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Analytical Hierarchy Process and Failure Mode and Effect Analysis on HVAC Semi-Hermetic Compressor Maintenance Strategy

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ABSTRACT

The article paper presents a strategic tool used in maintenance strategy deployment using failure mode and effect analysis method in oil and gas semi hermetic compressor perspective. This research aims to study and formulate framework of maintenance strategy using Analytical Hierarchical Process and Failure Mode and Effect Analysis of HVAC semi hermetic compressor used at the offshore oil platform. The case study has been conducted systematically at a company involved in maintenance activities at regular basis servicing HVAC equipment and parts which in this case focusing on Semi Hermetic Compressors at case studies taken from two companies, both involved in oil and gas production. The ranking of severity associated with Risk Priority Number in Failure Mode Effect Analysis table for this case study is obtained from assessment on maintenance history report lodged on Semi Hermetic Compressor serviced by the company. The severity assessment also studied based on Pareto Analysis on occurrence from maintenance history report. Based on the Failure Mode and Effect Analysis (FMEA) analysis, recommendations are made for semi hermetic compressor for maintenance strategy propositions to improve lifetime and reliability as FMEA output being used as input for synthesize using multi criteria method Analytical Hierarchical Process.

1. Introduction

This research aims to study and formulate framework of maintenance strategy using Analytic Hierarchical Process (AHP) method and Failure Mode and Effect Analysis (FMEA) HVAC semi hermetic compressor used at the offshore oil platform. A semi-hermetic compressor is one type of compressor available on the market. This maintenance model will assist service contractors to identify the maintenance criticality for HVAC semi hermetic compressor for the oil and gas sector thus reducing corrective maintenance technique. This research study also describes the process of making a failure

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modes and effects analysis (FMEA) for a company under study which is the HVAC servicing contractor to clients. FMEA is a method to assist in prioritizing risks and manage the highest risks in order to enhance system/sub system quality and reliability [1,2]. Choosing the correct maintenance strategy/policy is a crucial decision in maintenance decision making process [3].The AHP synthesize the decision criteria/problems into a decision hierarchy and utilize a structured pairwise comparisons to weigh the parameteres/criteria and determine the alternatives.

2. Background of Study

Maintenance programmed of the HVAC semi hermetic compressor system at the oil and gas platform will be done according to maintenance strategies practice (Preventive maintenance, Corrective maintenance, Prediction Maintenance and Risk-Based inspection) [4]. A decision-making aid is a method that helps manage the effect of requirements on different options. It is possible to carry out prediction scenarios and elaborate in the desired manner. Organizations may use maintenance techniques to prepare strategic action plans or even enhance existing processes. Maintenance is achieved by careful preparation and timely execution of maintenance activities. This study examines and utilize the tool (AHP) of study in the maintenance field of HVAC components support systems in general, with the study focusing on HVAC maintenance reports at a specific firm, the findings of which can be used as a reference and applied to other businesses.

2.1 Motivation

Maintenance workers in the sector frequently struggle to prioritize maintenance needs in order to develop an effective strategy. The AHP methodology is one of the methods used to prioritize the issue. The AHP method is used to track the impact of each failure mode in the reciprocating compressor until the root cause is identified, allowing the appropriate remedial action to be determined.

2.2 Objectives

The objectives of the current study are as follow

- This research utilizes and significantly applies the use of FMEA and AHP, as decision making and strategy tool for the company under study and aimed to propose recommendations for the best strategies based on outputs from FMEA being input for the AHP decision making for the strategy.
- Maintenance strategy formulations are aimed to be recommended in order to increase reliability of the semi hermetic compressor and enhance the maintainability of the compressor and increasing availability of the compressor. This report will then become a blueprint and manual procedure for semi hermetic compressor maintenance strategy for oil and gas industrial practitioners.

