Failure and Rectification of Double Stage Double Acting Reciprocating Air Compressor

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Abstract – *The operation of air compressors is crucial in various industrial and commercial applications, ensuring the availability of compressed air for numerous processes. However, like any mechanical system, air compressors are subject to failure modes that can lead to costly downtime, reduced productivity, and potential safety hazards. This study aims to conduct a comprehensive failure mode analysis (FMA) of air compressors to identify and understand the common causes of failures and develop strategies for prevention and mitigation. The methodology involves gathering data from diverse sources, including equipment manuals, maintenance records, and industry standards, to compile a comprehensive list of potential failure modes. Through a systematic approach such as Failure Mode and Effects Analysis (FMEA).*

***Key Words:* Discharge valve, suction valve, piston, lubrication system, cylinder, FMEA**

1.INTRODUCTION

Double-acting reciprocating compressors play a vital role in numerous industrial applications, including refineries, where they are indispensable for maintaining efficient operations. These compressors are designed to handle high-pressure gases and are favoured for their robustness, reliability, and versatility in handling various gases and operating conditions. In the context of refineries, where the demand for compressed air or gases is constant and diverse, the double-acting reciprocating compressor stands out as a key component in ensuring smooth and uninterrupted processes.

Refineries utilize compressed air and gases for a wide range of applications, including pneumatic tools, process control instrumentation, and pneumatic conveying systems. Additionally, compressed air is essential for combustion processes in various refinery units, such as furnaces and boilers. The reliability and performance of double-acting reciprocating compressors are critical for ensuring the uninterrupted supply of compressed air and gases to these essential processes, thereby optimizing refinery productivity and safety

2 LITERATURE REVIEW

1. FMEA: Methodology, Design and Implementation in a Foundry.

Author: Awadhesh Kumar and M.P. Poonia

This paper delves into the Failure Mode and Effect Analysis (FMEA) method to identify and rank potential process failures. It outlines the FMEA methodology in detail and its implementation in a foundry environment. By analyzing problems using Risk Priority Numbers (RPN), the study determined which issues needed urgent attention. The research also quantified risk by calculating the financial losses linked to core rejection.

2. Failure mode and effects analysis An integrated approach for product design and process control

Author: Sheng-Hsien (Gary) Teng and Shin-Yann (Michael) Ho

Failure Mode and Effect Analysis (FMEA) is a technique used to identify potential failure modes in a product throughout its lifecycle, determine the effects of these failures, and assess their impact on product functionality. During the FMEA process, engineers carefully evaluate product functions and list potential failures. This thorough analysis provides insights into each detailed functional design element, making FMEA an invaluable tool for quality planning and reliability prediction.

3. FMEA for Reducing Breakdowns of a Sub System in the Life Care Product in Industry

Author: Rakesh.R, Bobin Cherian Jos, George Mathew

This paper explores the application of Failure Mode and Effects Analysis (FMEA) to enhance the reliability of subsystems in order to boost productivity, thereby improving the bottom line of a manufacturing business. The study discusses various potential causes of failure, their effects, and suggested preventative measures to address them.

4. FMEA Implementation in a Foundry in Bangalore to Improve Quality and Reliability

Author: Piyush Kumar Pareek1, Trupti V Nandikolmath1 and Praveen Gowda1.

The study was conducted in an Indian foundry, with participation from selected internal staff forming the FMEA team, focusing on the core-making process. It examines the issues in various stages of the core-making process that contribute to high rejection rates. By analyzing these problems through the Risk Priority Number (RPN), the paper provides a way to prioritize attention for each identified issue. The monetary loss due to core rejection is used as a measure of risk

5. Design, modeling and characteristics research of a novel self-air-cooling reciprocating compressor

Author: Xiaohui Gao, and Yongguang Liu

High-pressure miniature air compressors play a crucial role in various applications, including refrigeration and pneumatic ejection in fighter jets. However, these compressors generate substantial heat during compression, leading to cooling systems that not only consume more energy but can also be larger and heavier than the compressors themselves. Consequently, designing an efficient cooling system becomes a key challenge.

