Closed Drain Transfer Pump Failure Analysis using Root Cause Failure Analysis (RCFA) Method

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Abstract. Maintenance is a process carried out to maintain the reliability of individual/group assets. Positive displacement type pumps are commonly used in closed drainage systems as transfer pumps in oil and gas processing plants. However, there are times when the pump fails which requires further effort to prevent the failure from recurring. Efforts that can be made to overcome this are using the method of Analysis of the Root Failure (Root Cause Failure Analysis). The RCFA method uses recollection of evidence related to design, procurement, and operation of a tool to find root causes and latent causes of problems. As a result of gaps found between the design process, procurement which leads to the root cause of pump failure, this study recommends pump-operating companies to pay more attention to piping installation to support pump performance and coordination between owner, design, and procurement to prevent this failure from recurring.

1. Introduction

In offshore oil field operations, a drainage system is used which in the context of production operations is tasked with collecting hydrocarbon remnants from the production platform and disposing of them without creating safety risks. In this system, one of the equipment that has an important role is the pump that has the duty to drain fluid and condensate from the flash drum to the liquid burner.

However, in reality, there are still failures at the drainage system pump that can potentially interfere with the performance of the platform or even threaten the safety of workers and the environment in the event of a malfunction of the hydrocarbon waste disposal system. In addition, we know that one of the incidents of upstream oil and gas facilities which caught the public's attention was the Deepwater Horizon Mobile Offshore Drilling Unit (MODU) accident in 2010 [1]. Therefore, as an application of corrective and preventive measures for failure of upstream oil and gas equipment, this study applies the Root Cause Failure Analysis (RCFA) method to be used as a failure analysis method which, in addition to being able to show the root causes of failure, also applies recommendations to prevent such failures from reoccurring, especially in hydrocarbon drainage pump systems.

2. Methods

2.1. Root Cause Failure Analysis (RCFA)

This research employs the Root Cause Failure Analysis (RCFA) method. RCFA is the process of identifying the main root causes of a failure and using that information to determine corrective actions and/or prevent them. Shown below in Figure 1 is a simplified flowchart of a RCFA process.
In this study, the system boundary that is the object of research is the progressive cavity positive displacement pump P-6450A and P-6450B closed drain transfer pump unit systems in company P field. This limitation is done because this equipment has a high level of criticality, of which the closed drain transfer pump is assigned to drain the remaining condensate of natural gas production from the KO drum to the liquid burner.

During the data collection process, there might be 3 kinds of data that could be encountered, such as shown in Table 1.

| Physical Evidence | Failed components, new (undamaged) components, deposit samples, fluid samples, filter samples |
|-------------------|---------------------------------------------------------------------------------------------|
| Recorded Evidence | Pictures, operator logs, SCADA logs, field vibration measurements, environmental conditions, inspection reports |
| Personal Testimony | Operators, maintenance staff, machinists, engineers, managers |

The RCFA case investigation, besides referring to the stages proposed by Ransom [2], also uses the concept proposed by Mobley [3]. The first stage carried out in conducting research is to coordinate with company P to conduct an RCFA case review. Furthermore, the case that will be reviewed for RCFA will be the subject of research. Then, the RCFA team for this case was formed with their respective positions and scope of work which included investigations, facilitators, technical inputs, and supervision of RCFA work.
The RCFA process begins with Incident Reporting, where at least incident reporting includes the date, reporter, incident description, specific location and equipment, preliminary causes, and corrective actions taken.

Then, the steps taken are the classification of incidents and from that classification the problem statement of the case under review is determined. According to SINTEF, the severity of failure can be divided into critical failure, degraded failure, incipient failure, and unknown failure [4]. After the problem statement is determined, data is collected that can be in the form of interviews, physical evidence in the form of equipment operating procedures, company policies related to equipment operation, records of operation and maintenance, P&ID of equipment, photo and/or video documentation, evidence of damage, records of the operating conditions of the equipment, as well as reports of incidents that have happened before.

