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A Root Cause Analysis Method for Industrial Plant Reliability Improvement and Engineering Design Feedback

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Root cause analysis (RCA) methodologies have been used worldwide to help preventing incidental events from recurring, contributing to avoid losses and worker injuries. A structured RCA methodology shall work as an efficient problem solving tool, facilitating proactive communication, documenting the most important and systemic causes of incidental events and also providing effective solutions as part of the decision decisionmaking process. From the industrial perspective, a RCA process shall improve the lessons learned from these incidental events for plant operation and also feedback engineering design, besides increasing plant operation reliability. This paper presents a practical experience using a systematic and structured RCA methodology on two actual incidental cases from an international air separation industry that demonstrate the mentioned benefits of this approach on plant operation reliability and engineering design improvement.

1. Introduction

Historically, incidental events have caused severe losses to industry worldwide, including injuries and property damages, with associated side effects, including on the organization's image. Although they are not always safety related these losses could also involve equipment malfunctioning, frequent maintenance, supply delay, system downtime, investment, process performance, and operation inefficiency, which impact on industrial plant reliability and also on its availability.

Safety and reliability are not products themselves, but the results of all work processes, policies, and protocols in place for every activity, system, facility, or environment (Nascimento, 2010). The experience gathered on engineering safety and reliability indicates that incidental events – and the associated injuries and reliability issues – can be avoided (Nascimento and Frutuoso e Melo, 2010). If it is critical to investigate these events, it is even more important to implement a learning process to help organizations' management to prevent them from recurring, as a problem-solving approach. This process shall start with a detailed problem definition, with all necessary information including potential consequences of the event, not limited by the real ones. It shall be followed by the effort to establish a consistent and nonlinear causality sequence – a complete cause and effect relationship, even though that causality relation shall be considered probabilistic or affected by random factors (Sloman, 2005) – in order to capture all contributing and the more basic and systemic causes for the event, and finish with a set of effective solutions to eliminate, change, or even mitigate these causes, following up their implementation and effectiveness (Okes, 2009). This whole process is usually known as a root cause analysis (RCA) methodology for management support (Andersen and Fagerhaug, 2006).

For any kind of incidental event, scientific knowledge – confirmed by the practice accumulated for more than a century – demonstrates common basic systemic precursors, based on the same causality process, involving undesirable or unsafe conditions – usually more than one for each event – and a special behavior or action – from an unsafe act through an unnecessary hazard exposure (Rundmoa and Haleb, 2003) – which can be generically designated as at-risk behavior (Choudhry and Fang, 2008), that set those conditions in motion (Heinrich et al, 1980). From an investigation standpoint, these aspects should be the main targets of a learning process to improve safety and reliability within an organization, and to provide feedback for a better design (Nascimento and Frutuoso e Melo, 2010).

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The two case studies presented here aim to demonstrate practical experiences using a systematic and structured RCA methodology on two actual incidental events from an international air separation industry that certify the mentioned benefits of this approach on plant operation reliability and engineering design improvement.

2. RCA Methodology

There are many RCA methodologies available for incidental events investigation. For the two case studies describe herein, we have the structured methodology originally developed by Apollo Associated Services (Gano, 2003), which is designed to minimize personal bias and maximize solution-oriented thinking, starting an event problem definition statement – based on a meticulous evidence data gathering and managing process – followed by a detailed cause-effect tree analysis, and finalizing with a complete investigation report which indicates the most effective solutions, including preventive and corrective actions to modify or prevent causes to avoid the event repetition. This methodology is associated with software for the graphic cause-effect analysis representation, evidence capture, and report facilitation.

This methodology is based on the most accepted incidental theory regarding Heinrich et al. (1980) studies, demonstrating that any incidental event is based on multiple causes, and each single event – or effect – is a consequence of a group of immediate causes occurring at the same time and place. These causes can be understood as a group of specific conditions set in motion by an action or a behavior. Engineering safety specialists define these causes as unsafe conditions and at-risk behaviors, respectively (Nascimento and Frutuoso e Melo, 2010). RCA starts with a primary effect (or cause), which is the problem the analysis wants to avoid recurring. For this original effect investigators keep asking “why?” or “caused by?” to find out immediate credible causes on unsafe conditions – usually more than one – and normally one at-risk behavior, supported by evidences. The analysis process continues to the past causes with the same procedure for each cause, now considered as new effects, searching for their immediate causes. The goal is to get the most structural, organizational and deep possible causes, that can be modified, corrected or mitigated to avoid that sequence repetition (Gano, 2003).