2.3 Literature Review

HVAC stand for Heating Ventilation and Air Conditioning or in the simple way system that are used to make people feel cozy warm and cool in any residential and commercial buildings. There are several parts in the system that keep the system working, the air returns for ventilation, ducting, electrical elements, compressor, condenser, expansion valve, outdoor unit and blower [5]. Air compressor is used in various industrial environments and is an important machinery in gas transmission via

pipelines, oil and gas platforms and chemical plants, power plant, water treatments plant etc. After a significant servicing period, unpredictable failures of sub components due to many unexpected factors mechanically and electrically will occur, and affect the semi hermetic's operational performance [6]. In order to maintain a performance of compressor, proper maintenance strategy must be adopted. Correct and wise air conditioning system inspection is paramount to enhance efficiency, optimize energy utilization, and lower operating costs [7]. A proper and accurate maintenance strategy/policy together with expertise of maintenance and operation personnel will protect assets failure and safety/environmental issues in the plant. Besides that, it will prolong asset integrity with reduced failures/breakdown. This subsequently will result in optimized and reduced operating costs with better production yield and improved overall equipment effectiveness of a plant/industry [7]. As normally, dimension wise semi hermetic compressor is large in size, it also able to provide high level of pressure to empower large/complex system. It is an important component among various industries, used to provide high pressured air to rotating manufacturing/process equipment which includees machines that are hydraulic and pneumatic based components. Hence, it is required to monitor and assess the system's continuous performance in order to operate in good health/condition at regular and periodic basis. The overall performance of HVAC system to produce a comfortable condition for example, building occupants must be maintained and continuously monitored. For instance, the monitoring system of refrigerant gas leakage must be taken into serious consideration for the inspection and maintenance activity.

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 from maintenance services provider/contractor 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 [8]. 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. The Analytic Hierarchy Process (AHP) is a multi-criteria decision making process to assist decision makers faced with several conflicting and subjective criteria [9]. One of the main reasons for AHP's success is that the first two stages do not demand sophisticated understanding of mathematics or decision analysis from the decision maker [10]. It is a theory of measurement that uses pairwise comparisons to establish priority scales and relies on the opinions of experienced professionals. These scales are used to calculate the relative value of intangibles [11,12]. The comparisons are done using an absolute judgement scale that indicates how much more one element dominates another in terms of a specific feature [13]. The judgement may be inconsistent, and the AHP is concerned about how to measure inconsistency and change judgments when possible to achieve better consistency [14]. By multiplying the derived priority scales by the priority of their parent nodes and adding for all such nodes, the final priority scales are created [15].

As a major contractor for HVAC maintenance and commissioning in the oil and gas sector in Malaysia, the company under this research study play an important role in providing expert consulting to keep HVAC equipment including semi hermetic compressor in good working order while controlling unnecessary costs and ensuring that the equipment is maintained until it reaches the end of its useful life. As for now, numerous failures which due to mechanical and electrical failure mode have affected the reliability of semi hermetic compressors as shown in Figure 1.

Fig. 1. Semi Hermetic Compressor Mechanical Failures under Study

2.4 Failure Mode and Effect Analysis

Failure mode and effect analysis is a tool that assess the potential failure modes of a system and identifies the most likely causes of the failures. This method was developed by US Defense Department to minimize the impact of failures. And this method also is commonly used to minimize the risk and improved the reliability of the products and services [16]. 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 [17]. 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. After the critical components with the associated most frequent failures been detected and stated, therefore it is then followed by scrutiny and evaluation of the failures thoroughly. Hence, it can propose solutions and actions to solve the problems/failures and their implications. Failure Mode and Effects Analysis, which was one of the first strategic techniques for failure analysis was formulated by reliability engineers in the 1950s to evaluate failures that occur from breakdowns of military systems [18]. An FMEA becomes a failure mode and effects analysis if priorities are associated with the failure mode effects. The FMEA shows that the failure modes with higher probability of occurrence and high severity, allowing the proposition of strategy/solutions that counter and solve these effects. In the FMEA process (in the operating condition of system, equipment or component), the failure modes are studied and assessed as accordance to their criticality [19]. FMEA procedure involves analyzing the failure within a system and categorizing them based on the severity and the occurrence to develops risk priority number (RPN). Each failure mode's risk is assessed using the Risk Priority Number (RPN) computed by multiplying the severity, an occurrence and detection assigned value. Throughout the analysis process, corrective action is recommended [18].

2.4.1 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 significant effects/implications of various types of failures to identify components that require attention and strategic maintenance decision.

2.4.2 List of Failure Mode and Failure Effects

Specific failure mode will show itself in form that can be seen in system behavior 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.

2.4.3 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 tables 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 [20]. 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 strategy. FMEA is one of the methods for mitigation from systematic failures. The process of the method which early identify the problem of the system have make the method popular to be applied as its detection earlier in design phase. FMEA techniques helps define, identify and eliminate failure through recommendation action for produce good reliability system support.