After data recollection is completed within a certain period, existing data is then analyzed to determine the root causes of physical causes, human causes, and latent causes. The tools used in the analysis are Fault Tree Analysis (FTA) and fishbone diagrams. From the root causes that have been found, recommendations and implementation of corrective actions are determined to mitigate the impact of failures and preventive actions to prevent problems with the same root causes from being repeated.

3. Results

3.1. RCFA Problem Definition

The P-6450A/B pump is a screw displacement positive displacement pump located in the closed drain system at the company's Onshore Receiving Facility P pump. The P-6450A/B pump is in charge of flowing the condensate leftover from pig receivers, inlets and blowdown from separator inlets, superheater for fuel gas, as well as sales metering gas package to the liquid burner. This equipment is classified according to the company as having a medium severity level, where the failure of this equipment has the potential to disrupt the productivity of the facility with the opportunity for a not too large security risk.

According to the results of the author's interview with the field technician and related documents, on December 1, 2016 the field technician reported that the pressure transmitters installed in pumps A & B recorded a discharge pressure of 3.0 barg and 2.0 barg respectively, which is a number far below figures for the supplier of the pump unit. According to the pump sheet data from the supplier, the pump unit should be able to produce a discharge pressure of 15.27 barg under normal conditions. Because the pump cannot build pressure, the field team turns off the pump and starts the troubleshooting process.

In the troubleshooting process carried out by the field team, the first step taken is to check the condition of the suction strainer at the pump. After the suction strainer condition is checked, the field team conducts a troubleshooting experiment by closing the VX-6441 and VX-6442 valves of the P-6450A and P-6450B pumps respectively, and draining water from drums placed above the suction strainer of each pump. This is done to ascertain whether this problem is coming from a suction valve that is not optimal.

After the troubleshooting experiment, the data obtained that the discharge pressure generated by P-6450A is 7 barg and P-6450B is 5 barg, which proves that the discharge pressure problem still appears even though the pump is in a by-pass condition. After these steps, the field team decided to dismantle the pump and the results found a kind of debris inside the pump and the condition of the pump stator was in a bad state, as shown in Figures 2 and 3.

As a result of this series of events, the operations engineering team began to initiate the RCFA process and form a team tasked with handling this case.
3.2. Data Recollection
According to the pump datasheet, the P-6450A / B pump is an AE2N-200ID Allweiler pump capable of producing a discharge pressure of 15.27 barg from a suction pressure of 0.13 barg, with an NPSHr of 2.05 m. This pump is supplied by an electric motor from Siemens with 5.5 kW power and mechanical energy transfer via John Crane gearbox with maximum torque of 315 Nm. Construction and pump material use SS 316 for pump casing, Building for stator and SS 316 TI for rotor and drive shaft from pump. By adapting the ISO 17776 standard [5], this equipment is determined to have a risk category C1.

In the process of data recollection, author found several kinds of things which according to the writer are anomalies that occur in the process of design, procurement, and installation and operation. This will be crucial later in determining the root cause (root cause) of this case. The data collection process is carried out in the following ways:

3.2.1. Interview
The author conducts direct interviews with related crews about this problem and extracts data that can help.

3.2.2. Physical Evidence Recollection
The author recollects physical evidence in the form of photos and documents that can help the writer do the Root Cause Failure Analysis process. During this research period, the authors managed to obtain the following documents:
- P&ID in accordance with ANSI rules [6] for closed drain systems where the system is the functional location of the P-6450A/B pump,
- Pump design calculations and pump datasheet,
- Datasheet for condensate flowing through the pump,
- Factory Acceptance Test from the pump fabricator,
- Isometric picture of piping systems from V-6450 to P-6450A/B, and
- Standard Operating Procedure for manual operation of P-6450A / B pumps.

