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Implementing FMEA for Multi-Stage Centrifugal Compressor in ASU "AQS"

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ABSTRACT

Air separation units (ASUs) play a crucial role in industrial processes that require gases of high purity. Within ASUs, multi-stage centrifugal compressors are vital since they efficiently compress and deliver air for subsequent separation processes. However, these compressors are susceptible to various failure modes, which can have a significant impact on the performance and safety of ASUs. To address this issue, Failure Modes and Effects Analysis (FMEA) is employed as a systematic approach for identifying, analyzing, and prioritizing potential failure modes in complex systems. This article provides an overview of the applications of FMEA in multi-stage centrifugal compressors within ASUs. It explores the challenges and benefits associated with FMEA, emphasizing its role in enhancing compressor reliability, reducing downtime, and fostering operational excellence.

1. INTRODUCTION

A multi-stage centrifugal compressor is a key component in an air separation unit (ASU), which is a facility used to separate air into its primary components, namely nitrogen, oxygen, and other rare gases. This type of compressor is specifically designed to handle large volumes of air at high pressures and deliver them to the subsequent stages of the ASU process [1].

The main purpose of the multi-stage centrifugal compressor in an ASU is to compress the incoming atmospheric air, raising its pressure and temperature to facilitate the separation process [2]. This compressor consists of multiple stages, each comprising an impeller and a diffuser [3]. The impeller, driven by a motor, rotates at high speeds, imparting kinetic energy to the air. The diffuser then converts this kinetic energy into pressure, further compressing the air [4].

One of the significant advantages of a multi-stage centrifugal compressor is its ability to handle a wide range of flow rates and pressures [5]. Each stage of the compressor contributes to the overall compression ratio, allowing it to achieve the high pressures required for air separation. The compressor stages are typically arranged in series, with the outlet of one stage feeding into the inlet of the next.

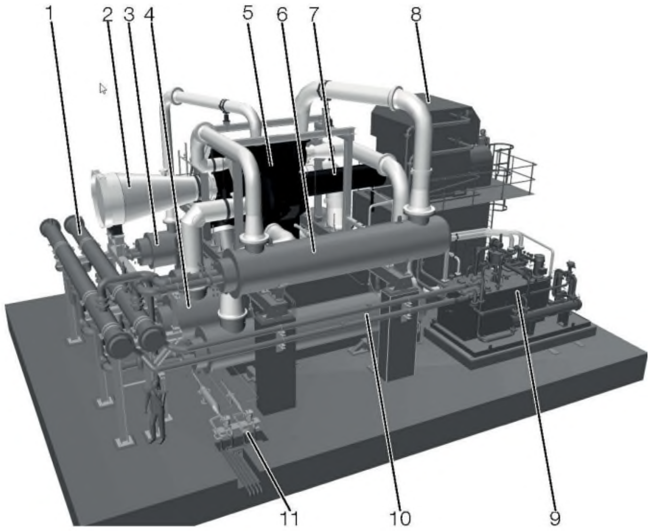
To ensure efficient operation and reliability, multi-stage centrifugal compressors for ASUs are built with robust construction materials and precise engineering. They are often equipped with advanced control systems and safety features to monitor and regulate parameters such as temperature, pressure, and vibration. These measures help maintain optimal performance, prevent operational issues, and ensure the safety of the overall ASU operation.

In summary, the main multi-stage centrifugal compressor in an air separation unit plays a vital role in compressing atmospheric air to the desired pressure levels required for the subsequent separation process. It is a critical component that enables the efficient production of nitrogen, oxygen, and other rare gases, serving various industrial applications such as gas manufacturing, chemical processing, and healthcare.

The rest of the paper is structured as follows. Section 2 briefly describes Failure Modes and Effects Analysis (FMEA), its applications in multi-stage centrifugal compressors, and its implementation process. Then in Section 3, a comprehensive analysis of the results obtained from applying FMEA to a multi-stage centrifugal compressor is presented. This analysis includes identifying critical failure modes, assessing their severity, and evaluating their potential impact on the compressor's performance and safety. In Section 4, conclusions are drawn based on the findings of the analysis, highlighting the effectiveness of FMEA in enhancing compressor reliability and safety.