2.5 Compressor

Compressor is like a heart part of the air conditioner. Low pressured, low temperature refrigerant enters the compressor as a low pressure, low temperature gas and come out as a high pressured and high temperature gas. As for the functionality, compressor task is to circulate the refrigerant needed for heat exchange through the indoor and outdoor unit's coils. Apart from that, it also provides 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 [21].

2.6 Reciprocating Compressor (Hermatic) 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 [21]. For semi hermetic compressor, the motor and compressor housing are housed in a two-piece shell of a semi-hermetic compressor. The covers are bolted together, allowing them to be opened for maintenance and other purposes. Due to the bolts and O-rings required to link the covers, semi-hermetic compressors are often more expensive than hermetic compressors. The main advantage of this compressor over the hermetic type is the ease with which it may be repaired in the event of a compressor failure or for routine maintenance [7]. The use of a semi-hermetic compressor in an HVAC system is well-established in all industries, with the oil and gas platform being no exception. It can be used in a chiller, freezer, or even air conditioner and various research are currently ongoing to extend its life duration and reduce repair costs, as the cost of spending in the oil and gas business is typically higher than onshore. This is due to logistics, which necessitates a boat delivery.

3. Methodology

As continuation in this report, the performance of maintenance report of HVAC support system produced by maintenance services provider such as blower, compressor, refrigerant data in industrial plant has been compiled into this report to be studied using Failure Mode Effect 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 affect the 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. It is important to maintain the HVAC support system so they can increase the life time of the system and continuously produce excellent service. This can be achieved with a good maintenance action. Data are gathered for the study by assessing and evaluate maintenance records produced by the maintenance service firm. The compressors' condition was investigated. It includes all compressors on the offshore platform, 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 is formulated. In the worksheet, the required details about failed components and prospective failure were noted and analyzed further. 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. The Analytical Hierarchy Process (AHP) method is formulated for semi-hermetic compressors used in the case study via maintenance report/history from a maintenance services provider company in order to determine the optimal maintenance strategy to extend compressor life. The Super Decisions open source software, which was built by the method's originator is used for this study. The AHP synthesis approaches are the most potent for combining judgement and data to rank options and forecast outcomes. It provides a complete and rational framework for constructing a decision problem, expressing and measuring its aspects, linking them to broader goals, and assessing potential solutions. Criteria under consideration for AHP analysis on this research study is shown as in Figure 2. The main strategies that we intend to choose and select are:

• Failure based maintenance i.e corrective maintenance, where a failure occurred induced the maintenance to be performed.
• Time/use based maintenance, i.e preventive maintenance, where either the passed time or the amount of utilization will induce the decision of maintenance
• Predictive maintenance where a condition based of the equipment/system influences the maintenance decision.

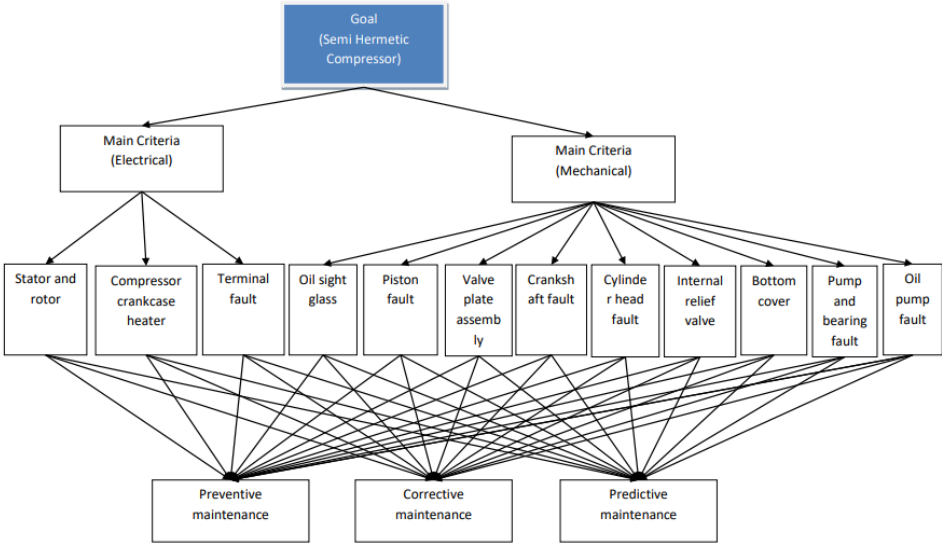

Fig. 2. Criteria for Maintenance Strategy Selection of Semi Hermetic Compressor

3.1 Data Analysis

Data were gathered for the study by reading maintenance records produced by the maintenance service firm. The compressors' condition was investigated. It includes all compressors on the Offshore platform, 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 analyzed further.

