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Innovative Remediation Techniques to Compressor Foundation Systems

by:

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Abstract:

When reviewing the major threats to reciprocating compressor performance reliability, substandard maintenance practices and loss of operating efficiency have profound negative impacts on the total life cycle costs - driving down overall profitability. Considering that the majority of maintenance budgets are spent on a minority of equipment[1], it is imperative to correctly diagnose and remediate issues before they lead to equipment breakdown and unintended stops in production. This paper will highlight some common threats to operational efficiency in reciprocating compressors, with a specific focus on the foundation system. Through the presentation of multiple case histories, innovative approaches will be shown that can help all personnel focused on proper maintenance and reliability best practices to effectively identify the root causes of poor performance and paths to successfully remediate and improve operating reliability.

1 Introduction

Due to the critical role that reciprocating compressors play in industrial environments, it is clear why so much attention is paid to reliability and efficiency of these critical pieces of dynamic equipment. With a thorough understanding of the economic factors that influence the asset profitability that is influenced by these machines, this focus is justified. This paper will show the importance of operational efficiency and how threats to this critical metric will affect total life cycle costs, and in turn overall profitability. With a specific focus on the foundation system, examples will be shown of innovative remediations implement to address deficiencies that led to increases in reliability and efficiency. Through effective collaboration between foundation experts and equipment manufacturers, long term solutions were provided to restore foundation integrity that will last for decades to come.

2 Effects of Poor Compressor Reliability

Poor equipment reliability has a direct negative impact on the overall profitability of an asset. Especially with compressors, the increased expenditures due to misalignment directly impacts the bottom line[1]. With power consumption accounting for as much as 90% of the total life cycle costs[3] or total cost of ownership, of dynamic mechanical equipment, maintaining precise alignment to maximize operational efficiency is critical to the desire to increase profitability.

The most effective methods of mitigating threats to overall compressor reliability come from design for the entire design environment and performing regular maintenance before costly failures occur. It is more profitable to invest incrementally and perform needed regular maintenance prior to a failure that necessitates the shutdown of equipment and an emergency repair[4].

In looking specifically at the effects resulting from the foundation system, a thorough understanding of the potential operating environment, including environmental exposures and operational requirements, will help to ensure that machinery operators more efficiently and with less potential degradation to wearable components. With a proper execution of a predictive maintenance program, including regular checking of the anchor bolts for proper tensioning, the foundation system can continue to accomplish its functions for extended lengths of time. It is not unheard-of for a foundation system to be in constant operation and without degradation after 40 years of constant operation.

3 Foundation Design for Compressor Reliability

For the perspective of this paper, a foundation system includes the following items:

• Dynamic Equipment
• Base Plate of Dynamic Equipment
• Anchor Bolts
• Load Transfer Medium
• Foundation
• Sub Foundation/Concrete Mat
• Sub-surface/Soil

Please see Figure 1 for more details on the foundation system.

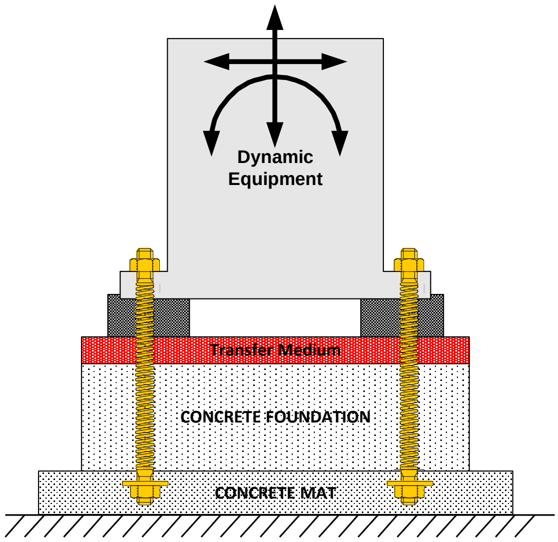

Figure 1: Foundation System for Dynamic Equipment

An effective foundation system design for a reciprocating compressor will achieve the following functions:

1. Keep equipment in position
2. Mitigate forces due to equipment operation
3. Prevent Foundation Degradation[5]

To be able to effectively accomplish these functions over long periods of time, it is imperative that initial design and installation of the foundation system fully considers the potential environmental and operation conditions which the system will be exposed[6]. By taking the time to fully understand and consider these factors in the up-front design, operational efficiency will be increased, resulting in reduced need for future remediation and increased overall asset profitability.

After a foundation system has been installed, regular inspection and maintenance of the system should be a core aspect of any maintenance plan. For the foundation system, it is key to perform regular reviews for any potential breaks within the system. This includes monitoring of the anchor bolt tensions, evaluation of the condition of control joints, and proper treatment of any cracks or breaks that develop over time. These are just some of the key aspects that will contribute to increased longevity of the foundation system.