6. Failure Risk Analysis on Screw Compressor using Failure Mode and Effect Analysis (FMEA) Method

Author Hendrik Elvian Gayuh Prasetya, and Joke Pratilastiarson

The context of a screw compressor, the FMEA methodology involves assessing failure risks by collecting three key pieces of data: severity, occurrence, and detection. By analyzing these elements, FMEA enables a comprehensive understanding of where and how failures might occur and provides a pathway for reducing the risks associated with these failures.

7. Reciprocating compressor prognostics of an instantaneous failure mode utilizing temperature only measurements

Author: Panagiotis Loukopoulos and George Zolkiewski

This study evaluates several prognostic methods for predicting valve failures in reciprocating compressors, focusing on their accuracy and variability. The first two methods examined—Multiple Linear Regression (MLR) and Polynomial Regression (PR)—fall under the category of trend extrapolation, which is favored in industrial settings due to its simplicity, despite limited academic research on it.

8. FMECA of the linear compressor

Author: Amit Jomdea , Virendra Bhojwanib and Shreyans Kedia

This paper presents a FMECA study of linear compressors, highlighting significant failure modes such as valve failure, coil former continuity issues, flexure bearing breakage, and leakage. The study examines the effects of these failures and categorizes system components based on the impact of these failure modes.

9. Modeling the valve dynamics in a reciprocating compressor based on two-dimensional computational fluid dynamic numerical simulation

Author Yu Wang1, Jianmei Feng1 and Bo Zhang

The analysis of valve dynamics includes sensitivity studies on the impact velocity and the angle of inclination, showing that impact velocity is more sensitive to changes in rotational speed and valve lift. Severe inclination occurs when valves are installed in a radial direction. This detailed examination of valve behavior and cylinder dynamics informs the design and optimization of reciprocating compressors, offering a better understanding of their operational characteristics.

10 Failure Analysis of Refinery Hydrogen Reciprocating Compressors

Author Paweł Bialek and Piotr Bielawski

The analysis distinguishes between wear margin loss due to overall wear of functional units and damage to specific compressor components. Typical faults of hydrogen compressor elements are described, along with estimates of fault risks for specific components and wear margin loss for selected functional units.

3 METHODOLOGY

The methodology requires identifying potential failure modes at different levels (e.g., component, subsystem, or system level) to understand how each failure can impact the compressor's functionality and performance.

Methodology

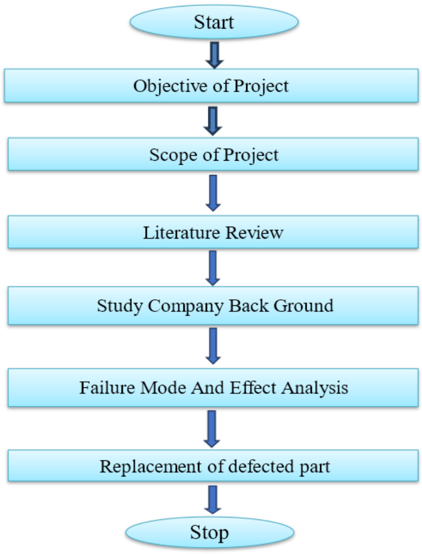

Fig 1: Project Methodology

4. INDUSTRIAL PROFILE

Bharat Petroleum Corporation Limited (BPCL) Kochi Refinery is one of the largest refineries in India, located in Kochi, Kerala. Its journey began in the early 1960s when the Government of India decided to set up a refinery in the southern part of the country to cater to the growing demand for petroleum products The refining capacity of 15.5 million metric tonnes per annum. It specializes in refining crude oil into various petroleum products, ranging from petrol and diesel to jet fuel and specialty products

4.1IREP (Integrated Refinery Expansion Project)

It is the one of the largest expansion projects in this refinery The refining capacity of 10.5 million metric tons per annum It consist of mainly 5 Units

1. Crude Distillation Unit [CDU]
2. Diesel Hydro Desulphurization Unit [DHDT]
3. Vacuum Gas Oil Hydrotreating [VGO HDT]
4. Petrochemical Fluidized Catalytic Cracking [PFCC]
5. Delayed Coker Unit [DCU]