3.2 Instrumentation for FMEA

The formation of the critical parameters named risk priority number (RPN) to represent the priority of the failure mode are presented as tabulated in Table 1. The RPN is computed by multiplying the severity with the occurrence and the detection rating assigned to each of them respectively.

Risk Priority Number(RPN) = Severity(S) X Occurrence(O) X Detection(D)

Table 1
Severity, Occurrence & Detection Rating table

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 or safety issue	High	Remote
9	Critical effect , system shutdown	Very high	Very remote
10	Hazardous , life threatening	Extremely high	No inspection

4. Results/Discussion

4.1 FMEA Outcomes for Semi Hermetic Compressor

The formulation of Failure Mode and Effect Analysis (FMEA) for specifically case study performed on the maintenance history report of semi hermetic compressor belong to first company is shown in Table 2.

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 analyzed from the industrial maintenance report by the maintenance service provider. 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). Table 2 shows the failure mode and effect analysis (FMEA) of semi hermetic compressor for oil and gas platform belong to first client maintenance issues under study (an oil and gas producer company).

Table 2
FMEA Outcome from Analysis of Semi Hermetic Compressor for First Company

Process Input	Failure Mode	Failure Effects	S	Potential Cause	Current Control	O	D	RPN
Electrical Issues	Physical winding melting	Overheat	9	Compressor overheating & very low oil level	Rewinding / Replace new compressor	5	1	45
	Cable for Oil sump heater damage	Leakage	3		Repair use tape	1	5	15
Mechanical Systems Failure/Malfunctioning	Oil level not seen at sight glass	Compressor Oil not return back	3	Insufficient compressor oil	Clean	1	8	24
	Suction valve plate	Wear & Tear	7	Liquid enter compressor	Replace	6	1	42
	Piston head damage	Damage	8	Locking debris in suction valve	Replace new compressor	2	2	32
	Piston oil ring stuck	Wear	8	Debris in piston		2	6	96
	Deep scratch at piston body	Wear	8	Debris in cushion valve	Clean & replace	2	6	96
	Internal relief valve	Wear	6		Suggesting to replace with new ones	9	4	216
	Bearing sleeve	Corroded	6			8	3	144
	Cylinder Head Assembly	Corroded	6			6	3	108
AHU Blower	Broken shaft / bearing	Damage	8			4	2	64

