdown.

	elements and stationary castings, which reduces friction-related wear.		
Discharge Valve	The discharge valve directs the high-pressure refrigerant to the discharge line, which leads to the condenser.	Due to high discharge temperature will cause to discolored valve and low suction pressure, because the oil loses its capacity.	Cause high compression ratio effect evaporator coil problem, improper pressure
Suction Valve	Through the suction piping and valve, the refrigerant is pulled into the compressor.	The failure mode that will occur is wear and slugging because when the oil becomes too hot, it loses its capacity to lubricate adequately. Also, cause leaky valves.	Unable to lubricate properly lead to Suction valve break, and dented valves. Next, from leaky valve it will affect to high discharge pressures & temperature.

2.6 Operating Requirements

Reciprocating compressors are typically built to run continuously for lengthy periods of time, up to one years without requiring major maintenance as per maintenance procedure. Oil change should be serviced every quarterly a year and normally only periodic inspection done on compressors parameter to check if the compressor is still in good conditions.

2.6.1 Continuous Duty

Consistency, efficiency, and dependability are all important factors to consider when selecting equipment for continuous operation. Reciprocating compressors can only run for about a year before valve and seal wear becomes too much to bear. When there is no regular maintenance performed on the equipment, the chance of failure increase.

2.6.2 Intermittent Duty

Although reciprocating compressors are tolerant of duty variations, recycling control is typically employed to manage flow changes because they are positive displacement machines. Some machines include unloading mechanisms, which can be complicated and result in localized high temperatures. Reciprocating compressors may be set up fast if thorough checks are performed and, most importantly, there is no liquid in the compressor or suction system.

2.6.3 Emergency Duty

When process deposits (salts, oxides) are exposed to damp air under poor ventilation conditions, the corrosion is the most severe. If there is a failure that inhibits a normal procedure clean out, this can happen. After that, the system is opened for examination and left opens while components and resources are procured. This can be avoided by performing adequate cleaning and venting activities after the inspection, as well as applying the appropriate chemicals. Clean lubricating oil without contamination should be used in the crankcase and cross-head areas, which should be totally isolated from the process. There should be little risk of corrosion, however. Moisture from the refrigerant system could occur and mixing with the compressor oil. Therefore, the oil become acidic becomes enemy of the inner parts of compressor.

2.7 Application of Semi hermetic and Hermetic compressor

2.7.1 Application for Refrigeration in Residential Building

Practically, domestic refrigeration system and small commercial refrigeration and air conditioning system both employ hermetic compressors. As in Beijing, during the winter to heat up themselves using a charcoal is non environmentally safe. So the use of an air source heat pump to heat residential buildings in Beijing is considered environmentally safe and encouraged (Wang et al., 2011). The type of compressor used in the building are the hermetic compressor type as the working principle of the system, which consists of a primary refrigerant circle, would provide a large amount of heat to the building while maintaining the same operating conditions. As stated in the journal, the bypass refrigerant may be utilised to raise the density of refrigerant at the inlet of the hermetic compressor used in the refrigeration cycle.

Semi hermetic compressor often used in appliances such as refrigeration and air-conditioning units suited to supermarkets and other commercial industrial applications, as well as major air conditioning project systems such as shopping malls. They are preferred choice of compressor system for larger size machines as these compressor type may give more financially efficient solution. According to Saengsikhiao & Taweekun, 2021, presented a research on energy efficiency enhancement option to the refrigerators in supermarket. In the journal stated that the installation of digital semi-hermetic compressor can adjust its duty cycle to match the present load while neither sucking or compressing the refrigerant in the unloaded condition, resulting in a 50% reduction in compressor energy usage.

Figure 2-8 A Digital Semi Hermetic Compressor Application At Supermarket.

As Thailand's household sector has been listed as one of the country that has second-highest energy usage rate. The use of semi hermetic compressor helps to cut expenses and conserve energy while ensuring that energy saving measures doesn't effect it maintenance costs. As the researcher's is proposed a low E glass door for open refrigerators and digital semi-hermetic compressor to fix the speed of semi hermetic compressor as an energy efficient enhancement option. From both cases, the application of both hermetic compressors used in residential building require for energy efficiency and has been proposed with various ways to enhance it, at the same time maintain the maintenance costs.

2.7.2 Application for Refrigeration in Offshore Platform

Next, into the application of semi hermetic compressor in HVAC oil and gas platform living cabin. One of application that has been use of an air conditioning system (HVAC) on offshore platform is cooling plant that made up of four major components such as a compressor, condenser, an expansion valve and evaporator. The application is depending on the type of offshore installation of the equipment, whether it is water-cooled and air cooled variants both are available. When cooling is required, it will be hard to maintain a comfortable indoor environment without a cooling plant. While, the application of semi hermetic and hermetic compressor in living cabin provide electrical warming and cooling to improve and provide personal comforts (Heinen & Hopman). Same goes in book (*Refrigeration units in marine vessels*, 2011) by Prof. Dr. –Ing.A. Hafner et al. write that refrigeration on passenger and cargo ships has a wide variety of cooling capacity, primarily to give comfort to passengers and crew via air conditioning and to preserve food. Life in the Oil and gas living cabin platform has many rigs house and employ over 200 persons, with the interiors resemble a mix between a hotel and a workplace. The cabins are shared with generally with minimum two people per room and shared canteen and restrooms with other cabins.

Figure 2-9 A Water Cooled Chiller With Hermetic & Semi Hermetic Compressor Used For Marine Air Conditioning System By DMA Marine Group.

2.8 Maintenance of HVAC

The methods for recognising and eliminating performance issues have been more advance as the systems have grown larger and more involved in larger temperature control applications. Due to that, FMEA is one of approach to prevent recurring failures from occur.

In order to keep the HVAC system in excellent working order, the building owner, engineer, technicians or contractor in charge recommends that it be serviced once a year, and the pump should be serviced every six months. Regular maintenance ensures that the heating, ventilation, and air conditioning (HVAC) system runs smoothly and efficiently for a long time. The HVAC system keeps the environment of the home comfortable and clean. Its job is to ensure that the indoor air quality is up to standard.

2.8.1 Importance of Maintenance

The variety of factors available for making maintenance management decisions is likewise noteworthy. It is critical to investigate how the maintenance crew presents their maintenance objectives. Despite the fact that maintenance is performed on the offshore platform. The same issues exist, however, when the maintenance department's maintenance programme does not identify the priority of maintenance options for each piece of equipment (Lee, H.H.Y, et al., 2009). Machine and equipment maintenance is essential for maintaining them in peak functioning order. As a result, plant maintenance is an important and inevitable service activity in a well-functioning production system (Jain. M, 2010). It has been demonstrated that maintenance is crucial to ensuring that equipment lasts as long as feasible, particularly on offshore platforms where maintenance costs are greater than onshore due to severe environments and a higher likelihood of equipment failure.

2.8.2 Type of Maintenance

There are two type of maintenance strategy which planned maintenance and unplanned maintenance. Planned maintenance is widely practiced in the field of maintenance management, consists of preventive maintenance, predictive maintenance, corrective maintenance and proactive maintenance. While unplanned maintenance also known as reactive maintenance. It is preventative maintenance in the event of unforeseen circumstances, which results in high maintenance costs, consists of breakdown maintenance.

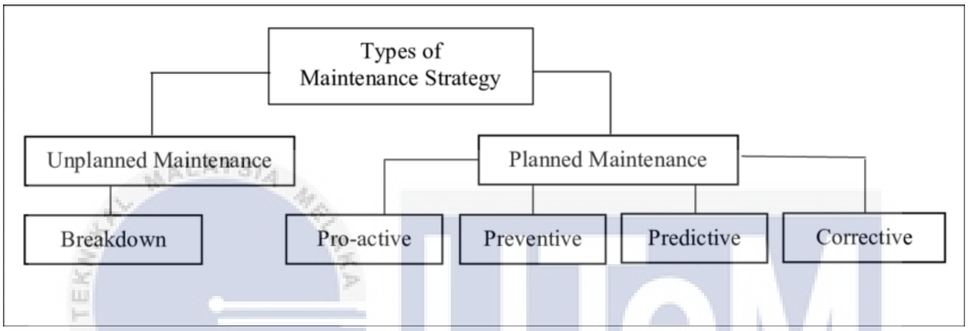


Figure 2-10 Types of Maintenance

Preventive Maintenance

A maintenance used to detect and correct the problem before the problem occur. Typically carried out in the form of routine inspections which are normally performed between an interval of time such as twice a year. This preventive maintenance is carried out by look for any symptoms of wear and tear, inspect any potential failure and replace any broken components right away. These activities will keep the component from critical failure. Also, this maintenance may avoid unexpected downtime before any issue develop.