4.1.1 Crude Distillation Unit [CDU]

This is the initial processing unit in nearly every oil refinery. It plays a crucial role by distilling incoming crude oil into different fractions based on their boiling points, which are then sent for further processing in other refinery units. The CDU, also known as the atmospheric distillation unit, operates at a pressure just above atmospheric pressure. It produces various products, including gasoline, kerosene, light diesel oil, heavy diesel oil, and heavy oil, among others

4.1.2 Diesel Hydro Desulphurization Unit [DHDT]

This unit consists of a Reaction Section and a Separation Section, essential for producing diesel with reduced sulfur content from crude oil. The process of lowering sulfur levels is known as hydro desulfurization, hence the name Diesel Hydro Desulfurization (DHDS). These sections work together to ensure the production of BS VI Grade diesel, characterized by a lower sulfur content and an enhanced cetane number.

4.1.3 Vacuum Gas Oil Hydrotreating [VGO HDT]

It is designed to lower sulfur levels in feedstocks for the Fluid Catalytic Cracking (FCC) process, such as VGO, before they are fed into the Petrochemical Fluid Catalytic Cracking (PFCC) unit. This treatment reduces sulfur in the FCC products and enhances the overall PFCC yield

4.1.4 Petrochemical Fluidized Catalytic Cracking [PFCC]

It's a vital part of a refinery that transforms heavy hydrocarbons into lighter, more valuable products like gasoline, diesel, and propylene. This process converts high-boiling point, high-molecular weight hydrocarbon fractions from crude oil into gasoline, alkene gases, and other petroleum-based products.

4.1.5 Delayed Coker Unit [DCU]

The process involves heating a residual oil feed to its thermal cracking temperature in a furnace with multiple parallel passes. This breaks the heavy, long-chain hydrocarbon molecules in the residual oil into coker gas oil and petroleum coke. The petroleum coke produced in a delayed coker has various commercial applications, with its primary use being as a fuel source. Green coke can be used as fuel for space heaters and large industrial steam generators.

5. WORK DONE

5.1 Problem Identified

Double acting double stage reciprocating air compressor (ICL-C101) which produce average output (7-8 kg/cm^2) Due to the long working condition its output decreases to 6.53 kg/cm^2.The efficiency of a compressor can reduce by different problems. In this compressor all other components are giving proper output without any interruption in their working condition. But pressure gauge reading in cylinder one is decreased (2.8 kg/cm^2) from proper maintained pressure (3.4-3.8 kg/cm^2) and also temperature rises at discharge valve and surrounding parts. Working of cylinder one discharge valve is not properly by the help of monitored pressure gauge difference and temperature difference in discharge valve is a cause of failure in this compressor.

	pressure	Temperature
Lube oil pump	3.1 kg/cm²	50ºC
Supply header	2 kg/cm²	60ºC

Table 1. Lube Oil Readings

<table>
<tr><td rowspan="5">Compressor</td><td colspan="2">Normal condition</td></tr>
<tr><td>Intermediate pressure</td><td>Final pressure</td></tr>
<tr><td>3.4 kg/cm²</td><td>7.13 kg/cm²</td></tr>
<tr><td colspan="2">Failure condition</td></tr>
<tr><td>2.8 kg/cm²</td><td>6.53 kg/cm²</td></tr>
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Table 2. Pressure Readings

5.2 Solution for Rectified problem

Replacement of new valve

5.3 Procedure for replacement

Turn on standby compressor and Shutdown the power supply of failed compressor. Then dismantle the compressor valve cover on the cylinder head by removing 4 bolts and remove gasket and replace both valve and gaskets

Fig 2. Compressor with Inter Cooler and After Cooler

Intercooling: Between the stages, an intercooler is employed to cool down the compressed air from the first stage before it enters the second stage. Cooling the air helps in reducing its temperature, which in turn reduces the work required for compression in the second stage. This cooling also helps to reduce the risk of damage to the compressor due to excessive heat buildup

Aftercooler: a mechanical heat exchanger designed to remove the heat and moisture of compression from a compressed air stream so the air is cool and dry enough for use in air-operated equipment. Positioned at the outlet of the air compression system, where air is discharged.