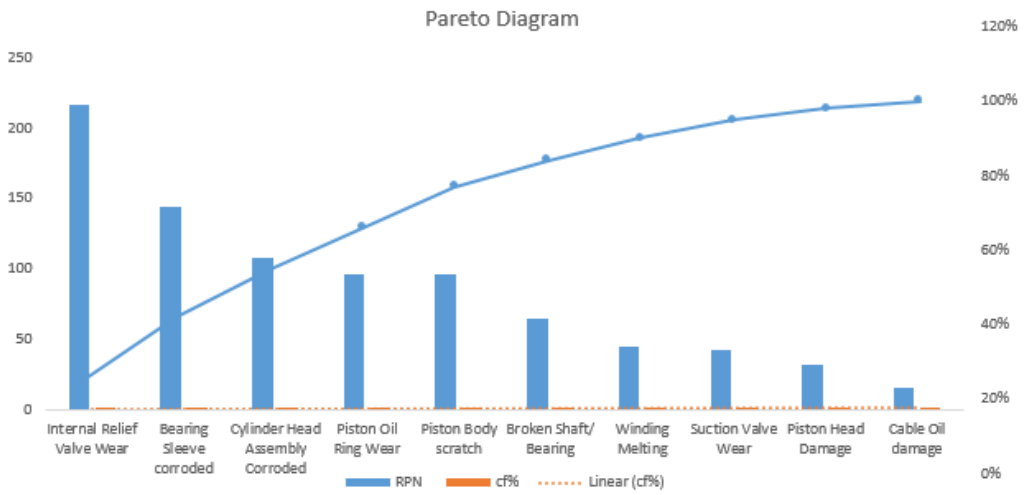

Fig. 3. Pareto Diagram for Compressor Failure Modes Vs. calculated RPN

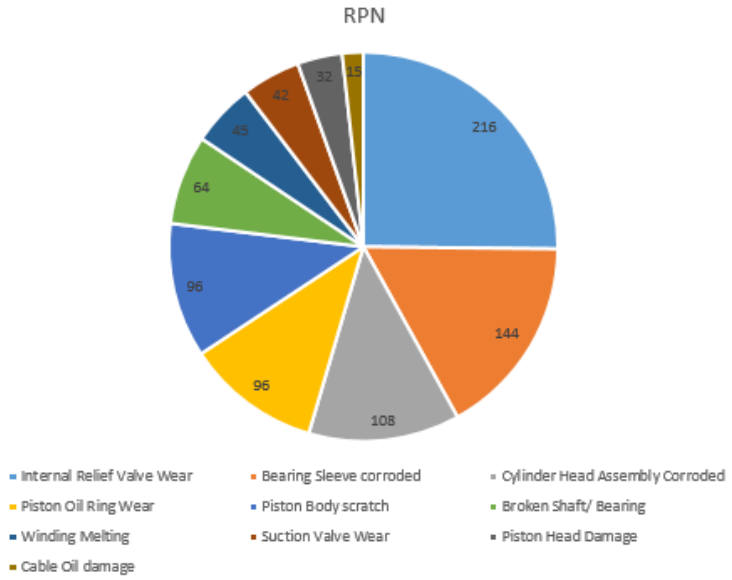

Fig. 4. Pie Chart according to compressor RPN

Various aspects clearly described in the Table 3 in terms of 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 Internal Relief Valve conquer of 25% from total RPN value. Followed by failure bearing with 17% until the lowest RPN value percentage damaged cable 2% from total of 858 RPN value.

On the other hand, a study on second client company (an oil and gas producer) also focuses on semi hermetic compressor in oil and gas platform. To carry out this analysis, a failure mode effect analysis (FMEA) table was created based on their maintenance reports in year 6th October 2018 until 22nd September 2020. The analysis focused on one of the basic components in HVAC which is compressor of refrigeration systems. This inquiry allowed for a thorough evaluation of the primary failure modes for reciprocating semi- hermetic compressors while they were in used in marine application (offshore). Based on each failure mode occurred then the failure effect, failure cause, severity, occurrence and detection rating are assigned. In FMEA Table the highest severity assigned

is 10 which the severity of the failure effect other components give danger to operation without warning and can be life threatening to the system. Failure mode assigned with highest severity is Tripped Compressor this is because due to trip compressor affects the other component such as evaporator, condenser, blower and other and cause system inefficiency. For trip compressor, occurrence assigned 5 the likelihood of the failure will occur is occasional due to the failure occur two times in the maintenance reports and the detection rating are assigned 5 remote because before the compressor trips other components will show a sign which it really broke down. And the other failure modes are assigned according to the Table 1 Severity (S), Occurrence (O), Detection rating (D) ranking table.

The results of the analysis shown in Table 3 for the cumulative RPN and associated failure modes and Table 4 for comprehensive failure and effect analysis (FMEA) for the case study of semi hermetic compressor for second company (client's company under serviced). Meanwhile, Figure 5 Pareto Chart and Figure 6 Pie Chart. Pareto Chart are chosen to emphasize the most significant of failure mode with higher risk priority number (RPN) and to prioritized significant failure to be done in Risk Based Maintenance (RBM) in order to achieve overall improvement. Where the bars indicate individual values in descending order and the line represent the cumulative total of the percentage values each failure mode. While, the pie charts showed the major failure mode occur in the compressor for easier observation. Based on both charts, the highest ranking failure are list descending start from tripped compressor due to overheat winding, corroded bearing, loosen service valve bolts, worn gasket and others. This is due to the increment of temperatures in the compressor head and cylinders getting hot whereby the oil loses its ability to lubricate wisely. That causes pistons, rings and cylinder walls to wear resulting in blow by, leaking valves and metal fragments in the oil.