Breakdown Maintenance

Breakdown maintenance is conducted on a machine's equipment that are malfunction. The purpose of this maintenance is to restore functionality to equipment that has failure.

Predictive maintenance

Predictive maintenance is a subset of condition-based maintenance which is systems are continually monitored on a regular basis in predictive maintenance allowing maintenance teams to take timely measures such as machine adjustment, repair or overhaul. Predictive maintenance employs direct monitoring of mechanical condition and other indications to calculate the real mean time to failure across the life spans of the machine.

Corrective Maintenance

Corrective maintenance is widely applied in HVAC maintenance which the fault is replaced at after the faults is occur. Because it is based on the state of the equipment, it differs from preventive maintenance. According to (Nik Myeda et al., 2011) corrective maintenance is what most maintenance managers rely onto complete daily maintenance activities. CM lowers emergency repairs and promotes employee’s safety since corrective maintenance concerns are discovered on time. Corrective maintenance may be quite costly since the failure of one thing might result in a lot of damage to other parts of the structure, and the failure of one item can happen at an inopportune moment.

Pro-active Maintenance

Proactive maintenance, as defined by (Jabar, 2015) is a sort of maintenance that detects failures at their source. It has the potential to increase production capacity while also increasing the life of equipment. Preventive and predictive maintenance are not the same as proactive maintenance. proactive maintenance is aimed to extend the usable life of equipment until it reaches the wear-out stage by adopting a high degree of competence in terms of operational precision.

2.9 Risk Assessment on Maintenance strategy of a compressor.

Risk assessment is a term used to describe the whole process or method to identifying hazards and risk factors that have the potential to cause harm (hazard identification). Analyze and evaluate the danger posed by that threat (risk analysis, and risk evaluation).

2.9.1 Objectives of Risk Assessment

- Identifies and evaluates risk.
- Reduce and eliminate harmful threats
- Support efficient use of resources
- Better communication with an organization

2.9.2 Steps in the Risk Assessment Process

- Identify the hazards
- Determine who might be harmed
- Evaluate the risks and take precautions
- Record the findings v. Review assessment

The risk analysis process aids the organization's effective and efficient operation by identifying hazards that demand management's attention. They'll have to prioritize risk management activities based on their ability to benefit the company. If the refrigeration system's compressor overheats, the problem can only be remedied by upgrading the refrigeration system's design and maintenance. The problem cannot be solved fundamentally by replacing a new compressor.

Table 2-3 Likelihood of Occurence

LIKELIHOOD (L)	EXAMPLE	RATING
Most likely	The most likely result of the hazard	5
Possible	Has a good chance of occurring and is not unusual	4
Conceivable	Might be occur at sometimes in future	3
Remote	Has not been known to occur after many years	2
inconceivable	Is practically impossible and has never occurred	1

Table 2-4 Severity of Hazard

SEVERITY	EXAMPLE	RATING
Catastrophic	Numerous fatalities, irrecoverable property damage and productivity	5
Fatal	Approximately one single fatality major property damage if hazard is realized	4
Serious	Non-fatal injury, permanent disability	3
Minor	Disabling but not permanent injury	2
Negligible	Minor abrasions, bruiser, cuts, first aid type injury	1

Table 2-5 Risk Matrix

Likelihood (L)	Severity (S)				
	1	2	3	4	5
5	5	10	15	20	25
4	4	8	12	16	20
3	3	6	9	12	15
2	2	4	6	8	10
1	1	2	3	4	5

Table 2-6 Priority based on the range

Risk	Description	Action
15 – 25	High	A high risk requires immediate action to control the hazard as detailed in the hierarchy on the risk assessment form including date for completion.
5 – 12	Medium	A medium risk requires a planned approachto controlling the hazard and applies temporary measure if required. Actions taken must be documented on the risk assessment form including date for completion.
1 - 4	Low	A risk identified as low may be considered as acceptable and further reduction may not be necessary. However, if the risk can be resolved quickly and efficiently, control measures should be implemented and recorded.

2.10 Pressure requirements of HVAC compressors commonly used at the platform.

There is a difference of requirement for HVAC compressor for the specific type of gasses such as R22, R407C, and R410. For R22, the low pressure is 60-70psi while high pressure is between 250-300psi. R407C requires 75-80psi at low pressure and 275-300psi at high pressure. Lastly for gas R410a, the low pressure is at 120-130psi, and for high-pressure 450-500psi. If the requirement of the compressor is not followed such as refrigerant overcharge or refrigerant undercharge, it may cause some result that can be creating risk. Some of the risks are: -

i. Compressor motor overheating.

This may prevent the compressor from starting or cause the circuit breaker to trip prematurely. Left unchecked, the motor will eventually burn out and fail to run at all.

ii. Loss of cooling capacity

The system is no longer able to maintain the humidity and temperature at the required levels.

iii. Flooded condenser

Condenser flooded with liquid refrigerant, which will reduce its capacity; besides causing excessive sub-cooling at the condenser outlet, this condition may cause the compressor to short cycle on the high-pressure cut-out.

iv. Liquid refrigerant enters the suction line

Commonly referred to as “liquid slugging”, this is a dangerous condition potentially leading to compressor damage.

To ensure that undercharge and overcharge occur, proper maintenance must be done. The condition of the HVAC system must be observed timely within the maintenance schedule. Proper charging of the refrigerant must be done to ensure that the overcharge and undercharge of refrigerant occur.

2.11 Oil Acidity Impact on HVAC Compressors and Type of Compressors Oil Used.

2.11.1 Type of Analysis Used for Measuring Oil Acidity

i. HVAC Acidic Refrigerant

According to the HVAC 2018 Annual Review Report, lightning is always the most common stated risk to HVAC systems in home-owners' claims year after year and is also the most common misdiagnosed cause of loss. Acidic refrigerant in the system is a sign that is sometimes misunderstood as lightning damage. In contrast to the widespread perception of contractors, lightning in the coolant circuit of an HVAC system cannot create acid. Rather, this symptom is produced by one of three conditions: wear and tear, inadequate repair or maintenance of the system. Because this widespread misunderstanding is frequently mentioned as a lightning damage indication, adjusters must grasp why it isn't.

ii. Factors Cause the Acidic Refrigerant

When humidity, excess heat, pollutants or other impurities are submitted to the coolant circuit, it produces an airborne chemical reaction. This is caused by age (usual wear and tear), maintenance failure or incorrect system repair. Leaks in copper coils containing the refrigerant can occur as a system age and provide an entrance point for external pollutants. The compressor components can also be disintegrated owing to ageing and contamination in the refrigerant may be introduced. The ensuing chemical reaction generates acid as soon as impurities or moisture reach the refrigerant belt. Acid coolant can also develop if a blocked coil or malfunctioning condenser fan overheats our system. The absence of ventilation causes excessive heat to speed the formation of acid in the coolant. Finally, if a compressor is bruising because the acidic refrigerant is there and eventually is replacing it, acid can be reintroduced in a new Compressor (but a line set isn't completely flushed or a new filter drier is not fitted).