2. MODELLING OF OUR SYSTEM:

This section describes the design and function of our machine unit. The figure 1 below shows the arrangement of the assemblies set up directly at the machine unit.



1 Coolant collector	2 Suction line 1
3 Process gas cooler	4 Process gas cooler
5 Compressor	6 Process gas cooler
7 Coupling with covering	8 Main drive motor
9 Oil system on base plate	10 Process gas cooler
11 Drains	

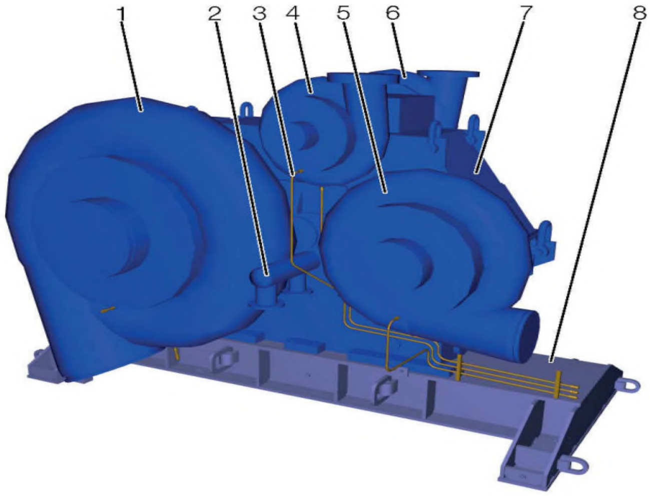
Fig-1: Structure of the machine unit and arrangement of the assemblies [6]

2.1 Main drive motor

The electric main drive motor converts electrical energy into mechanical rotational energy. This rotational energy is used to drive the machine train.

2.2 Compressor

The compressor compresses the process gas according to the laws of fluid mechanics.
The mechanical energy transmitted by the driver is transmitted in the compressor stages to the process gas flowing in through the suction nozzle. After an incremental increase in pressure in the individual compressor stages, the process gas enters the downstream process [7].



1 Compressor stage 1	2 Main oi pump
3 Drainage, compressor stage5	4 Compressor Stage 5
5 Compressor stage 3	6 Compressor Stage 4
7 Gear unit housing	8 Bage frame

Fig-2: Compressor[6]

2.3 Coupling

The coupling is a flexible steel multiple-disk coupling. Equalizing shaft misalignment, it transmits the torque via flexible steel multiple-disk packages.
The coupling transmits speed and torque from the main drive motor to the compressor.

2.4 Process gas system

The process gas system consists of pipes and assemblies in which the process gas is handled.

2.5 Coolant system

The cooling water system supplies the following machine unit assemblies with cooling water:

- Main drive motor
- Process gas cooler
- Oil coller

2.6 Drainage system

The compressor stages are equipped with drain line, which reach down to the lower level of the machine unit.
The drain lines feature handwheels for opening the drains before start-up, as well as blind plugs with which the drainage pipe are closed.

2.7 Oil system

The oil system supplies the required lube oil for the bearings and the other lubrication points of the machine unit. It is designed for circulation which is maintained by oil pumps. The lube oil cools and lubricates the machine unit assemblies which are supplied with lube oil, reducing corrosion effects and minimizing wear of the machine bearings.

2.8 Control system

To ensure efficient operation, maintain desired pressure levels, and protect the compressor from operational issues like surges or overloads, the control system for a multistage compressor is essential.

2.9 Monitoring system

The monitoring system consists of the assemblies below:
- Measured value transmitter (Temperature, Vibration, Positions)
- Oscillators / proximity sensors
- Electronic monitoring unit

The monitoring system of the machine unit ensures that any malfunctions of the machine unit are detected at an early stage. During operation, the monitoring system continuously monitors critical operating values [8].

In the diagram below, the functionality of a single-stage centrifugal compressor is depicted.