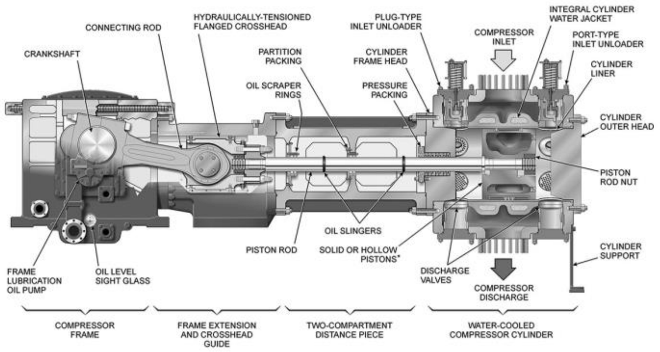

Fig 3. Reciprocating Compressor Components

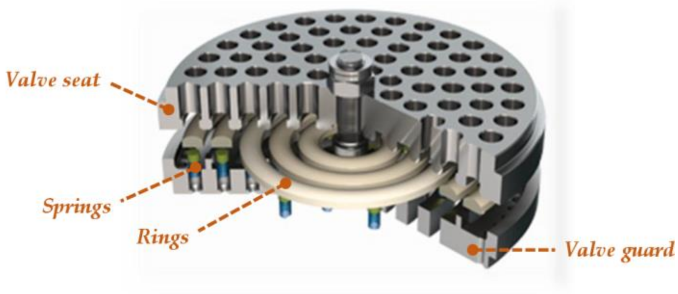

Fig 4. Ring Valve

The scope of the task is similar to that of plate valves. Reworking the valve seats typically demands specialized tools and highly trained personnel. To ensure a proper seal, the seal rings must fit the seat perfectly. Discrepancies in the thermal expansion rates of the ring and seat materials can cause unwanted leaks during operation. Common ring materials include Nylon, PEEK, and other thermoplastics.

5.4 Flow process chart

A flow process chart is a diagrammatic representation of the sequence of steps involved in a specific process, showing the flow of materials, information, or operations. It helps to visualize the overall process, highlighting the different stages and actions required to complete a task.

A flow process chart for the replacement of a discharge valve is given below

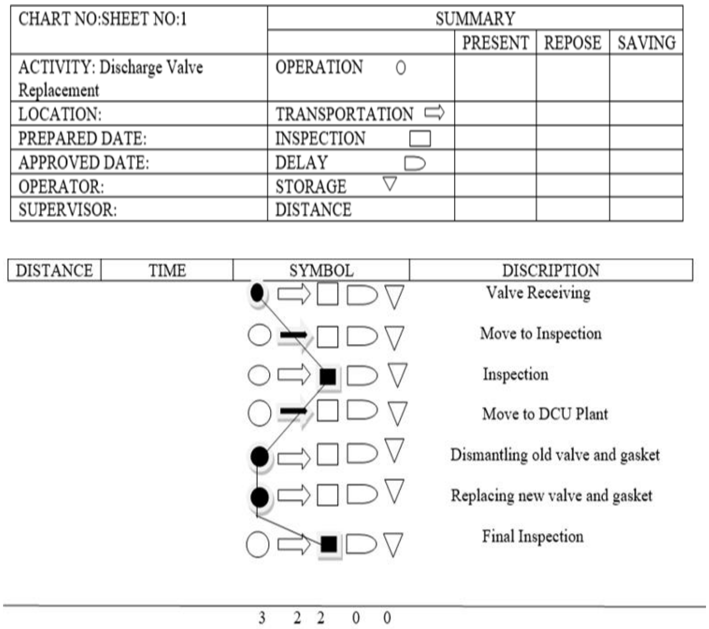

Fig 5. Flow Process Chart

6. APPLICATION OF FMEA

Failure Modes and Effects Analysis (FMEA) is a systematic method used to identify and evaluate potential failure modes within a process, product, or system, and to assess the impact of those failures. The goal is to detect possible failure points, determine their consequences, and implement corrective actions to mitigate risks. FMEA involves a detailed examination of components, processes, or systems to identify where and how failures could occur, then prioritizing them based on severity, likelihood of occurrence, and detectability. It's widely used in industries like manufacturing, aerospace, and healthcare to improve safety, quality, and reliability.