Acid Number (AN) is the non-aqueous solution measurement of the concentration of acid. The level of potassium hydroxide (KOH) needed to neutralize the acid in one gram of the oil sample is calculated. The default measuring unit is mg KOH/g. The absolute acid level of the oil sample does not reflect AN. Both organic acids and powerful inorganic acids are detected in the measurement of AN. Multiple causes may cause a change in the acid content of oil. The rise can be caused with acid impurities, incorrect oil, losses of alkaline reserves and by-products of oxidation. Table 1 provides a list of detectable common acids. In calculating the RUL of oil, understanding the level of additive depletion is critical. Certain additions are mildly acidic and can increase the initial AN of the oil. With the age of the lubricant, these additives will diminish, lessening their acidity. A specific AN trend is produced during lubricant ageing by the common wear additive, zinc dialkyl dithiophosphate (ZDDP). At the same time, it may be polluted with acidic components and the acid level in the oil increases. In identifying what the AN signifies, the combined impacts of additive depletion, acidic contamination and other an acidificate processes provide a difficulty. The fundamental components of the AN during lubricant ageing are displayed in Figure 1. The antioxidant compounds are lost throughout an induction phase; once these additives have been depleted, base oil oxidizes when stress is enough. This growth may be observed by trending the AN.

iii. Type of Compressor Oil (Organic Vs. Inorganic Refrigerant Acids)

Depending on the type of chemical reaction, the acid generated will be either organic or inorganic in nature. The type of refrigerant, oil composition, and the type of contaminant all influence this reaction. While both types of acids are destructive to compressors, the types of damage they cause are very different. One factor in determining the composition of the acid produced is the combination of refrigerant and oil. Hydrochlorofluorocarbon (HCFC) systems, such as those that contain the refrigerant R-22, typically use mineral oil to lubricate the systems. When moisture or contaminants enter these systems, the refrigerant breaks down, because the natural lubricating oil is more stable than its accompanying refrigerant. This results in the creation of an inorganic acid. Such acids result in abnormally high temperatures in the motor windings and/or discharge area of the compressor. These high temperatures break down the windings and lead to the loss of electrical resistance of the compressor, or a compressor burnout.

iv. Acid Number (AN)

Acid Number (AN) is the measure of acid concentration in a non-aqueous solution. It is determined by the amount of potassium hydroxide (KOH) base required to neutralize the acid in one gram of an oil sample. The standard unit of measure is mg KOH/g. AN does not represent the absolute acid concentration of the oil sample. The AN measurement detects both weak organic acids and strong inorganic acids. A change in the acid concentration of oil can originate from multiple sources. Acidic contaminants, wrong oil, alkaline-reserve depletion, and oxidation by-products can cause an increase in acid concentration. Table 1 lists common acids that can be detected

Understanding the extent of additive depletion is key in determining the RUL of oil. Some additives are weakly acidic and can elevate the oil's initial AN. As the lubricant ages, these additives deplete, thereby reducing the acidity created by the additives. The common anti-wear additive, zinc dialkyl dithiophosphate (ZDDP), produces a certain AN trend during lubricant aging. Concurrently, the oil is possibly being contaminated with acidic constituents, increasing the acid content in the oil. The combined effects of additive depletion, acidic contamination, and other acidic-affecting events create a challenge in determining what the AN represents

Figure 2-11, shows the underlying components that affect the AN during lubricant aging. It can be seen that during an induction period the antioxidant additives are depleting; once these additives are depleted, the base oil begins to oxidize if the stressing conditions are sufficiently high. By trending the AN, this increase can be detected.

Acid Type	Source	Lube Application
Organic (1)	Oil oxidation product	All severe lubrication environments
Hydrochloric (2)	Freon refrigerant breakdown	Chillers
Hydrofloric (2)	Freon refrigerant breakdown	Chillers
Sulfuric (3)	Diesel fuel and water H_2S contamination AW and EP breakdown	Diesel engines NG compressors Hydraulic systems
Nitric (4)	Nitration and nitric oxides	Gas engines Gasoline engines
Phosphoric (5)	Phosphate ester degradation by-products Phosphate mine environment	Mobile equipment, especially hydraulics
Confirming tests: (1) FTIR oxidation (4) FTIR nitration	(2) Vacuous thinning (5) Elemental analysis - phosphorus	(3) FTIR sulfation

Figure 2-11 Type of Acid

2.12 Caused and impact of vibration on HVAC Compressors

HVAC systems involve plenty of moving components, it is normal to have some vibration and noise, even in a correctly installed and well-maintained system. However, excessive vibration and noise indicate that an installation should be serviced, and they can also lead to other performance issues. Vibration and noise are normally addressed together because they are closely related. The second is often a consequence of the first. Some property owners only focus on noise and use plenty of soundproofing, but this is not the best approach because it does not solve the underlying issue.

Here are some common sounds that an HVAC system can make:

i. Banging: -

Banging is usually a sure sign that there's a loose or broken part a connecting rod, piston pin, or crankshaft inside the air conditioning compressor.

ii. Clicking: -

The clicking of electrical components at start-up and shutdown is a normal part of the system's operation, but constant or ongoing clicking is not typical. It could be a sign of a defective control or a failing thermostat.

iii. Buzzing: -

A buzzing noise from the outside unit could mean, it had loose parts, debris in either the indoor or outdoor unit, the outdoor fan motor is loose or about to fail, fan blades are loose or out of balance, the copper lines from outside to inside are rubbing against something.

2.13 Special design of explosion-proof HVAC compressors for onshore.

Air conditioners are not made to explode. Yet, few cases of HVAC system explosion were failed in past years. The explosion-proof of HVAC systems is essential in hazardous areas in offshore production areas such as the oil and gas industry. As the explosion-proof heating, ventilation, and air conditioning systems are designed by a skilled engineer to ensure safety. This system is very durable and reliable in use. Since it is an offshore used compressor, so its anti-corrosion ability is enhanced. This is purposely to increase the machine's life working time and prevent unexpected shut down of the machine. As the explosion-proof is the internal sparks or explosion that occurs in the casing which causes a larger blast. This could damage the compressor, especially internal components. Therefore, it is important to minimize the explosion of the compressor. Besides, some standards can be referred to reduce the explosion occurs.

2.14 Effect of High Suction and Discharge Temperature of HVAC Compressors

i. High return gas temperature

The evaporating temperature is used to calculate the return gas temperature. To prevent fluids from returning to the compressor, a return superheat temperature of 20°C is generally necessary. The superheat degree will be considerably over 20°C if the return gas pipe is not adequately insulated. The suction and discharge temperatures will be higher if the return gas temperature is higher. The temperature of the return gas will rise by 1°C, while the temperature of the discharge gas will rise by 1°C to 1.3°C.

ii. Burned valve reeds Reed

Valves are a form of check valve that restricts fluid flow to a single direction and opens and closes as the pressure on each face changes. Flexible metal or composite materials are frequently used in modern versions (fiberglass or carbon fiber).

iii. High compression ratio

The compression ratio has a significant impact on discharge temperature. The higher the compression ratio, the higher the discharge temperature. Reducing the compression ratio, as well as raising the suction pressure and lowering the discharge pressure, can considerably lower the discharge temperature. Evaporating pressure and suction line resistance determine suction pressure. The suction pressure may be efficiently raised by raising the evaporation temperature, and the compression ratio can be swiftly lowered, lowering the discharge temperature. The temperature difference can be increased by lowering the evaporation temperature, but the compressor cooling capacity is lowered, so the freezing speed is not guaranteed. Besides, the lower the evaporation temperature, the lower the refrigeration coefficient; yet, since the load has grown, the power consumption will rise if the operating duration is extended

iv. Stator spot burns from metal debris

The unequal voltage between phases due to uneven loads on the power source, a faulty connection at the motor terminal, or a high resistance contact can cause thermal deterioration of insulation in one phase of the stator winding.

2.15 Study of caused compressor motor damage

Compressor failure is usually characterized by some excessive discharged temperatures, and some of the parameters are recommended to measure first when compressors show signs of distress. It is important to know these causes to prevent such failures and troubleshoot the problems. If there is any troubleshooter towards compressor failure, a replacement compressor will suffer the same problem. Compressor motor failure can be caused by a variety of electrical or mechanical conditions. All compressor manufacturers do spot teardown analysis on returned compressors. Occasionally, a compressor manufacturer will teardown all returned compressors, for some time, to analyze them and determine the cause or causes of failure. This is expensive, but the information gathered helps the manufacturer to improve the product, the manufacturing process, and the literature regarding installation and maintenance.

Here are some of simplify and explanation causes that are mostly found in the causes of compressor motor damaged. Which are:

i) Slugging: Broken component, break connection rods, even crankshaft.
ii) Flood back: The continuous return of liquid refrigerant.
iii) Loss or lack of lubrication: Not enough oil in the crankcase.
iv) Electrical problem: Unbalance of current towards the compressor system.
v) Contamination: The debris or any slight dirty substance affecting flow system 6.
vi) Overheating: Increase of temperature of the compressor system.
vii) Flooded start: Oil in the crankcase-absorbing refrigerant during the mix cycle.