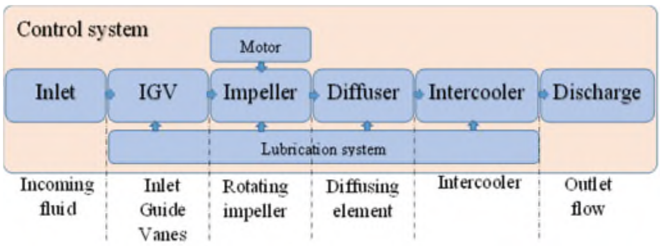


Fig-3: Centrifugal Compressor Process (Single stage) [9]

3. FAILURE MODE AND EFFECTS ANALYSIS

Failure mode effect analysis was originally developed by NASA to improve and verify the reliability of space program hardware [10]. FMEA is one of the most important and widely used tools for reliability analysis [11]. It is intentional to be a proactive action process carried out in advance implementing new or changes in products or process ideally FMEA are conducted in the design or process development stages [12], although conducting it an existing products and processes may possibly have benefits in effective FMEA identifies corrective actions required to reduce failures to assure the highest possible yield safety and reliability [13]. Failure mode effect analysis is four types system, design, process, service. System FMEA focus on systems and sub systems in early concept stage to demonstrate balancing among the operational components. Design FMEA minimizes the effect of failures in sub and main assemblies it maximizes the design quality and reduces cost. Process FMEA identifies the deviation in the process flow, materials, methods, people and environment. Service FMEA maximizes customer satisfaction through quality and reliability. Even though it is widely used reliability technique it has some limitation in prioritizing the failure modes and output may be large for even simple systems, may not easily deal with time sequence, environmental and maintenance aspects [14].

3.1 Risk Priority Number

Risk priority number methodology is a technique for analysing the risk associated with potential failures during a FMEA analyses. To calculate risk priority number severity, occurrence, and detection are the three factors need to determine [15].

$$RPN = Severity \times Occurrence \times Detection \quad (1)$$

3.2 Severity (S)

Severity is the seriousness of the effect of potential failure modes. Severity rating with the higher number represents the higher seriousness or risk which could cause death. An example rating for severity is given in table 1 [16].

Table 1. Example table of Severity

Severity rating	
1	No safety or financial impact, easily correctable
2	Minor inconvenience or minor financial impact
3	Moderate financial impact, customer dissatisfaction
4	Significant financial impact, potential legal implications
5	Major financial impact, safety hazard with severe consequences
6	Serious safety hazard with potential for injuries
7	Major safety hazard, potential loss of life
8	Catastrophic consequences, extensive damage or loss
9	Severe safety hazard, high likelihood of fatalities
10	Maximum severity, imminent danger, or irreparable damage

3.3 Occurrence (O)

Occurrence ratings for FMEA are based upon the likelihood that a cause may occur based upon past failures and performance of similar system in similar activity. Occurrence values should have data to provide justification. An example rating for occurrence is presented in the table 2 [17].

3.4 Detection (D)

Detection is an assessment of the likelihood that the current controls will detect the cause of failure mode. An example for detection rating is as shown in table 3 [18].

Table 3. Example table of Detection

Detectability rating	
1	Very easy to detect or identify
2	Easy to detect or identify
3	Moderate difficulty in detection or identification
4	Moderate to high difficulty int detection or identification
5	High difficulty in detection or identification
6	Very high difficulty in detection or identification
7	Extremely challenging to detect of identify
8	Rarely detectable or identifiable
9	Virtually undetectable or unidentifiable
10	Impossible to detect or identify

3.5 Steps in FMEA

To conduct FMEA there are some necessary steps as to follow [19].

System analysis:

- Step 1: Planning & Preparation
- Step 2: Structure analysis
- Step 3: Function analysis

Faire analysis and risk mitigation:

- Step 4: Failure analysis
- Step 5: Structure analysis
- Step 6: Optimization

Risk communication:

- Step 7: Result documentation

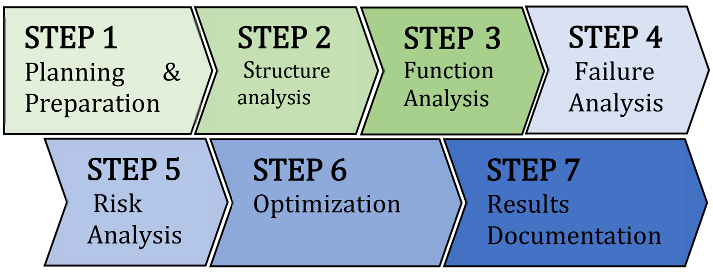


Fig-4: FMEA steps process

Figure 3 shows step by step process to conduct FMEA. Review team first collects all the component data with the help of process flow diagrams, P&ID. With that information review team finds the potential failure mode and its effects. Next step is to find the failure occurrence with its severity rating. List the current control methods to rate detection, with the help of severity, occurrence and detection rating calculate RPN. Give the control measures to prevent the occurrence of failure and finally document and follow up the FMEA report [20].