Table 3
Failure Mode and Risk Priority Number (RPN) for Semi Hermetic Compressor Problems at Second Client Site

Failure mode	RPN	CF (%)
Tripped compressor	400	27%
Bearing corroded	256	44%
Service valve loosen	256	61%
Gasket worn out	168	72%
Loosen Bolts	144	82%
Corroded piping & copper line	120	90%
Leakage Pressure switch	108	97%
Pressure gauge damaged	24	99%
Terminal plate worn out	20	100%
TOTAL	1496	

The ordered frequency counts of values for the several levels of a categorical or nominal variable are shown in Pareto charts. The bars reflect individual values in decreasing order, while the line represents the sum of the % values for each failure mode. For easy observation, the pie charts demonstrated that the predominant failure mode occurs in the semi hermetic compressor. According to the pareto analysis, the most failure mode occur in compressor; is compressor tripped which is 24%. Then, follow with terminal plate worn out and leaking on gasket which is both of them is 11%. Gasket worn out is 9% while compressor valve leaking, discharge service valve leaking and mounting wear and tear is 7% each. There are five types of faults or failure with 4% which is nipple service valve leaking, capacitor fault and overheat, txv issue, compressor jammed, and pressure switch leakage. Lastly, 2% number of failure is flair cracked and leaking copper pipe.

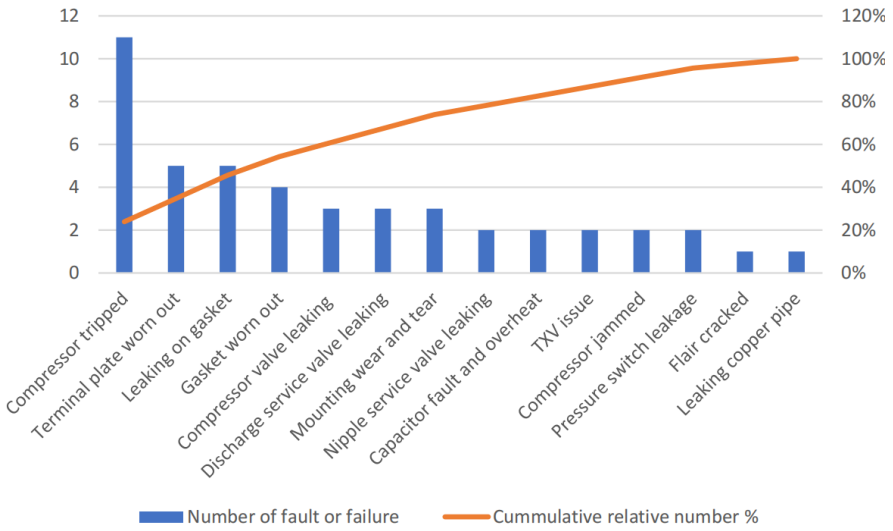

Fig. 5. Pareto Chart of Failure Mode vs. Risk Priority Number (RPN)

Electrical winding defects of compressor happen because of several causes which include contamination of the wiring, damaged materials/wires, insulation defects/wear,power surges thermal overload and other failure causes. Apart form that, this can be caused also by multi loading issues exposed to the compressor as well as dynamic/vibration effect while in operating condition. Besides that, the fact that the compressor is in continuous contact with the refrigerant and refrigerant machine oil will also impose potential failure modes/occurrence.

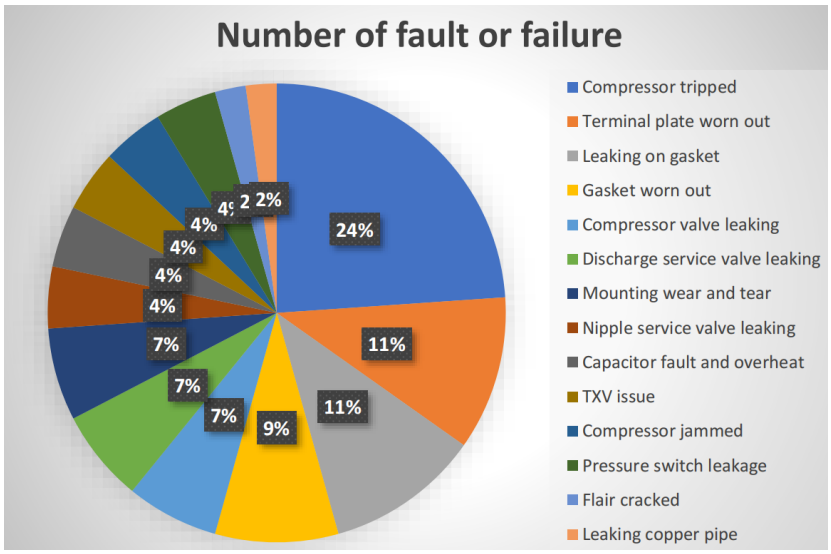

Fig. 6. Pie Chart of Failure Mode Vs. Risk Number

4.2 Analytical Hierarchical Process (AHP) Synthesize/Findings

In performing the pairwise comparisons process, a rating from 1 to 9 is used to show the degree of important/dominant one criteria/alternative is over another whereby 1 to represent an equal importance, while 2 to 9 shows a more significant importance. Their respective inverse pairwise are utilized to show a lower importance. The normalized priorities eva from criteria considered in this study is depicted in Figure 7.