In addition to the operational and physical aspects involved in the event (Strauch, 2002), a complete and structured RCA methodology shall take into consideration all types of possible causes (Dekker, 2006), specially regarding behavior-based aspects (Saurin et al, 2010), like psychological conditions, human errors (Reason, 1990) and also human factors (Stranks, 2007), operational discipline aspects, etc. (Walter, 2002).

3. The WMGI Praxair Case 1

The event described herein occurred at a White Martins Gases Industriais Ltda. (WMGI, Praxair Inc. subsidiary in Brazil) air separation facility in South America. WMGI’s Operations and GSS (Praxair’s Global Supply System group, which provides engineering solutions worldwide) shared this investigation.

3.1 Event Description

On October 2010, during a normal plant operation, there was an unexpected stop of the base load nitrogen compressor (BLNC), causing the immediate plant shut down. Plant maintenance team with a BLNC supplier technical support personnel examined the equipment and certified a few internal broken pieces, like rotor, diffuser, bearing, impeller, and axis, as seen in Figure 1.

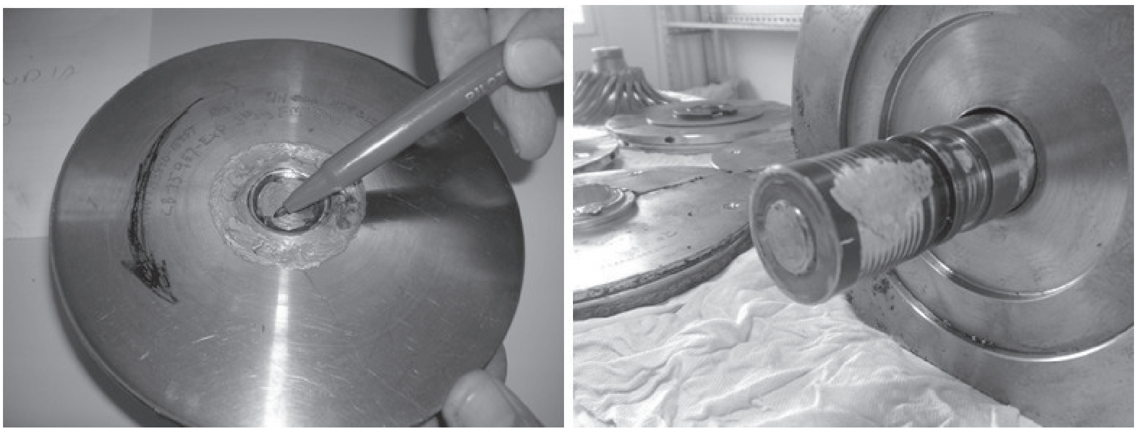

Figure 1: BLNC internal broken pieces

Process data from advanced control-monitoring systems demonstrated that BLNC had operated in reverse flow without oil pressure for about 20 min, resulting in the failure. Actually, it demonstrates that during a normal BLNC shutdown it is possible to identify the decrease of discharge pressure, followed by suction pressure decrease, while the lube oil pressure and vibration for the first and second stages remain on operational levels. During the abnormal shutdown on that incidental event the control-monitoring system demonstrates a discharge pressure decrease, also followed by suction pressure decrease, but with the sudden lube oil system pressure decrease, and it is also observed the suction pressure recovery with a residual discharge pressure, and a severe vibration oscillation, characterizing the incidental event occurrence.

This event, with the consequent plant shut down, seriously impacted the plant's reliability and availability specific goals to be achieved, named Key Performance Indicators (KPI), besides the production losses, equipment repair, and customer supply issues. There was also a severe safety issue potential regarding the equipment broken process and a possibility of debris generation.

3.2 Results of the Investigation

After the new air separation plant start up, Operations noticed that the plant N_2 supply line for purge, seal and instrument air backup was installed downstream of the orifice plate for flow measurement to the customer. To avoid future problems with customers, it was decided in accordance with GSS to install a new tie-in for a new line upstream of the BLNC discharge check valve. A marked up P&ID and a detailed engineering schematic for this installation was sent by GSS to the site, calling for 2" globe and check valves for this new line. As the valves had not yet arrived at the site and in order to take advantage of the presence of GSS's field assembly team at the plant for other issues, it was decided to assembly that line to get the valves installed later. The assembly team had used a gate valve that existed at the site, with no specific function, which was installed to replace the designed globe valve. The check valve was not installed.

This temporary system was not supposed to operate with the unique gate valve open and no check valve. But as part of an incomplete management of change (MOC) process, which did not involve the proper authorizations, inspections, and documentation, this new system was put into operation. The investigation pointed out that during an unexpected BLNC stop, this new pressurized line was the power that drove the machine backwards for about 20 min, including the compressor's oil pump system, and caused the wreck. Although there is an automatic compressor discharge vent valve that would also have prevented the failure, it closed after 1 min to avoid ambient air intake.