Table 2. Example table of Occurrence

Occurrence rating	
1	Extremely rare occurrence
2	very low probability of occurrence
3	Low probability of occurrence
4	Moderate probability of occurrence
5	Moderate to high probability of occurrence
6	High probability of occurrence
7	Very high probability of occurrence
8	Near-certain probability of occurrence
9	Virtually certain occurrence
10	Continuous occurrence

4. FMEA IMPLEMENTATION

Case study is conducted and FMEA technique is applied to a multi-stage centrifugal compressor within an air separation unit (ASU). A multi-stage centrifugal compressor is a key component in an air separation unit (ASU), which is a facility used to separate air into its primary components, namely nitrogen, oxygen, and other rare gases. This type of compressor is specifically designed to handle large volumes of air at high pressures and deliver them to the subsequent stages of the ASU process.

Failure mode effect analysis is executed by a multidisciplinary team of experts in a multi-stage centrifugal compressor with the help of process flow chart the analysis team identifies the components in process. For the analysis break down details; accident reports for the past five years are taken. Criteria of ranking of severity, occurrence and detection are selected suitably by analyzing the past failure records of the multi-stage centrifugal compressor. Using values of severity, occurrence and detection number risk priority number is calculated.

4.1. Steps to Calculate RPN

To calculate the RPN, we adhere to the following systematic steps:

Step 1: Potential failure mode of multi-stage centrifugal compressor.
Step 2: Potential effect of failure found with severity. Failure not only stops the process it also causes serious accident.
Step 3: From the table values of severity, occurrence, detection values are calculated.
Step 4: RPN value calculated as RPN = S × O × D

Table 04. FMEA chart

Process Function	Potential Failure Mode	Potential Effect(s) of Failure	Potential Cause(s)/ Mechanism(s) of Failure	Current Process Controls	Sev	Occur	Detec	RPN	Recommended Action(s)
Inlet system	Clogged Filter	Reduced airflow, Decreased efficiency	Duct Accumulation, filter blockage	Regular filter inspections and cleaning.	9	6	8	432	Increase filter inspection frequency
	Damaged damper	improper flow control	Mechanical wear, excessive vibration	Regular inspections, condition monitoring	8	4	7	224	Implement predictive maintenance for dampers
	Ductwork leakage	Loss of pressure, inefficient intake	Poor installation, corrosion	Pressure testing, visual inspections	7	5	8	280	Conduct regualr ductwork integrity checks
	Valve malfunction	Flow instability, reduced performance	Component failure, wear	Routine maintenance, periodic valve testing	9	6	9	486	Implement real-time monitoring of valve performance
	Inadequate insulation	Heat loss, increased energy consumption	Insulation degradation, improper installation	Visual inspections, thermal imaging	6	3	7	126	Upgrade installation and conduct isulation audits
Impeller	Erosion/corrosion of impeller blades	Reduced efficiency, imbalance reduced performance	Impurities in the gas,abrasive particles	Regular maintenance and claining corrosion, resistant materials	8	6	7	336	Use coatings or materials resistant to erosion/corrosion, improve filtration system
	Impeller imbalance leading to excessive vibration	Increased vibration, reduced efficiency, ptoential damge to other components	Manufacturing defects, debris accumulation,imbalance during assembly	Balancing during manufacturing,periodic inspections and balancing	7	5	9	315	improve manufacturing processes, implement regular balancing and inspection
	Mechanical failure of impeller shart or hub	Sudden impeller failure, catastrophic damage, compressor shutdowne	Material defects, excessive loads, improper assmebly	Material testinig and quality control, proper assembly procedures	10	3	6	180	Enhance material inspection and quality control, implement proper assembly techniques
Diffuser	Flow instability	Flow fluctuations, reduced efficiency	Inadequate difuser designe	None	6	5	9	270	Conduct Computational fluid dynamics analysis to optimize the diffuser design and minimize flow instability
	Flow separation	Pressure loss, reduced performance	High flow velocities, improper diffuser shape	Testing and validation protocols	8	4	7	224	Perform flow testing and validation to ensure the diffuser shpe preents flow separation
	Boundary Layer	Increased turbulence , reduced efficiency	Doundary layer growth, rough diffuser surface	Surface finishing, periodic inspections	7	6	6	252	Implement proper surface finishing techniques to reduce boundary layer growth, Regularly inspect the diffuser surface for roughness
	Corrosion	Material degradation, reduced lifespan	exposure to corrosive fluids or environments	Corrosion resistant materials, protective coatings	9	3	8	216	Esure the use of corrosion resistant materials and apply protective coatings to the diffuser.
	Ftigue failure	Sudden component fracture, catastropick	Repeated high-stress loading	Material selection, fatigue analysis	10	5	7	350	Conduct comprehensive fatigue analysis and select materials with high fatigue resistance
	Vbration	Excessive noise, mechnical stress	Imbalance, misalignment, worn coponents	Vibration monitoring system, regular maintenance	7	7	9	441	Implement advanced vibration monitoring systems to detect early signs of imbalance or misalignment
	Fouling / Scaling	Flow blockage, reduced performance	Deposition of contaminants or scaling	Filtration systems, regular cleaning and maintenance	8	6	8	384	Enhance filtration systems and establish regular cleaning procedures to prevent fouling or scaling
	Structural failure	Component deformation, risk of rupture	Excessive operations loads,material defects	Finite Element analysis (FEA), quality control measures	9	4	6	216	Perform FEA to assess strcuctural integrity and implement stringent quality control measures during manufacturing