Table 4

Failure Mode and Effect Analysis (FMEA) for Semi Hermetic Compressor in Second Company

No.	Item	Failure Mode	Failure Effects	Severity	Failure Cause	Occurrence	Current Controls	Detection	Recommend Action	RPN
1	Bearing	Corrosion	Damage to bearing & shaft	8	Chemical and electrochemical reactions between the surface	8	Change new	4	Include removal water from lubricating oil on a regular and continual basis in maintenance activities.	256
2	Gasket	Worn Out	Leaking gas and produce noisy sound	6	Deteriorated over time	7	Fabricated and change new	4	Maintain proper evaporator and compressor superheat. Also change new.	168
3	Service valve	Loosen	Leak	8	Many leaks founds on valve showed there are contaminant,	8	Tightened the valve	4	Periodically inspect & tightened the bolts	256
4	Piping And Copper line	Corrosion	Damaged and leaking	6	Due to acidic and highly oxygenated state also large quantities of dissolved oxygen.	5	Clean the corroded and injected leak stopper.	4	Current control is enough, if the parts corroded badly change new	120
5	Pressure Gauge	Damaged	Mechanical vibration produce badly sound	4	Pressure gauge can't function properly and cause wear and tear on other components.	2	Change new	3	Apply diaphragm seals mounted with pressure gauges, the component can used in extreme temperature.	24
6	Terminal Plate	Worn out	Refrigerant circuit clogging	4	Liquid refrigerant flood back	1	Change new	5	Correct problem or replace fan or correct piping.	20
7	Pressure Switch	Leakage	Control circuit system fail & Pressure's unit drop	9	System performance insufficient	4	Change new switch	3	Replace new.	108
8	Bolts	Loosen	Liquid slugging	6	Cause gas leaking	4	Tightened the bolts	6	Tightened the bolts	144
9	Electrical winding	Tripped and grounded	Overheat, many leaks and corrosion all parts.	10	Mechanical part jammed system can't function properly and material sludge found inside the unit.	5	Change new compressor	8	Check for unbalanced voltage during interval maintenance activity. Replace compressor.	400

List of all priorities for Semi Hermetic Compressor.

Main Network: AHP method software(update).sdmod: rating...

Here are the priorities.

Icon	Name	Normalized by Cluster	Limiting
No Icon	CM	0.20564	0.068545
No Icon	PDM	0.50099	0.166996
No Icon	PM	0.29338	0.097792
No Icon	GoalNode	0.00000	0.000000
No Icon	Compressor Electrical	0.25000	0.083333
No Icon	Compressor Mechanical	0.75000	0.250000
No Icon	1. Stator and rotor	0.14841	0.049469
No Icon	2. Compressor crankcase heater	0.06233	0.020776
No Icon	3. Terminal fault	0.03926	0.013088
No Icon	4.Oil sight glass	0.03299	0.010998
No Icon	5.Piston fault	0.13772	0.045908
No Icon	6.Valve plate assembly	0.11450	0.038167
No Icon	7.Crankshaft fault	0.15193	0.050642
No Icon	8.Cylinder head	0.04478	0.014927
No Icon	9. Internal relief valve	0.05424	0.018081
No Icon	10. Bottom cover	0.02825	0.009417
No Icon	11. Pump and bearing fault	0.12791	0.042636
No Icon	12. Oil pump fault	0.05767	0.019224

Fig. 7. Priorities for all the Criteria Considered for Decision Making Using AHP for Semi-Hermetic Compressor Under Study (Taken from Super Decision Software)

Name	Graphic	Ideals	Normals	Raw
CM		0.528656	0.223795	0.074598
PDM		1.000000	0.423329	0.141110
PM		0.833573	0.352876	0.117625

Fig. 8. Recommendation for Maintenance Strategies using AHP via Super Decision Software