After a detailed RCA, the investigation pointed out a few causes that can be part of the basic failure process and indicated as root causes:

- Operations management failure for the lack of the MOC process.
- GSS management process for the incomplete, not documented and unapproved temporary installation.
- Lack of inspection and review of the new installation prior to start up, as part of the Pre Start up Safety Review (PSSR), which was not done.

Other important contributing factors were pointed out by the investigation:

- GSS failure on safety review due to the lack of the HAZOP study revalidation for this new system.
- Possible operational indiscipline of the professionals involved on this new system start up, keeping the gate valve open.
- Lack of Praxair standard not including the compressor's oil system in the P&ID.
- Supplier standard design not including check and relief valves on the oil system.

As a result of the investigative process, a group of corrective/preventive actions were put in place to avoid recurring:

- Revise the project's P&ID to incorporate this new system with all necessary protections.
- Revise the product line P&ID to incorporate the concept that sources of high pressure gas need to be properly isolated and/or vented to avoid backward rotation and surge during compressor shut down, with the thought that check valves will eventually fail, even when they are properly placed.
- Revise the plant HAZOP to include all hazards related to this new installation; especially the compressor's reverse flow and its oil pump reverse flow impact.
- Complete the MOC process for this new system.
- Retrain all operators for the PSSR process prior to putting a new system in operation.
- Work with the supplier to improve the compressor and its oil system design.
- Formal GSS approval is required for any new temporary system for any site.
- Issue a corporate non-compliance report (NCR) to share this event with all corporate regions.

The lessons learned from this investigation involve crucial engineering and operation processes, operational discipline, hazard and design reviews, which have the potential to lead to incidental events with severe safety and reliability consequences. This learning process shall improve future plant reliability and new plant design.

4. The WMGI Praxair Case 2

The events described herein occurred at a few WMGI air separation facilities in South America. The Operations and GSS teams shared this investigation.

4.1 Event Description

Since October 2010, a dramatic loss of few VPSA (Vacuum Pressure Swing Adsorption) air separation plants production capacity was observed over several months. In order to understand the problem, Praxair collected molecular sieves – the process adsorbed vessel load – samples for analysis. Tests indicated the presence of moisture on the inner portion of the bed, product circuit, suggesting that moisture contamination had occurred in vacuum step. Possible external leakage points of vessels and valves were checked but no problems were found. Finally, the vessels' beds were opened, where it was found a discontinuity weld sealing between "I" beam (total of 8 "I" beams) and the vessel's top head and another point in the lower vessel head.
These events caused severe impacts on different plants' operational capacity and, consequently, on their KPI reliability and availability, followed by several retrofits and vessel repairs, associated with production losses and customers supply issues.

4.2 Results of the Investigation

The beds under investigation were manufactured by FEC – WMGI's mechanical factory, in Rio de Janeiro, Brazil, responsible for fabrication, maintenance, and field erection of Cold Box, tanks, and skids – using the generic product line (PL) fabrication drawings, whose revision did not have the chamfer representation at the structural "I" beams, and did not include any specific note or information about the importance of this seal weld characteristic (chamfered/notched). The chamfer at the structural "I" beam facilitates the seal weld between beams and the head of beds. With these "I" beams not chamfered/notched, the seal welds stopped at the "I" beam, suggesting that several welds were done after the "I" beams were installed, causing potential seal failure points inside the vessels, as shown in Figure 2, after one structural "I" beam removal for verification. It is important to mention the additional ergonomic difficulty for that complete welding process due to the restrict space inside the vessel.
There were specific fabrication drawings for each project, which had already been issued by Praxair's PL team. But the formalization of new bed design issuance was made by email, without a proper warning or certification of the need to adjust any mandatory process or safety issues for ongoing projects.
During the adsorbed vessels fabrication process inspections at the shop floor, an old revision of fabrication checklist, issued in 2003, was used, although there was a new revision, issued in 2007, available at Praxair's database. As usual, a FEC professional responsible for bed inspections filled that fabrication checklist as a quality control process. The checklist was also in English and that professional was not very well familiar with the language. Although this professional was using an updated version of the fabrication drawing with the new requirements – a note regarding the chamfer need – he decided not to apply that specific information even for the vessels under fabrication at the factory by considering them only structural improvements and not relevant changes, without consulting the fabrication management.