To conclude the finding of the causes of the compressor motor damage, the technician must pay attention to symptoms such as higher than normal discharge temperatures, low amp draw, and higher than normal suction pressures. Also, report any malfunctioning parts of the compressor or towards the system itself to ensure the safety of the manufacturer and the engineer. While taking notes and record all the malfunction in a general input data that stored safely for future references. The engineer or the maintenance team who is in charge of the system must be also be recorded to ensure all the possibilities of unknowing the causes of the system can be resolve due to their action of using the system itself performing an inspection on the motor winding

Electric motor inspection testing is an important part of establishing the condition of the motor and beginning the troubleshooting process. There are several different tests involved, and basic knowledge of what the tests are can help understand the repair data received back from the electric company that handles electrical maintenance.

The most critical motor inspection tests include the following:

i) Winding phase-to-phase resistance: To detect any large differences in resistance that exist between the winding.
ii) Insulation resistance (IR) to the ground: Resistance measured between each motor winding and frame.
iii) DC hi-pot: Stress test for insulation and requires the use of DC hi-pot tester.
iv) Surge comparison: Detect insulation weaknesses and short. Incorrect internal connection.
v) Polarization index: Act as insulation resistance to ground test.
vi) AC and DC voltage drop (DC motors): DC motor repair to identify shorted.

These tests should be performed by experienced technicians using the methods and voltages prescribed by EASA (Electrical Apparatus Service Association) and IEEE (Institute of Electrical and Electronics Engineers) standards. In addition, all phase-to-phase resistance tests and IR tests must be passed before performing the high voltage DC hi-pot and surge comparison tests. Note that electric motor inspection test values are compared between the initial inspection test data and the final test data to ensure that improvements were made. To conclude the study of performing an inspection on motor winding is thorough takes electric motor inspection testing with seriousness. Carefully documented the results of each test performed and keep the data onto a safe and secured data collection for future references. If the result showing poorly, perform an additional cleaning and check for any components that are needed for the test or the coil itself including the armature rewind. Repair any broken component of the testing part or replace if there is any damage on the component needed for inspection of the motor winding. Knowing the condition of the windings is one important part of ensuring motors' proper.

2.16 Moisture affect system in long term.

Air conditioners cool homes by removing heat and moisture from the air. When humidity levels are excessive, they need to work a lot harder. If the equipment doesn't have sufficient cooling capacity, it may be unable to cope with extreme humidity. As a result, the home may never feel truly comfortable. A few common signs of high indoor humidity include:

i) Moist, clammy air: In fact, your skin may feel clammy when you're inside your home.

ii) Foggy windows: This happens because the humidity is vaporized water in the air. When it becomes bottled up in your home, it may fog up the windows.

iii) A musty odour: Excessive humidity causes dampness around the home and can eventually lead to this unpleasant problem.

2.17 Safety devices are used to protect the compressor from premature failure.

i) High Pressure Cut Out

High pressure can be caused by a variety of factors, including overcharging, a loss of cooling water, a high ambient temperature, air, or other incompressible gases in the system, and an obstruction in the compressor's discharge line. A high-pressure cut-out is provided to protect the compressor from high pressure and subsequent failure. It takes a pressure tapping from the discharge line and stops the compressor when it detects an overpressure. The HP cut-out is not automatically resettable and must be reset by the operator. This is because high pressure is a serious fault that must be investigated and corrected before the system can be restarted.

ii) Low Pressure Cut Out

A low-pressure cut-out is provided to protect the compressor from low pressure in the system and to prevent air from entering the system if a vacuum is generated in the lines. When the solenoids cut off the air conditioner compartments and there is no return gas, the low pressure cut out is activated. When the solenoid of the air conditioner compartments opens, the return gas enters the compressor's inlet and the suction pressure rises, and the compressor's low pressure switch cuts in

iii) Low Oil Pressure Cut Out

The oil is pumped under pressure by an attached oil pump, which supplies lubricant to the bearings. Any problem with the lube oil pressure can jeopardize the bearings, so a tapping from the pump outlet is taken and fed to the oil pressure switch. Any pressure drop will activate the cut-out, causing the compressor to stop.

iv) Oil Separator

Since oil is miscible with the air conditioner and frequently exits the compressor with it, it can enter the evaporator and reduce heat transfer. An oil separator is used to prevent oil from entering the evaporator and forming a layer or causing the obstruction. It consists primarily of baffle plates that separate the oil from the refrigerant and return it to the compressor. Afloat valve is provided to prevent the refrigerant from being short-circuited.

2.18 Implication due to incorrect Design Selection of HVAC Compressors.

Airflow issues in HVAC systems can also be caused by incorrect size and design. To maintain the required temperature and humidity levels, an HVAC unit that is too small for a building, for example, may have to run for longer periods or cycle on and off more frequently. This will result in higher energy costs and a shorter lifespan for many components, including the compressor. Most airflow-related issues in HVAC systems are simple and affordable to resolve. Neglecting them, on the other hand, may result in decreased system efficiency, which appears as:

i) Inadequate cooling

The temperature surrounding the coil might drop below the freezing point due to a faulty component that obstructs airflow to the evaporator. When ice forms on the coil, it prevents heat transfer between the air and the refrigerant. As a result, to effectively cool the building, the system must work harder and longer.

ii) Inadequate heating

Decreased airflow through the central heating system can cause the heat exchanger to overheat and fail to meet the pre-set limit. The high-limit control switch will turn off the burner as a safety precaution, allowing the heat exchanger to cool. If this happens frequently enough, the HVAC unit will be unable to produce the necessary heat to keep the building at the proper temperature. Higher operating and repair expenses will result from an inefficient HVAC system.

2.19 Risk affect due to inappropriate refrigerant into HVAC compressor.

i) Low-Side Air Conditioner Compressor Motor Pressure

This is the pressure in the refrigerant suction line of the air conditioner (low side pressure during compressor operation), and it will be low, generally less than 100 psi. During operation, refrigerant from the cooling (evaporator) coil in this line returns to the compressor. The compressor might pull a real vacuum on the line if the suction line was connected directly to a sealed vacuum test gauge. The low side of an air conditioning system is always found inside the cooled space, or inside an air handler that transports air through the cooled space. The compressor allows liquid refrigerant to be discharged into the cooling coil on the "low side" of the air conditioning system by lowering the pressure in the cooling coil, where the change in refrigerant state from liquid to gas absorbs heat and brings the cooling coil to the proper operating temperature. The low-pressure and low-temperature side of a refrigeration system is known as the low side. This is usually the interior air handler, which is positioned inside the room to be cooled and is responsible for getting indoor air to working temperature.

ii) High-Side Air Conditioner Compressor Pressure

The pressure of the compressed refrigerant gas as it leaves the compressor motor is known as output (high side pressure during operation). In other words, refrigerant gas returns to the compressor through the cooling coil's suction line (which is cooling building air). Inside the compressor motor, the low-pressure refrigerant gas is compressed into a high-pressure refrigerant gas. This high-temperature refrigerant gas is subsequently cooled to form a refrigerant liquid, which is then returned to the air handler and evaporator coil to chill the building air. The compressor, condensing coil, and fan unit utilized to cool the condensing coil of an air conditioning system are positioned outside of the conditioned or refrigerated room and will be submerged in the air at the ambient outside temperature, say 72 °F. The high side of a refrigeration system is constantly above ambient temperature and operates at a greater (refrigerant) pressure. As a result, in a cooling system, it will be placed outside to transfer heat to the outside air. When in heating mode, a heat pump intended to pump heat into a building will, of course, invert these functions. If the compressor's requirements are not followed, such as refrigerant overcharge or refrigerant undercharge, it may result in a risky situation. Some of the risks are: -

a) **Flooded condenser**: Flooded condenser reduces capacity; in addition to generating excessive sub-cooling at the condenser output, this situation may cause the compressor to short cycle on the high-pressure cut-out.

b) **Loss of cooling capacity:** The system is no longer capable of maintaining the appropriate humidity and temperature conditions.

c) **Compressor motor overheating:** The compressor may not start or the circuit breaker may trip prematurely as a result of this. If left alone, the motor will ultimately burn out and stop working.

d) **Liquid refrigerant enters the suction line:** Also known as "liquid slugging," this is a hazardous situation that can result in compressor damages.