The AHP tool was performed and synthesized to process the selection of best maintenance strategies for maintenance services contractor. The study incorporate the selection of main and sub criteria related to maintenance problems, relating these criteria to suitable/potential maintenance strategies and quantify/value these strategies. The finalized selection of accurate maintenance strategies from the AHP were the result of the described process and a deeper synthesizing step that associate with the technical/practical applicability of the potential maintenance strategies. It was synthesized using Super Decision software, as shown in Figure 8 and it computed the overall percentage of 42.33% for Predictive Maintenance i.e. Condition Based Maintenance, followed by Preventive Maintenance i.e. Time Based Maintenance (35.28%) and lastly followed by Corrective Maintenance at 22.38%. This finding is in agreement with the outcome from AHP of maintenance selection for newly constructed chemical fertilizers plants as authored by [10]. The best maintenance strategy was found to produce a combination of Predictive Maintenance, Preventive Maintenance and Corrective Maintenance with approximate percentages of 50, 23 and 19% respectively[10]. The same trend also from a research of maintenane strategy at water treatment systems [20]. Besides that, the finding from[3] which studied the naval companies maintenance strategies using AHP, also in parallel and in agreement with the outcome of this research under study. It was obtained from

AHP computation that corrective maintenance is not and will always not be an option, whereby good strategy is between time i.e use based maintenance and predictive maintenance [13]

As the time based compressor maintenance practice, it is best to review the compressor's operating and maintenance log history. Preventive maintenance is time based whereas predictive maintenance will assess condition of compressor operation until irregularities/defects occur. Detection needs special skills and predictive monitoring tools. Utilization of those specific comes with high cost. Specialist/Certified personnel have to be hired to perform the predictive monitoring/condition based maintenance. Predictive maintenance assess potential problems by sensing performance/behaviour of equipment. This strategy/maintenance monitors health of the machine, evaluate irregular/excessive trends, and conclude failure/problems. For instance, example of condition based maintenance is an operator, hearing an abnormal/irregular sound from the equipment anticipate a potential failure mode/problem. This will bring to decision of either to perform corrective or preventive/time based maintenance.

4.3 Limitation

The decision making being proposed is limited in the scope of semi-hermetic compressor for HVAC maintenance strategy deployment for oil and gas platform (living cabin and equipment room) perspective. The failure modes, RPN (which comprises the severity, occurrence and detection) hence the recommendation will vary if the application of semi-hermetic compressor is at the other context such as supermarkets, other commercial (such as shopping centers) and industrial applications.

5. Conclusion

Failure Mode and Effect Analysis has been performed on semi hermetic compressor on a company involved in maintenance service provider. The analytical hierarchical process (AHP) method have been strategically performed where inputs/parameters for assessment have been gathered from the outcomes of FMEA performed on maintenance activities at two oil production sites serviced by the company under study. The synthesized outcomes for all the priorities and maintenance criteria using open source software Super Decision yield the findings of 42.33% for Predictive Maintenance i.e Condition Based Maintenance, followed by Preventive Maintenance i.e Time Based Maintenance (35.28%) and lastly Corrective Maintenance at 22.38%. The Risk Priority Numbers (RPN) have been evaluated based on occurrence, severity and detection measure analyzed from maintenance history report obtained from HVAC maintenance service provider. The outcomes of the FMEA analysis from the study depicted that maintenance strategy must be appropriately adopted in regards of highly criticality failure modes and maintenance problems assessed from both companies such as electrical windings, bearing seen corroded, cylinder head assembly and bearing sleeve corroded and service valve leakage.

6. Future Works

It is intended and strategically thought that more criteria and sub criteria will be incorporated for maintenance selection process. It is also suggested for future work so that survey on maintenance personnel perception and view as well as comparative study of alternatives to be conducted that can assist in understanding the condition of maintenance issues and in selecting the best decision making. Example such as providing questionnaire to be answered by the maintenance personnel (engineers, technicians, vendors) is good to be part of data gathering. As for current case study, the data and judgement are based merely based on maintenance history report for both oil production sites and

no interview have been made in deciding the judgement/priority for the criteria and sub criteria.Other examples of parameters should be taken into consideration are safety, reliability and availability. Besides that, costs issue can be important. Other secondary criteria, such as experience with maintenance, commitment from management for performing high cost maintenance activities such as predictive maintenance can also be taken into account in the future study.

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