Motor /Driver	Motor overheating	Motor damage, shutdown of the compressor	Insufficient cooling, high ambient temperatures	Cooling system, temperature sensors, alarms	9	6	8	432	Improve cooling system, monitor temperature closely
	Motor insulation breakdown	Short circuit, motor damage	Aging insulation, high voltage spikes	insulation resisitance chekcs, surge protection	7	5	9	315	Regular insulation testing, install votage surge protection
	Motor bearing failure	Excessive vibration, motor damage	Lack of lubrication, misalignment	Lubrication system, vibration monitoring	8	4	7	224	Improve lubrication maintenance, conduct regular vibration analysis
	Motor controller failure	Loss of motor control, shutdown of the compressor	Electrial component failure, software glitch	redundant controllers, regular software updates	9	3	9	243	Implement redundant controllers, establish comprehensive update plan
	Motor power supply failure	Loss of motor power, shutdown of the compressor	Power supply instablility, electrical grid fluctuations	Backup power supply, voltage regulators	9	4	8	288	Install backup power supply, implement voltage regulation measures
	Motor winding damage	Motor malfunction, shutdown of the compressor	Overcurrent, overheating	Overload protection, thermal sensors	8	5	7	280	Enhance overload protection, install additional thermal sensors
Intercooler	Reduced cooling efficiency	Decreased compressor efficiency	Fouling /dirt accumulation	Regular cleaning and mantenance	8	5	6	240	Improe filtration system to minimize fouling
		Higher outlet temperature	Reduced coolant flow	Monitoring intercooler outlet temperature	9	4	8	288	Increase coolant flow rate or upgrade intercooler design
	Piping leakage	Loss of cooling efficiency	Corrosion	Regular inspection and maintenance	7	3	7	147	Replace corroded sections of piing or implement corrosion resistant materials
		Potential damage to downstraim components	Vibrations	Vibration monitoring system	6	2	9	108	Reinforce piping supports or add vibration dampening measures
	Valves sticking	Disruption of coolant flow	Cantamination	Regular inspection and maintenance	6	4	6	144	Clean or replace stickingvalves to ensure proper operation
		Inconsistent cooling	Wear and tear	Vave performance monitoring	7	3	7	147	Implement valve mantenance program or replace worn valves
	Sensors faulty reading	Inaccurate temperature monitoring	Sensor mafunction	Regular calibrationand testing	8	2	8	128	Calibrate or replace faulty sensors for accurae readings
		Misjudgment of coolant flow	Wiring issues	Wiring integrity checks	7	3	9	189	Conduct thorough inspections and repairs of sensor wiring
Discharge section	Discharge casing leakage	Loss of compressed gas, reduced efficiency	Material defects, improper sealing	Robuste construction, gasket seals, inspection procedures	8	4	8	256	* Conduct regular to identify and address any signs of casing leakage * Implement stringent quality control measures during manufacturing. * Ensure proper installation and tightening of casing components
	Nozzle erosion	Deterioration of nozzle performance, reduced efficiency	Hig-velocity gas flow, abrasive particles	Material selectin, nozzle design, regular inspections	7	5	7	245	* Monitor gas flow rates and implement measures to reduce erosion effects. *Use erosion resistant materials for nozzle construction. * Conduct regular inspections to identify erosion and perform timely Maintenace.
	Silencer clogging	Increased backpressure, reduced performance	Foreign object ingress, particulate accumulation	Filter systems, regular cleaning and mantenance	6	4	8	192	* Install effective filtration systems to prevent debris ingress. * Establish regular cleaning and mantenance schedules. * Implement protective measures to prevent particulate accumulation.
	Discharge valve sticking	Inadequate flow control, reducedperformance	Contamination, valve malfunction	Routine inspections, proper lubrication,maintenance checks	9	3	7	189	* Implement a regular maintenance program for valve cleaning and lubrication. * Install reliable contamination prevention measures. * Conduct routine inspections to identify and rectify valve malfunctions.