Finally, undercharging or overcharging refrigerant gas might destroy an HVAC system. If this problem is not resolved immediately, the HVAC system may be put in jeopardy. Proper maintenance and assembly are required to guarantee that the danger is minimized.

2.20 Failure Mode and Effect Analysis (FMEA)

Failure mode and effect analysis is a method that accesses the potential failure modes of a system and identifies the most likely causes of those failures. This method was developed by US Defense Department to minimize the impact of failures. And this method also is commonly use to minimize the risk and improved the reliability of the products and services. Most prevalent practice in marine industry. One of the widely industry used this method is marine. FMEA are essential components of a marine vessel's safety design and operation. They are often required to perform various tasks related to the safety of vessels to improve its reliability and minimize its undesired events.

The FMEA is a conceptual framework that identifies the expected operational modes of a particular system. It is generated through a process that involves identifying the various design and configuration weaknesses of that system.

2.20.1 FMEA Purpose

FMEA method use as supporting documentation as this method used to analyse the product design characteristic in relation to manufacturing process and to experiment with the design. When the potential failure modes are identified, a corrective action can be taken to eliminate those failures and reduce the likelihood of an occurrence. FMEA procedure involves analysing the failure within a system and categorising them based on the severity and the occurrence to develops risk priority number (RPN).

2.20.2 FMEA Procedure

The FMEA is created using analytical process that identifies system design and configuration flaws in expected operational modes of specific system. Once listed, FMEA will be performed. By mitigating the expected failure modes, FMEA method assists engineer in designing a reliable and safe system. Each failure mode's risk is assessed using the Risk Priority Number (RPN) which are calculated by multiply the severity, an occurrence and detection rating. Throughout the analysis process, corrective action is recommending.

i. Gathering of Data Analysis

Data can be gathered from many sources from observation actual industrial risk data in field service report, personal experience and from communication with supervisor. The collecting data include image captured and also by doing interview with industrial workers. Also, evaluate and identify the whole system where it might fail as well as assessing the relative impact of various failures to identify parts that need to remarks and take action on it.

ii. List of Failure Mode and Failure Effects

Specific failure mode will show itself in form that can be seen in system behaviour and variety of indicators. The identification of failure detection mechanism for each failure mode is necessary component in FMEA. Detection by difference physical view, from stronger noise, comparing before and other.

iii. List and assign severity, an occurrence & detection rating

According to list of failure mode and failure effects list down and assign each severity, occurrence and detection rating which usually in a group of table given numbering and the description. Severity measured the seriousness of the effect, Occurrence likelihood failure occur in system and lastly Detection rating determine failure mode occurred.

2.20.3 Identify Failure Mode

Failure mode identifications allow engineers to assess the possibility of finding or recognising faults for each function. The potentials failure modes are identified through examining the gathered data taken from the functional components reports. These failure modes the are discovered and explained within the physical and operational boundaries of the research scope. Further details need to ensure that the failure modes reveal a loss of that function. The functions of the component consideration must be specified before performing a functional failure FMEA.

2.20.1 FMEA Failure Effect

Failure effects a list come out of effects of each failure mode on the system that related to the system or process. Then determine the severity of each failure effects. Called severity rating abbreviated as S. severity is often graded on a scale from 1 to 10, with 1 being inconsequential and 10 being disastrous. If there are several effects occur on each failure mode, taken into the table failure mode with the greatest severity level on FMEA Table.

2.20.2 FMEA Disposition

Determine probable root cause for each failure mode. Then, determine the occurrence rating (O) for each cause. This grade predicts the likelihood of failure due to the cause occurring throughout the lifespan of the component. Lastly, from the current process control, determine the detection rating (D) this rating graded the control is certain to identify or goes undetected.