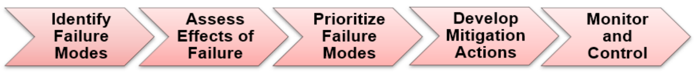

Fig 6. FMEA Flow chart

FMEA is calculated and the output is a Risk Priority Number (RPN). The RPN is calculated as

Severity * Occurrence * Detection

- Severity is an assigned value that indicates the effect of a particular failure mode.
- Occurrence is an assigned value that designates how frequently that particular failure mode is likely to occur.
- Detection is an assigned value that indicates how fast that particular failure mode can be detected.

Severity Table

Code	Classification
10	Dangerously High
9	Extremely High
8	Very High
7	High
6	Moderate
5	Low
4	Very Low
3	Minor
2	Very Minor
1	None

Table 3. Severity Table

Occurrence Table

Code	Classification	Example
10 9	Very High	Inevitable Failure
8 7	High	Repeated Failures
6 5	Moderate	Occasional Failures
3 2	Low	Few Failures
1	Remote	Failure Unlikely

Table 4. Occurrence Table

Detection Table

Detection	Rank	Criteria
Extremely Likely	1	Can be corrected prior to prototype/ Controls will almost certainly detect
Very High Likelihood	2	Can be corrected prior to design release/Very High probability of detection
High Likelihood	3	Likely to be corrected/High probability of detection
Moderately High Likelihood	4	Design controls are moderately effective
Medium Likelihood	5	Design controls have an even chance of working
Moderately Low Likelihood	6	Design controls may miss the problem
Low Likelihood	7	Design controls are likely to miss the problem
Very Low Likelihood	8	Design controls have a poor chance of detection
Very Low Likelihood	9	Unproven, unreliable design/poor chance for detection
Extremely Unlikely	10	No design technique available/Controls will not detect

Table 5. Detection Table

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 11 Issue: 05 | May 2024 www.irjet.net p-ISSN: 2395-0072

6.1 MAJOR TYPES OF FAILURES OF AIR COMPRESSOR

- Suction valve failure
- Discharge valve failure
- Piston failure
- Failure in cylinder
- Failure in lubrication system

Suction valve Failure

ITEM FUNCTION	POTENTIAL FAILURE MODE	POTENTIAL FAILURE EFFECT	SERVITY (1-10)	POTENTIAL CAUSE	OCCURANCE (1-10)	DECTION (1-10)	RPN
• Sealing • To control the flow of air into the compression chamber • Prevention of Backflow	Suction valve failures might lead into a complete loss of compression causing more dangerous failures	• Reduced Compression Efficiency • Overheating • Increased Maintenance Costs • Overloading of Components	10	Mechanical Wear	6	8	480
				Corrosion due to Moisture Condition	8	7	560
				Deformation-Excessive heat or pressure can cause	7	3	210
				Foreign Object Ingestion-dirt, debris,	5	6	300
				Valve Sticking-Improper lubrication	6	4	240

Table 6. Suction valve FMEA

Discharge valve Failure

ITEM FUNCTION	POTENTIAL FAILURE MODE	POTENTIAL FAILURE EFFECT	SERVITY (1-10)	POTENTIAL CAUSE	OCCURANCE (1-10)	DECTION (1-10)	RPN
• Releasing the compressed air from the cylinder into the discharge line. • Prevention of Backflow • preventing the pressure from exceeding safe limits	• An unusually low head pressure will result from the problem	• Loss of Efficiency • Fluctuations in the compressed air pressure • Overheating • Decreased Air Quality • Unstable Operation	10	Wear and Tear	7	8	560
				Corrosion Exposure to moisture, contaminants	9	7	630
				High Operating Temperatures	9	3	270
				Contaminants in the Air: Particulate matter, moisture, oil,	5	6	300
				Improper Installation - misalignment of components	4	3	120