Lubrication system	Insufficient lubricant flow	Clogged or blocked lubricant supply lines	Increased friction and wear on compressor	* Lubricant flow monitoring system, regular visual inspection. * Regular maintenance schedule or lubrication system components.	8	7	5	280	*Implement regular maintenance and cleaning of supply lines. *Monitor lubricant flow rates regulary. *Establish proactive replacement schedule for supply lines.
	Lubricant contamination	Inadequate filtration or improper maintenance practices	Reduced compressor efficiency and increased wear	*Filtration system with regular maintenance and replacement schedule. *Regular lubricant analysis and condition monitoring.	9	6	6	324	*Upgrad filtration system for better conatminant removal. *Conduct regular maintence and cleaning of filters. *Implement proper lubricant storage and handling procedures. *Perform regular lubricant anlysis and condition monitoring.
	Oil leaks or seal failures	Poor sealing designor excessive pressure within the system	Lubricant loss, potential equipment damage, and downtime	* Regular inspection and maintenance of seals. * Proper torque procedures during seal installation. *Monitoring system for pressure control	9	3	7	189	*Conduct regular inspection and mainteance of seals. *Implement proper seal installation and torque procedures. *Monitor and control system pressure levels. *Establish leak detection systems or procedures.
Control system	PLC power supply faillure	Loss of control signal	Power outage	*Install uninterruptible power supply(UPS). * Regularly test backup power system.	8	3	9	216	Use redundant power supplies.
	Communication failure	Communication failure	Network failure	*Monitor network connections. *Establish backup communication channels.	9	5	7	315	Implement redundant network connections.
	PLC program error	Erroneous control	Software error	* Develop and validate error-free PLC program. *implement version control for program updates.	9	5	7	315	Regularly revieuw and update PLC program.
	Sensor drift	inaccurate readings	Aging or calibration drift	Calibrate sensors regularly.	6	4	8	192	Implement redundancy for critical snesors.
	Sensor failure	Loss of feedback	Sensor malfunction	*continuosly monitor sensor health. *Replace faulty sensors promptly.	9	3	7	189	Implement redundancy for critical sensors.
	Sensor misplacement	Inadequate measurment	Incorrect sensor placement	*Verify sensor specifications before installation. *Periodically inspect sensor installation. *Provide clear labeling and documentation.	7	4	9	252	

5. RESULTS AND DISCUSSION

The FMEA study's risk priority number indicates a positive assessment, revealing an absence of critical cases within the analyzed scope. However, it does identify areas with potential for enhancement, recommending specific actions to fortify and refine system functions. This favorable evaluation highlights the robustness of the existing compressor while emphasizing opportunities for proactive optimization. Notably, the alignment between the findings of the FMEA study and maintenance and production reports for the past 5 years underscores the consistency and reliability of the analysis process. This synergy signifies a cohesive understanding of the system's intricacies, ensuring that the insights from both sources complement each other, thereby reinforcing the accuracy and effectiveness of the study's recommendations. Overall, while no critical issues have surfaced, the outlined actions serve as proactive measures to further fortify the system's performance and resilience.