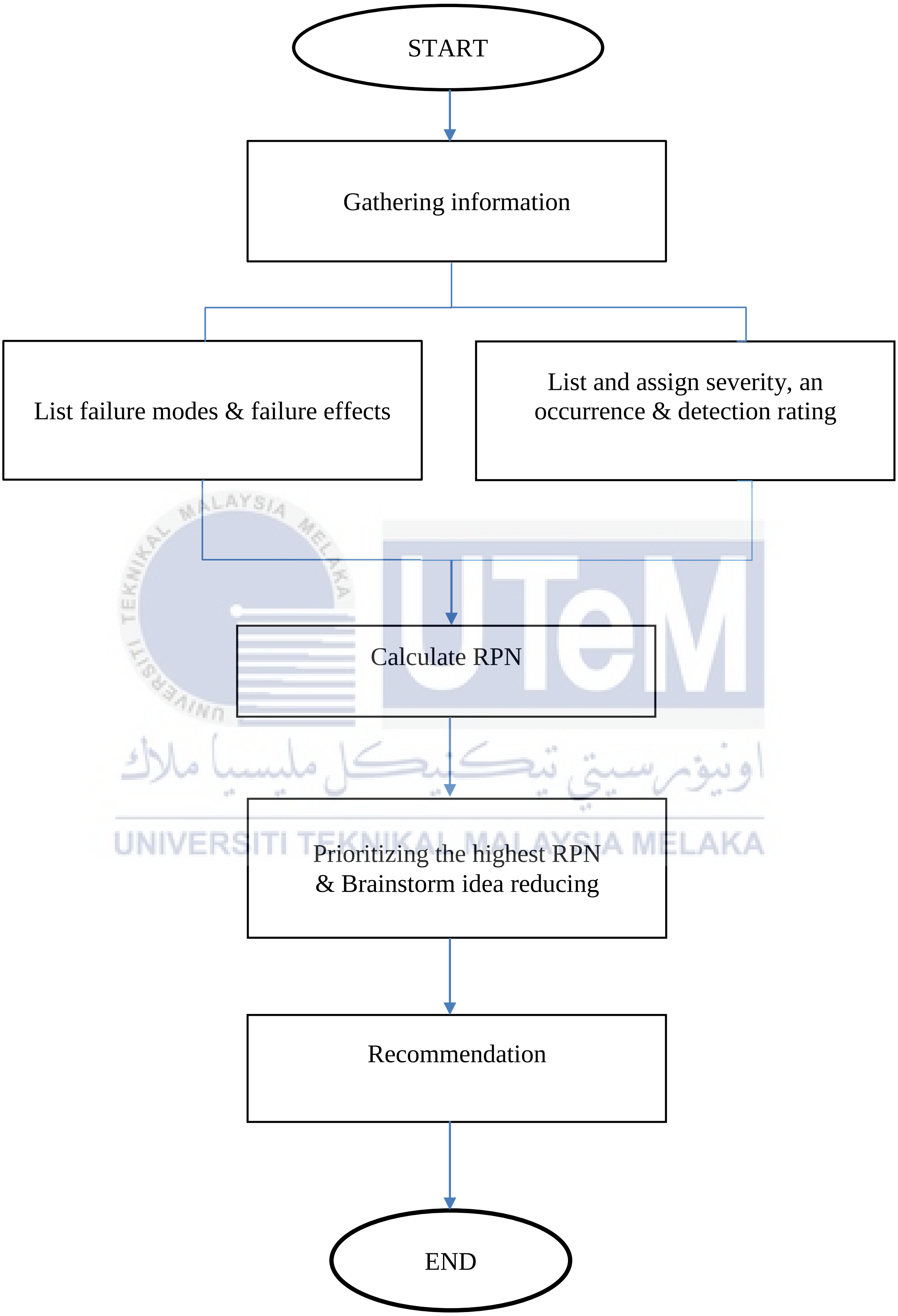
CHAPTER 3

METHODOLOGY

3.1 Introduction

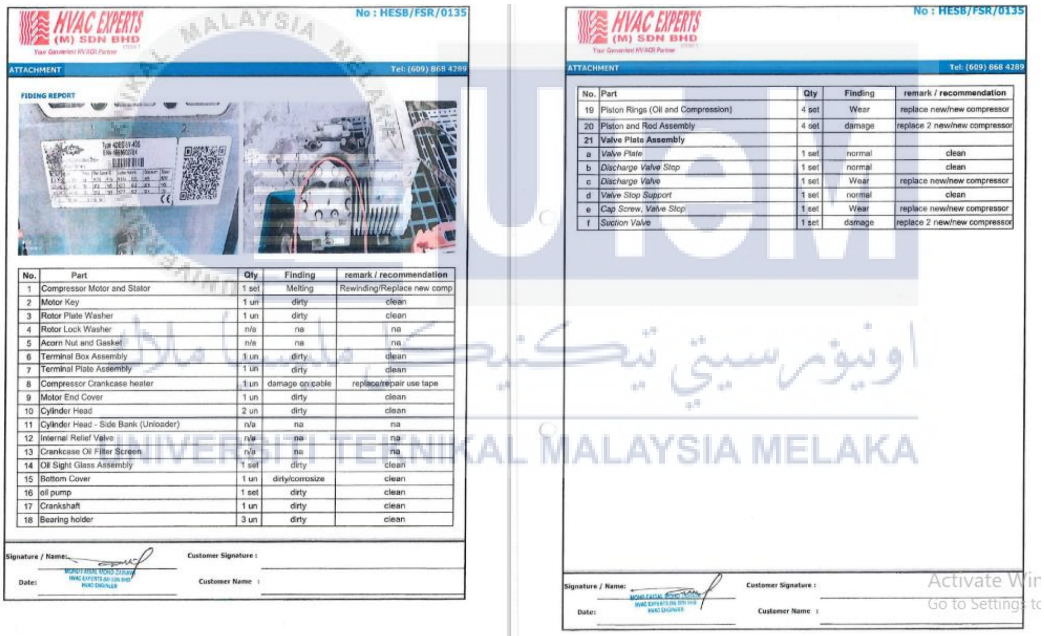
In this research, study regarding structure integrity assessment through study of the identify the failure mode and failure effect in HVAC system in order to improve energy consumption reduction, enhances reliability of the system and identify the system flaws also recommend best maintenance practice for the system. It is important to maintaining the HVAC support system so they can increase the life time of the system and continuously produce excellent service. This can be successful along with a good maintenance action. Failure Mode and Effects Analysis is one of the method for prevention from systematic error. The process of the method which early identify the problem of the system have make the method popular to be applied as it detection earlier in design phase. The FMEA table are create for semi hermetic compressor use in Malaysia offshore platform to identify highest failure risk and then are compared to other semi hermetic compressor used in commercial building in academic literature. In this thesis, the failure mode arises in the compressor mentioned are assigned with severity of the risk, occurrence and detection rating. To carry out the study, analysis table created based on four years maintenance report from HVAC Experts. FMEA techniques helps define, identify and eliminate failure through recommendation maintenance type for produce good reliability system support.

3.2 Methodology Procedure



3.3 Gathering Data Analysis

Data was gathered for the study by reading maintenance records produced by the maintenance service. There are total of four maintenance report from the company. That consist the maintenance report, daily service report and the testing that has been done to the sub-systems along from the year 2017 to the latest March 2021. Observation of failure mode occur in the maintenance report data for five years then are conclude into the FMEA table and are categorized by the type of sub-system. Then each of failure mode are listed and assigned by their severity, Occurrence and detection rating lastly the RPN number are calculate.



HVAC EXPERTS (M) SDN BHD
No : HESB/FSR/0135
ATTACHMENT
Tel: (609) 868 4289

FIDING REPORT

No.	Part	Qty	Finding	remark / recommendation
1	Compressor Motor and Stator	1 set	Melting	Rewinding/Replace new comp
2	Motor Key	1 un	dirty	clean
3	Rotor Plate Washer	1 un	dirty	clean
4	Rotor Lock Washer	n/a	na	na
5	Acorn Nut and Gasket	n/a	na	na
6	Terminal Box Assembly	1 un	dirty	clean
7	Terminal Plate Assembly	1 un	dirty	clean
8	Compressor Crankcase heater	1 un	damage on cable	replace/repair use tape
9	Motor End Cover	1 un	dirty	clean
10	Cylinder Head	2 un	dirty	clean
11	Cylinder Head - Side Bank (Unloader)	n/a	na	na
12	Internal Relief Valve	n/a	na	na
13	Crankcase Oil Filter Screen	n/a	na	na
14	Oil Sight Glass Assembly	1 set	dirty	clean
15	Bottom Cover	1 un	dirty/corrosize	clean
16	oil pump	1 set	dirty	clean
17	Crankshaft	1 un	dirty	clean
18	Bearing holder	3 un	dirty	clean

Signature / Name: Customer Signature :
Date: Customer Name :

HVAC EXPERTS (M) SDN BHD
No : HESB/FSR/0135
ATTACHMENT
Tel: (609) 868 4289

No.	Part	Qty	Finding	remark / recommendation
19	Piston Rings (Oil and Compression)	4 set	Wear	replace new/new compressor
20	Piston and Rod Assembly	4 set	damage	replace 2 new/new compressor
21	**Valve Plate Assembly**			
a	*Valve Plate*	1 set	normal	clean
b	*Discharge Valve Stop*	1 set	normal	clean
c	*Discharge Valve*	1 set	Wear	replace new/new compressor
d	*Valve Stop Support*	1 set	normal	clean
e	*Cap Screw, Valve Stop*	1 set	Wear	replace new/new compressor
f	*Suction Valve*	1 set	damage	replace 2 new/new compressor

Signature / Name: Customer Signature :
Date: Customer Name :

Figure 3-1 Maintenance Report from HVAC Experts Sdn. Bhd.

In this analysis, air conditioning is the primary system. Semi hermetic compressor is the sub-system. While, Condenser, expansion valve, and evaporator are the additional sub-systems in addition to the compressor. The failure rates of these three sub-systems are not examined deeply in this study since they do not have any moving parts. This study focusing on the compressor failure analysis.

The compressors' condition was investigated. It includes all compressors, whether they are new, old, or still under warranty. All of the compressors were affected by the failure. After all of the data has been obtained, an FMEA worksheet paper is created by inserting the data onto the paper. In the worksheet, the required details about failed components and prospective failure were noted and analysed further.

Table 3-1 FMEA Tables on Compressor in HVAC at Petronas.

Component	Failure Mode	Failure Effects	S	Potential Cause	Current Control	O	D	RPN
Compressor motor winding	Physical winding melting	Overheat	9	Compressor overheating & very low oil level	Rewinding / Replace new compressor	5	1	45
Oil sump Cable	Crankcase heater damage	Leakage	5	-	Replace	1	5	25
Oil level	Oil level not seen at sight glass	Compressor Oil not return back	3	Insufficient compressor oil	Clean	1	8	24
Crankshaft	Scratch on the shaft	Wear & tear	9	Liquid enter compressor	Replace new	8	3	216
Pistons	Piston head damage	Damage	8	Nocking debris in suction valve	Replace new compressor	9	2	144
	Piston oil ring stuck	Wear	8	Debris in piston		8	3	192
	Deep scratch at piston body	Wear	8	Debris in cushion valve	Clean & replace	8	3	192
	Internal relief valve	Wear	6	Contaminated with water particles over time	Suggest replace new	9	4	216
Bearing	Bearing sleeve	Corroded	6			8	3	144
Cylinder head	Cylinder Head Assembly	Corroded	6			5	3	90
TOTAL								**1288**

The severity rating is assign starting from 1 the lowest effect to the system until 10 the highest rating that give hazardous and the effect will threaten the life of the system. As in the table the highest severity rating is 9 which is caused the effect to be replace new, if the effects occur continue to be using it will cause running compressor to fail. The physical winding melting caused from the excess heat that weaken the insulation of the compressor. Observably if the severity is more than 7 the system need to be replace new. Next, Occurrence rating indicate the chance of the failure mode present in the system, rated from 1 extremely less chance to occur to 10 extremely high chance of occurrence of the failure mode. The occurrence ranking based on the analysed from the industrial maintenance report by Hvac Experts (M) Sdn. Bhd. Lastly, List of the detection rating each cause on FMEA table graded on scale of one to ten to identify the problem from extremely certain to less detection of the problem (no inspection = none exists).

Figure 3-2 a) Damage compressor Piston b) Deep Scratch body piston

Figure 3-3 Both Picture shown Deep Scratch on Crankshaft compressor

3.3.2 Prioritizing Highest RPN using Pareto

Based on Table 3-2, the failure mode versus RPN number shown through the Pareto Diagram and Pie Chart for clear description of the Failure Modes and Effects Analysis of the compressor.