Table 7. Discharge valve FMEA

Pistion Failure

ITEM FUNCTION	POTENTIAL FAILURE MODE	POTENTIAL FAILURE EFFECT	SERVITY (1-10)	POTENTIAL CAUSE	OCCURANCE (1-10)	DECTION (1-10)	RPN
To draw in atmospheric air, compress it, and then expel the compressed air into a discharge line	a loss of compression efficiency, decreased air output, and potentially rendering the compressor inoperable.	• Loss of Compression Efficiency • Decreased Air Quality • Increased Energy Consumption • System Overheating • Noise and Vibration • Compressor Downtime • Component Damage	10	Piston Ring Wear	7	8	560
				Piston Scoring - due to Abrasive particles	8	6	480
				Misalignment: Improper alignment of the piston within the cylinder	5	4	200
				Overheating: Excessive heat buildup	8	4	320
				Piston Cracks or Breakage: High-stress conditions	8	3	240

Table 8. Piston FMEA

Cylinder Failure

ITEM FUNCTION	POTENTIAL FAILURE MODE	POTENTIAL FAILURE EFFECT	SERVITY (1-10)	POTENTIAL CAUSE	OCCURANCE (1-10)	DECTION (1-10)	RPN
It is a chamber where the air compression process occurs. It houses the piston, which moves up and down to compress air	Damage, malfunction, or deterioration of the cylinder components, leading to reduced compression efficiency	• Reduced Compression Efficiency • Air leaks result in wasted energy • Loss of Pressure • Increased Operating Costs • Noise and Vibration	10	Worn Piston Rings Over time, the piston rings in the cylinder can wear out due to constant friction	9	6	540
				Scoring or Scratches on Cylinder Walls: If foreign particles or debris enter the cylinder,	8	7	56
				Piston or Cylinder Misalignment: Improper installation	6	4	240
				Corrosion: Exposure to moisture or corrosive substances	5	5	250
				Excessive Heat Continuous operation	7	4	280

Table 9. Cylinder FMEA

Failure in Lubrication System

ITEM FUNCTION	POTENTIAL FAILURE MODE	POTENTIAL FAILURE EFFECT	SERVITY (1-10)	POTENTIAL CAUSE	OCCURANCE (1-10)	DECTION (1-10)	RPN
To reducing friction and wear between moving parts, ensuring smooth operation, and extending the lifespan of the compressor	Failure of this system causes the friction between moving components increases, leading to accelerated wear, overheating, and potentially catastrophic damage to the compressor	• Increased Friction and Wear: Without proper lubrication • Overheating • Continuous operation without proper lubrication can cause severe mechanical damage	7	Lubricant Contamination - dirt, debris	8	5	280
				Improper Lubricant Selection: The use of incorrect or low-quality lubricants that are not suitable for the operating conditions	3	9	189
				Oil Leaks	8	4	224
				Oil Pump Failure	4	3	84
				Insufficient Lubricant Supply	6	3	126

Table 10. Lubrication System FMEA

Remedial Measures

Major types of failure	Potential cause	Highest RPN	Remedial measures
Suction valve	Corrosion due to Moisture Condition	560	• Add a dehumidifier to the compressor room • Maintain all filtration system and replace the intake and inline filters as needed
Discharge valve	Corrosion due to Moisture Condition	630	• Consider insulating your compressor room for better temperature control. • Fix leaks, and don't allow water to pool on the floor near the compressor
Piston	Piston Ring Wear	560	• Ensure there is adequate lubrication • Perform a compression test and leak-down test to assess the sealing ability of the piston rings
Cylinder	Worn Piston Rings Over time, the piston rings in the cylinder can wear out due to constant friction	540	• Ensure there is adequate lubrication • Replace Piston Rings: Worn or damaged piston rings can cause increased friction and cylinder failure.
Lubrication system	Lubricant Contamination - dirt, debris	280	• Provide proper filtration • Scheduled maintenance of filter

Table 11. Remedial Measures

CONCLUSION

The FMEA for the reciprocating air compressor has highlighted critical failure modes, such as piston wear, valve malfunction, and cylinder damage, driven by causes like inadequate lubrication, high temperatures, and insufficient maintenance. By addressing these risks with targeted mitigation strategies, the compressor's reliability and safety are expected to improve, reducing downtime and operational disruptions. Overall, the FMEA provides a clear path for ensuring optimal performance and longevity for the compressor.

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