4. Discussion
The authors used the Fault Tree Diagram and Events and Causal Factor (Ishikawa) Diagrams to find the root cause of problems in the P-6450A / B with the following results, as shown in Figures 4 and 5.
From the data recollection, the writer found that there were some irregularities during the procurement, installation and operation of the P-6450A/B pump with the following explanation:

4.1. Standard Differences Used

In the Factory Acceptance Test document, it is found that the pump vendors and pump manufacturing plants use the API RP 674 standard as a reference standard in testing P-6450A / B pumps. According to the authors, this is a mistake because API RP 674 is the standard used for reciprocating type positive displacement pumps [7], as shown in Figure 6.

For positive displacement pump types of progressive cavity, the right target standard for use of the API is API Standard 676, which has a special scope in the design, material selection, testing, delivery, installation, and operation of the rotary type positive displacement pump, which also includes positive displacement pump types of progressive cavity [8].
Loss of pump discharge pressure

Caused by

Pump cavitation

Justification(s):
- Excessive vibration
- Excessive noise
- Stator damage at suction port

Dry running

Justification(s):
- Stator damage at suction port

Pump tripped (spurious stop)

Justification(s):
- Pump shut down after 3 minutes without reaching proper discharge pressure

Excessive stator wear

Justification(s):
- Stator debris found after casing removed

Insufficient liquid supply

Justification(s):
- Presence of gas fraction in condensate
- Filters are performing properly

External air leaking into piping

Justification(s):
- No evidence found
- Different fluid from calculation and actual conditions, thus piping lose some elasticity

Liquid vaporizes in piping

Justification(s):
- Piping has no insulation, but not enough evidence
- Difference in vendor calculation and actual piping conditions
- Difference in conforming standards used

Incorrect fluid used

Justification(s):
- Different fluid from calculation and actual conditions, thus piping lose some elasticity
- Difference in vendor calculation and actual piping conditions

Incorrect piping design

Justification(s):
- Difference in conforming standards used

Incorrect pump selection

Justification(s):
- Difference in vendor calculation and actual piping parameters

Pumping ran on too low speed

Justification(s):
- Higher speed leads to more stator damage
- Difference in vendor calculation and actual piping parameters
- Difference in conforming standards used

Notes
- Disproved causal factor
- Inconclusive causal factor
- Justified causal factor

Figure 6. Fault Tree Analysis of case P-6450A/B
4.2. Difference in Working Fluid during Factory Acceptance Test with Routine Operating Conditions

When the vendor performs a Factory Acceptance Test (FAT) at the pump manufacturing plant, the test is carried out using ordinary tap water working fluid which has different parameters from the condensate used in routine operating conditions. This is evidenced by document '11 -ORF-M-REP-06-0004_FAT Report for Closed Drain Transfer Pump_0_AFC_NC' and pump specification document where the FAT document listed the test fluid is water while the routine condensate consists of a mixture of various hydrocarbon chains and almost none water. This is crucial considering that the two fluids have different specific gravity and have different vapor pressure and friction loss so as to allow a gap for problems when the fluid used in operation is different from the fluid used during testing, as shown in Figure 7.

Figure 7. Working fluid used when testing.

4.3. Empty Pre-Commissioning Check List

In the document ‘11 -ORF-M-LST-06-0006_Pre Commissioning Check List for Closed Drain_A_IFR_NC ‘does not contain anything that shows the ability of the system pumps to carry out their duties in accordance with the expectations of the owner. Meanwhile, the project implementation process consists of:
Detailed design  
Fabrication  
Individual Performance Test (IPT)  
Pre-commissioning  
Commissioning and System Performance Test  
Start-up

From this evidence, indications of negligence both from the vendor as the equipment supplier, the EPCC company as the general contractor and the owner company as the user of the tool in ensuring the appropriateness and capability of the equipment before entering operational conditions.

4.4. Differences in Piping Design and Installation
Cavitation and dry-running can occur when the pump does not have enough fluid in the suction section [9]. Due to the lack of incoming liquid fluid, air bubbles will form on the suction part of the pump because the remaining fluid reaches its vapor pressure [9]. The old piping system that was installed allows this to happen, because there is a reverse U-loop in the pipeline without the venting process in the air phase of the condensate as shown in Figure 8. The venting process as stated in the SOP for the pump exists but the process is carried out after pumping process so that it still allows the presence of airlock in the pipeline, thereby reducing the liquid phase discharge entering the suction side of the pump.