Failure Mode	RPN	Cf%
Scratch Crankshaft	216	17
Wear Internal relief valve	216	34
Piston (Scratch)	192	48
Piston (Oil ring stuck)	192	63
Piston (Damage piston head)	144	75
Bearing Corroded	144	86
Corroded Cylinder Head	90	93
Overheat Physical winding	45	96
Damage Crankcase heater	25	98
Not seen Oil level	24	100
Total	1288	

Figure 3-4 Tabulated Data Results for Failure Modes Vs. RPN

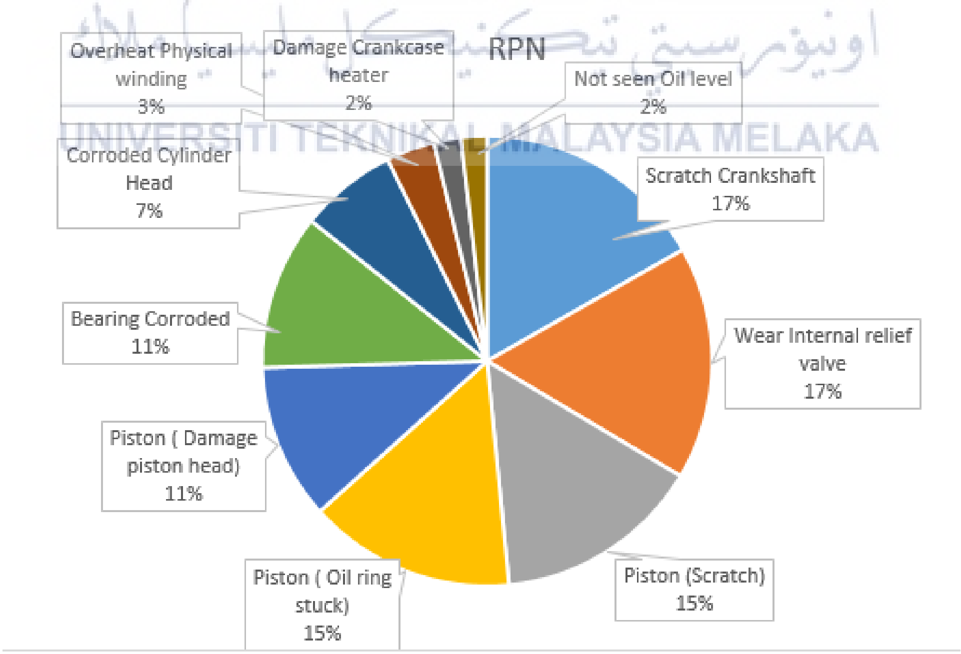


Figure 3-5 Failure Mode HVAC Experts Compressor Pie Chart

Various aspects clearly described in the Table 3.3 the failure modes, severity ranking, likelihood of occurrence and the detection ranking were explicitly specified, assisting in the calculation of the RPN of each compressor system parts. From Pie Chart showed that wear and tear on the Crankshafts and Internal Relief Valve conquer of 17% from total RPN value. Followed by failure bearing with 15% respectively for both failure modes occur on the component until the lowest RPN value percentage damaged cable 2% from total of 1288 RPN value.

Table 3-3 FMEA Tables occur on Compressor in multiple application.

Application	Component	Failure Mode	Failure Effects	Failure Cause	S	Corrective action	O	D	RPN
Food Product Conservation (Bassetto & Hernandez, 2007)	Head Gasket	Compression in chamber	Fatigue and high aggressive wear	Gasket misaligned, worn, cracks hole occur & creating airflow causes gas escape result in compression loss	7	Maintain evaporator and compressor superheat at suitable levels.	3	5	105
		Refrigerant flood back		Results in oil foaming and abnormally high crankcase pressures.	8		3	6	144
	Bearing	Wear Bearing	Contamination due to moisture	The contamination occurs, increased influence of liquid stroke lead compressor to fail.	8	Make sure sufficient oil and properly lubricate in the crankcase	10	2	160
		Overheating		The compressor's evaporator running out of refrigerant.	8		10	2	160
	Piston	Liquid stroke in compression chamber	Mechanical overload	Substantial amount of water trapped and have porous that increase rate of heat transfer.	8	Lubricate well , lacks of lubricate cause friction and mechanical overload occur.	5	3	120
	Wiring	Poor winding & supply low energy	Electrical failures	Poor energy supply	6	Taken care the mechanical failures.	4	4	96

Laboratory test (Checket-Hanks, 2003)	Crankshaft	Wear	Causing a fractures on crankshaft surface	The failure occurs due to installation faults and residual stress	9	Maintain compressor superheat and evaporator at safe level as well as correct oil management and pipe sizing.	5	3	135
	Valve plate	Overload/ Overheat	High temperature causing the oil to breakdown and lead to scoring and damage parts.	Discoloured and excessive wear occur due to high temperature	8	Control the heat and temperatures enter in the system	7	2	112
	Thermal relay/ block	Overload	The overload relay trips due to excessive current for too long.	Overload trips	8	Check and control the desired amount of superheat enters.	5	5	200
	Pistons	Liquid flood back	The oil film is washed away	Worn pistons	8	Check superheat temperatures that enter the compressor	4	5	160
Offshore compressor (Harris & Birkitt, 2016)	Crankshaft	Corrosion fatigue in crankshaft	Oil leaking	Worn shaft, corrosion attack on the crankshaft surface	9	Check the material and the coating thickness	5	3	135

3.4 Instrumentation

The combination of these three parameters called the risk priority number (RPN) to reflect the priority of the failure mode identified as described in Figure 3.4. The risk priority number (RPN) is simply calculated by multiplying the severity rating, times the occurrence probability rating, times the detection probability rating. Usually the RPN can up to more than 1000.

Risk Priority Number = Severity x Occurrence X Detection

Table 3-4 Parameters Instrumentation.

Rating	Severity	Occurrence	Detection rating
1	Effect not noticed	Extremely less	Certain
2	Very slight effect noticed	Remote	Very high
3	Slight effect causing annoyance	Very slight	High
4	Slight effect causing return of product	Slight	Moderate
5	Moderate effect causing return of product	Occasional	Medium
6	Significant effect	Moderate	Low chance
7	Major effect	Frequent	Slight
8	Extreme effect, safety issue	High	Remote
9	Critical effect , system shutdown	Very high	Very remote
10	Hazardous , life threatening	Extremely high	No inspection

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results and analysis on the total Risk Priority Number of the failure mode occur in the compressor. There will be two result comparison of failure mode and RPN number between Petronas (HVAC Experts) and Academic Journals results. The chosen academic journal according to the type of compressor used which is semi hermetic, hermetic and reciprocating compressor that are in different type of application. By finding the failure mode occur in these journals and assigned the severity, occurrence and detection rating on each failure. The reason is to make comparison between the failure mode occur in the various application with failure mode occur in offshore compressor based on the maintenance reports.

The failure mode and effect analysis (FMEA) tables are done in previous chapter taken based on the failure mode occur in the academic journal and articles of other researcher in multiple application. These results are shown in Pie Chart and Graph.

4.2 Results and Analysis of Failure Mode and RPN

Based on FMEA table, below are Pareto diagram of the failure mode occur in offshore compressor in the maintenance report from HVAC Experts Sdn. Bhd. The Pareto analysis consist of the type of failure mode and risk priority number of each failure mode occur and arranged in descending order.

Figure 4-1 Pareto diagram results for FMEA compressor HVAC experts

In Figure 4-1, according to the findings on the analyses the percentage of failure component based on the HVAC Experts maintenance report as below :

Crankshaft and Internal Relief Valve – 17 % respectively

Pistons – 15 %, 15% and 11%

Bearing - 11%

Crankshaft and Internal Relief Valve (PRV) are the component that contains highest risk priority number with 219 each. Follow by piston, bearing and others. The risk priority number are calculated by assigned severity, occurrence and detection rating of the component and failure mode occur based on the maintenance reports. Basically, these component are highest because of the high severity and high occurrence of the failure mode occur in the compressor. Majority type of failure occur due to wear and tear happen a lot on the component that can lead to the damaged of the component and system.