6. RECOMMANDATIONS

As the results of our study, in the following points, we highlight the more important recommendations aimed at optimizing the reliability of our system:

➢ **Implement real-time monitoring of valve performance in the inlet system by electrical and mechanical maintenance service:**

- This entails the installation of state-of-the-art monitoring systems capable of providing instantaneous feedback on valve functionality.
- Electrical and mechanical maintenance teams will collaborate to ensure seamless integration and continuous monitoring.
- Regular inspections and data analysis will allow for proactive maintenance and timely intervention to address any deviations in valve performance.

➢ **Implement advanced vibration monitoring systems to detect early signs of imbalance or misalignment in the diffuser by electrical and mechanical maintenance service:**

- Cutting-edge vibration monitoring technology will be deployed to detect even subtle deviations in diffuser performance.
- Electrical and mechanical maintenance specialists will work in tandem to install and calibrate these systems for optimal sensitivity.
- Continuous monitoring and data analysis will enable early detection of potential issues, allowing for timely corrective action to prevent system failures.
-

➢ **Increase filter inspection frequency in the inlet system by the mechanical team:**

- The mechanical team will conduct thorough inspections of filters at shorter intervals to proactively identify and address any signs of clogging or deterioration.
- Enhanced frequency of inspections will ensure that filters are functioning optimally, maintaining efficient airflow and preventing potential damage to downstream components.
- Regular maintenance and cleaning of filters will be performed to remove any accumulated debris and maintain peak performance of the inlet system.

➢ Improve motor cooling system, monitor temperature closely by electrical maintenance service:

- Upgrades to the motor cooling system will be implemented to enhance its efficiency and reliability, ensuring optimal operating conditions.
- Electrical maintenance specialists will install temperature monitoring devices to closely monitor motor temperature in real-time.
- Any deviations from the optimal temperature range will trigger immediate alerts, prompting swift action to prevent overheating and potential motor damage.

➢ **Enhance diffuser filtration systems and establish regular cleaning procedures to prevent fouling or scaling by mechanical maintenance service:**

- The mechanical maintenance team will upgrade diffuser filtration systems to improve their effectiveness in capturing contaminants and preventing fouling or scaling.
- Regular cleaning procedures will be established to remove accumulated debris and maintain the integrity of the filtration system.
- Preventive maintenance measures will be implemented to minimize the risk of fouling or scaling, ensuring uninterrupted operation of the inlet system.

7. CONCLUSIONS

In this study, a comprehensive analysis of Multi-stage centrifugal compressor operations was conducted through the implementation of FMEA as a risk assessment tool. The assessment meticulously examined various potential failure modes, their corresponding severity values, and calculated occurrences of causes. Through this process, we derived the Risk Priority Number (RPN) for each Process function, enabling the identification of critical areas within the compressor system.

Moreover, the study culminated in the formulation of preventive control measures specific to each failure mode. These proposed measures aim not only to mitigate potential failures but also to enhance operational safety.

By implementing the safety precautions recommended in this study, the anticipated outcomes include a significant reduction in downtime due to failures, thereby minimizing their adverse effects on the overall system reliability and efficiency.

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NOMENCLATURE

AQS	Algerian Qatari Steel
ASU	Air Separation Unit
FMEA	Failure Modes and Effects Analysis
NASA	National Aeronautics and space administration
C1161	Multi-stage air compressor
E2416	Direct contact air cooler
E2417	Evaporation cooler
S	Severity
O	Occurrence
D	Detection
RPN	Risk Priority Number
SO2	Sulfur dioxide
SO3	Sulfur trioxide
NH3	Ammonia