![Figure 8. The shape of the pipeline that allows airlock.](image)

The presence of air 'stuck' in the piping system (water entrainment) can also explain why the same pump takes longer to build a discharge pressure in accordance with the provisions stipulated in the DCS system, because the presence of air entrainment reduces the effective diameter of the pipe which can be passed through the liquid so that it takes longer to meet the suction side of the pump. This lack of suction flow results in a combined effect of cavitation and dry-running due to the inability of the pipeline to supply sufficient fluid for pump operations to occur at this pump as a result of the existence of the reverse U-loop pipe. In the condition of water entrainment, bubble gas has formed before the process of phase change from liquid to gas. While the cavitation process can still occur even if the positive displacement pump is not as severe as the centrifugal pump in its detection [9]. Dry running can be proved by damage to the stator liner in the form of stator material flakes, but with the drastic change in the composition of the working fluid it can also prove that the stator is not damaged by chemical reactions, but a mechanical reaction to the swelling of the stator due to dry-running.
This results in the stator rubbing against the rotor which gradually erodes the stator layer so that debris appears when the P-6450A / B pump is disassembled. Other additional evidence is the condition of the pump suction hole which also shows the presence of a drive shaft that is eroded, supporting the claim that there is a combination of damage between dry-running and cavitation at the P-6450A / B pump, as shown in Figures 9 and 10.

According to Dillon [10], damage to the progressive cavity pump stator can be caused by both cavitation and dry-running, but the difference is in the case of cavitation, the stator damage starts at the suction side and runs to the pump discharge side, while in the case of dry-running, stator damage occurs starting from the middle side of the pump between the suction and discharge sides.

5. Conclusions

5.1. Root Cause Determination

Based on the analysis conducted, the conclusion that can be drawn is that there are 3 types of root causes of the problems that occur at the P-6450A / B pump, namely:

5.1.1. Physical Cause

The physical cause of this problem is the presence of a reverse u-loop line in the pipeline without venting so that the pump has a fluid flow deficiency on the suction side.
5.1.2. Human Cause
The human cause of this problem is the contractor's error in calculating the conformity of pump specifications and designing pump pipeline.

5.1.3. Latent Cause
The latent cause of this problem is management's negligence in applying strict regulations regarding the design and installation of equipment.

5.2. Corrective and Mitigation Actions
As a form of output from the RCFA methodology which requires the results of a solusional investigation, the corrective and mitigative steps taken by the RCFA team are as follows:
- For physical causes, the corrective steps taken are eliminating U-shaped inverted pipelines and replacing them with straight pipe lines to reduce losses and prevent air trapping, as shown in Figure 11.
- Maintains KO drum levels so that the hydrostatic pressure and head are able to resist the head loss of the piping system.

![Figure 11. Reverse U-Loop elimination on the pipeline to the P-6450A/B pump.](image)

For human and latent causes, both the owner as the operator and the vendor as the tool provider are responsible for conducting a thorough design review, with important points including:
- The vendor is responsible for recalculating the pump specifications and matching the needs of the owner.
- The owner is responsible for maintaining the operational and maintenance conditions of both the pump and the support system such as piping and KO drum itself, bearing in mind that there are still symptoms of trip on the pump due to setting LL alarms that are too tight.
- Using updated and relevant standards during new equipment design, procurement, and installation processes.

5.3. Evaluation of RCFA Implementation
From the stages of Root Cause Failure Analysis that has been done, the authors propose a number of suggestions which could help the implementation of RCFA in the future at PT. P, which includes:
- Safeguard evidence at every failure occurrence, because of the evidence can help the process of analysis of failures that occur and can be supporting arguments in determining the root of the problem.
- Improve coordination and cooperation between vendors, EPCC contractors, and PT. P as the operator, because it was seen from the design process to the installation there were misunderstandings between each party.
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