The failure mode occur on crankshaft is there are deep scratch on the component and wear on the internal relief valve. Internal relief valve important to the system as it controls the pressure into the system that when it fails to utilised it can lead to damage to other components. The rises pressure & temperatures gets into the compressor reduce the compressor speed and reduce the pump ability disconnecting power to the compressor and causing the compressor to shut down. Then, according to (Betcher & Betcher, n.d.) due to rising temperature into the compressor rotor will result in a protector opening and eventual stop down. Same goes to crankshaft some failure occurs on the component it will cause other component damage as the crankshaft are linked to connecting rod and piston at the other end of crankshaft. The reason why the current control changing to new compressor is because the component is related.

On the other hand, there are multiple failure mode occur on the pistons there are scratch on the piston, piston oil ring stuck and damaged piston head. Based on observation on the maintenance report, usually if there are wear on the piston rings and rod assembly it will cause totally damaged to the compressor's piston.

Figure 4-2 Damaged Pistons (by HVAC experts maintenance reports)

4.3 Analysis of Failure with Highest Risk Priority Number

Nowadays, there are tremendous growth usage of hermetic and semi hermetic compressor in many applications that because of it smaller size, lightweight and easy to maintained. In this report, focused on failure mode occur in the application of food conservation, onshore and offshore and laboratory. After calculated various RPN calculations, realized that risk priority number above 120 are risky component. Below is the graph on failure mode occur on different application with each component risk priority number. The graph using the highest RPN number that are above 120. Failure mode compressor on different application Vs. RPN.

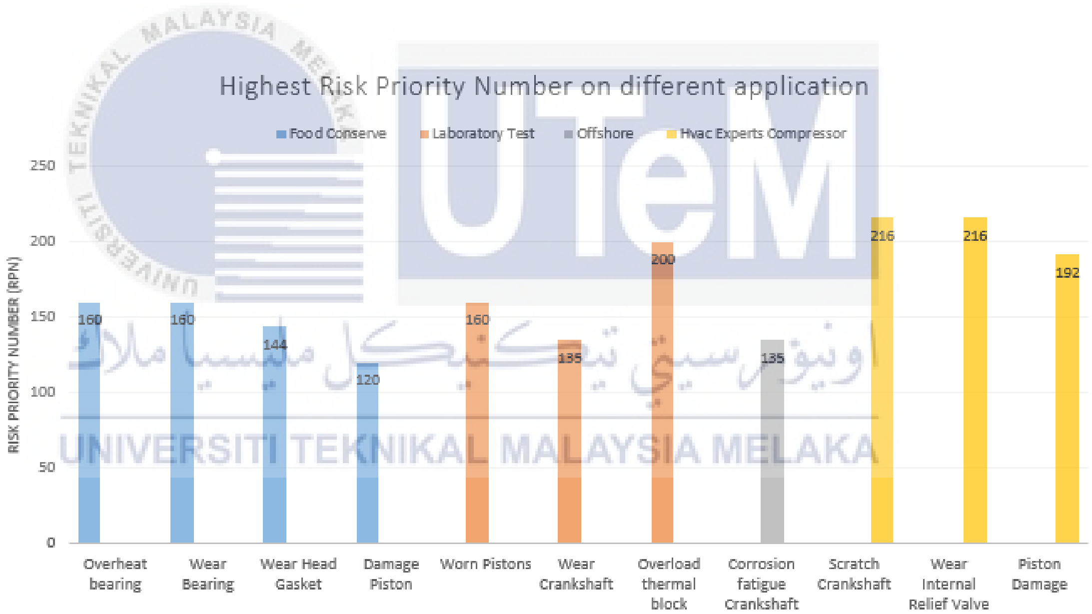


Figure 4-3 Highest Risk Priority Number on different application

Based on Figure 4-3, the risk analysis of failure occur on four different compressor application are shown along highest risk number respectively; food conserve refrigeration, Laboratory test on compressor, Offshore compressor inspection on North sea oil and gas platform and HVAC experts inspection report on Petronas in Terengganu oil and gas platform.

The food conserve refrigeration used semi hermetic reciprocating compressor with 160 risk number of failure mode bearing component. The wear on the bearing assigned with extreme effect of severity because of the wear effect the system brings contamination due to moisture. Which the contamination occurs increasing influence of liquid stroke. Followed by fatigue and excessive wear occur on the head gasket, second highest risk effect the author state that liquid refrigerant flood back is the cause of high aggressive wearing. Because of the of the failure effect occur causing the wears happen to the components. Due to wear happens it triggers the liquid stroke causing the compressor to fail. The food products conservation is widely used in mall that required to consume electrical and mechanical on its own can fail and damage the entire machine.

Secondly, there are eight compressors has been sent to do laboratory tested in Ohio. The analysis has been done many years back on the compressor of Copeland shows that major compressor problem due to motor damage that results to the fail of the system. Based on the laboratory tested focused on Copeland semi hermetic compressors the causes of failure occur in the compressor is refrigerant flood back, flooded starts, slugging, overheating and oil loss. In 2003, total of six semi- hermetic compressors are dissembled to find out the failure mode occurs. The failure mode occurs then are put into the FMEA tables Table 3-2 with calculated RPN. The highest risk priority number for the laboratory tested is overload thermal block, worn pistons and wear crankshaft with percentage of 39%, 26% and 22% respectively. Overload thermal caused by loss of oil in the system that affect the bearing, and crankshaft to wear. Piston ring wear and worn pistons has the high occurrence since the failure occurs on two out of six compressors. These failure was caused by an overheated state that caused oil breakdown, which affect to wore out of mechanical components lead to motor fails.

However, on North Sea and Petronas oil and gas platform application the compressor shows same highest risk failure components which is crankshaft. In the maintenance report of the North Sea identified a crack on the crankshaft because there are oil leak detects. While, on the Petronas oil and gas platform, stated the failure mode occurred is deep scratch, dirty crankshaft and the worst case is that the crankshaft is gone missing. As observation done through the Petronas maintenance report recognized that every time there are failure occur on the crankshaft, the piston and the internal relief will affected such as wear, damaged and corroded. These failure modes occur on crankshafts component may be due to its location, used in offshore location probable the chlorine came from the sea water. The chlorine caused a moderately acidic and anodic one at the base of the pit structures, resulting in a potential difference with the crankshaft's cathodic surface allows the crack expands (Harris & Birkitt, 2016).

Figure 4-4 A) Scratch on Petronas crankshaft B) Crack on North Sea Crankshaft

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

There are few analyses has been done on the reliability of the compressor used in industry in different application. The failure mode and effect analysis of the compressors has been examined and assigned the risk number based on the examination of the functions subsystem compressor. The failure mode is examining as to improve the dependability and the system availability.

The failures that influence the system and the key to the failure on these applications then are examined. Tabulated into FMEA analysis. Then the failures are assigned with the severity, occurrence and detection rating lastly calculated the Risk Priority Number for each failure. Based on analysis results, show that crankshaft and internal valve is crucial component that has to be maintenance as it will lead to other components damage on offshore platform. In the observations, on oil and gas platform the failure of crankshaft will affect the pistons too as the component are connected. While, pistons and bearing are the component that the failure will occur even in other applications. These failures occur can make the maintenance costly, by practice the right maintenance by execute the failure likelihood in descending order it can reduce the maintenance cost

5.2 Recommendations

Proper compressor maintenance is crucial as for the compressor to ensure smooth operations and minimize disruptions also unexpected downtime to the system. to maintain its operability and its lifespan, it should maintenance programme that involves compressor and its system reviewed on a regular basis. Corrective and preventive maintenance are widely performed on industry compressor. Even though, there are through maintenance it still not enough.

For future recommendation, suggested to do Risk Based Condition Maintenance (RBM) taken into the maintenance work. As it aims for the component or subsystem that have poses greatest risk of failure. Also, risk based maintenance is the most cost effective as maintenance strategy that optimise the maintenance work in order from the highest risk to the component's failure with lower risk. It can reduce the likelihood of the breakdown.

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TAJUK: **INTEGRITY ASSESMENT OF HVAC AND SYSTEM SUPPORT USE IN COMMERCIAL BUILDING AND OFFSHORE PLATFORM**

SESI PENGAJIAN: **2021/22 Semester 1**

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