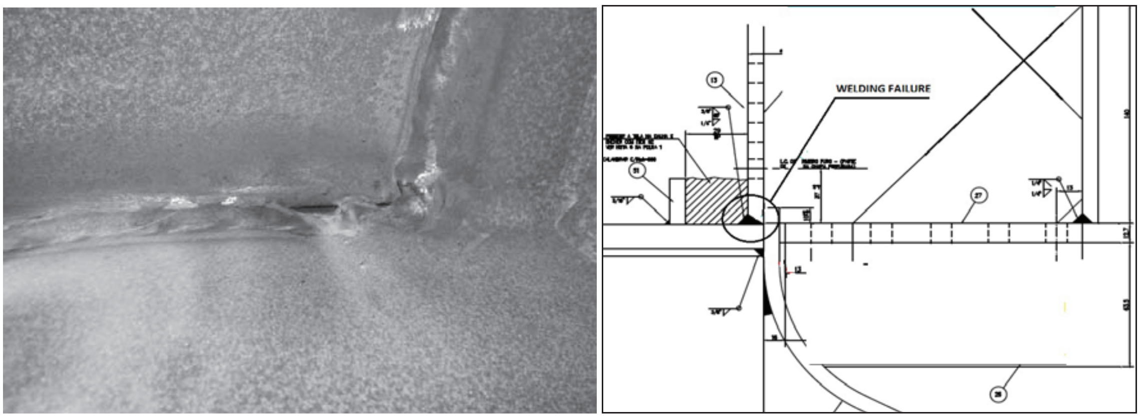

Figure 2: Seal failure point after structural "I" beam removal and the design position for fabrication

After a detailed RCA process, the investigation team pointed out a representative root cause for this systematic failure: the manufacturing management failure, regarding the ineffective training process for that FEC fabrication professional, the process vessels inspection handled by a not qualified professional, manufacturing drawings distribution process failure, and the use of an out of date revision of fabrication checklist.

Other important contributing factors were pointed out by the investigation:

- Personal decision regarding the FEC professional responsible for bed inspections that decided not to apply the new revision drawing considering them only structural improvements.
- The lack of a full trained professional on vessel fabrication process with a focal point role.
- Observation failure of the fabrication supervision**.**
- The failure on the communication process of the new revision documentation: the issuance formalization of new adsorbed design was made by email, without a proper certification.
- Shop floor communication process failure: the fabrication checklist was in English and the professional who filled the document was not well familiar with the idiom.

As a result of this investigation, an action plan was put in place to avoid recurring:

- Repair and correct sealing weld within process vessels at the shop floor.
- Plan an inspection and retrofit process for all similar plants fabricated with the same set of drawings.
- Assign both design and fabrication focal point professional with approval authorization.
- Review the new assembling process sequence for adsorption vessels manufacturing based on the new company's drawings.
- Translate the fabrication checklist into Portuguese and create a procedure to check revision prior to the beginning of each project.
- Create a new inspection checklist for process vessels by joint to be approved and implemented by fabrication and quality teams.
- Establish a formalization process to alert about new design documentation available.
- The new GSS Electronic Design Managing System (EDMS) shall file all documentation revision.
- Retrain all inspectors and fabrication personnel on the new processes.
- Issue a corporate non-conformance report (NCR) to share this event with all corporate regions.

5. Conclusions

The two case studies presented here demonstrated important practical experiences and lessons learned using a systematic and structured RCA methodology on two industrial incidental events, facilitating proactive communication, documenting the most important and systemic causes of these events, and also providing effective solutions as part of the decision making process on management system, adding value for the plant operation reliability and safety, and also engineering design improvement, helping effectively to avoid events from recurring, with their associated losses.

For both cases, a superficial investigation analysis could have pointed out just an operation or equipment failure (Case 1), or a fabrication failure, or even a quality control issue (Case 2), disregarding all the complete set of systemic causes obtained by the use of a structured and complex RCA methodology in place, which helped to interrupt high severe potential failure processes that could have affected several future plants with high potential losses for the company and customers, causing impact on the company's image. This RCA approach also helps to prevent such widespread culture of punishment, which rarely can be considered an effective solution or even add some value to the process to avoid incident recurrence. These lessons learned from the two investigations involve crucial engineering and operation processes, fabrication procedures, maintenance criteria, operational discipline issues, hazard and design reviews, which have for the first case, the potential to lead to incidental events with severe safety consequences, and also important reliability consequences for both cases studied. This learning process shall improve operating plant reliability and new plant design, helping the organization to increase its ability to respond to the demands of a disrupting situation – as defined by the resilience engineering approach (Hollnagel et al, 2002) – which includes the proper situation assessment, a good decision making process with the appropriate resources available.

Finally, this learning process also allows an organization to develop a readiness to respond to proactive strategies anticipating disrupting scenarios as part of its preventive operational and safety culture. This culture shall certainly impact on daily aspects of industrial plants, such as operational and maintenance strategies – like the use of a reliability-centered maintenance (RCM) approach (Selvik and Aven, 2011) – helping to overcome uncertainties and risks, which are normally addressed to a limited extent.

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