The following case histories will show identification of deficiencies within the foundation system, and steps that were taken to complete remediation. In each of these examples, a regular maintenance schedule that included inspection would have allowed the asset owners to identify and diagnose the underlying root causes before they became larger concerns. Early detection and treatments lead to reduced remediation, meaning less direct expenditure and greater profitability of the asset.

4 Case History – Equipment Removal and Foundation Rework

A major operator of a petrochemical facility was experiencing ongoing performance and mechanical problems with a critical, one-stage, 4-cylinder reciprocating process gas compressor. The asset owner contracted the original equipment manufacturer (OEM), which partnered with a regional team of foundation experts. Through the innovative collaboration of all parties, the remediation work was identified and performed to bring a non-operating asset back into service and increase the operational efficiency.

4.1 Previous Installation

The compressor was originally installed in 1978. When installed originally, the foundation was mounted on a cementious grout. Over time, the vibrations resulting from the operation of the compressor steadily increased. This resulted in extensive mechanical damage to the compressor, as well as damage to the foundation system. Initial efforts were made to ensure the proper tensioning of the anchor bolts, but the bolts kept relaxing over time. The vibrations eventually increased to the point that the equipment could no longer be operated due safety concerns.

4.2 Problem Identification and Proposed Solution

As part of the overall overhaul of the equipment, the first step was to evaluate the state of the anchor bolts and identify all areas in need of overhaul. All anchor bolts were tensioned to the recommended load, and the alignment was checked. From this review, it was determined that only the piston loaded areas would need remediation.

4.3 Removal of Previous Transfer Medium

After determining the scope of the intervention, the compressor was removed from the remainder of the foundation system. The compressor was being overhauled off-site, and this allowed full access to the remaining portion of the foundation system. Removal of the existing sole plates and the damaged cementious grout was performed. Please see Figure 2**,** Figure 3**, &** Figure 4 for detail on the initial condition and removal of the previously installed transfer medium.

Figure 2: Removal of Existing Cementious Grout

Figure 3: Degradation of Existing Cementious Grout under Support Rails

Figure 4: Surface of Concrete after removal of Cementious Grout and Support Rails

This step also included removal of the anchor bolts using a core drill. Core drilling was performed using a 6” OD core drill bit and were drilled down to a depth of 1000 mm, to accommodate the new bolts with a length of 950 mm. Please see Figure 5 & Figure 6 for details on the removal process of the anchor bolts and the foundation after core drilling was completed.

Figure 5: Core Drilling Damaged Anchor Bolts

Figure 6: Foundation After Damaged Anchor Bolts Removed

A total of 4 support rails and 16 damaged bolts were removed under the compressor. The core drilling of the anchor bolts also allowed access for further inspection of the cracks within the concrete foundation, as well as the overall integrity of the concrete block.

4.4 Reinstallation of Compressor

After delivery of the new anchor bolts was completed, the final portion of the foundation overhaul could be completed. The new anchor bolts were Class 8.8 per ISO 898-1. After ensuring that the anchor bolts were cleaned, the compressor was aligned, and the anchor bolts were hung into the newly drilled anchor bolt pockets. Formwork was constructed to allow filling of the mounting area. The mounting area under the compressor support rails were filled with a superior epoxy grout, as recommended and installed by the regional foundation expert team. Please see Figure 7 & Figure 8 for preparation and pouring of the epoxy grout under the compressor.

Figure 7: Formwork for Mounting Support Rails on Epoxy Grout

Figure 8: Superior Epoxy Grout Installed Under Compressor Support Rails

After sufficient time had elapsed, as advised per the recommendations of the epoxy grout manufacturer, the formwork was removed, the removable alignment devices were backed out, and the anchor bolts were properly tensioned per the recommendations of the OEM. Please see Figure 9 for a view of the final mounting of the compressor.

Figure 9: Final View of Compressor Support Rails on Superior Epoxy Grout

4.5 Follow Up

A follow up visit was conducted approximately 1 year after the initial installation. At that time, the anchor bolts were observed to be maintaining the proper tension without concern and the compressor was reported to have been operating very well. There were no concerns with excessive vibrations or wear to the mechanical components of the compressor.

Through a successful collaboration between the asset owner, original equipment manufacturer, and a foundation expert, a solution was designed and effectively installed to return a compressor with a history of poor performance back into service.

5 Case History – In-situ Anchor Bolt Remediation

An operator at a large petrochemical facility in Western Canada had experienced on-going difficulties with being able to achieve proper anchor bolt tension for a critical piece of dynamic rotating equipment. The asset owner partnered with a regional team of foundation experts for review of the anchor bolts and proposed solutions. An innovative solution was proposed and implemented to replace the anchor bolts without requiring the removal of the equipment. The reduction in associated downtime minimized the amount of time that the process had to be offline, directly leading to greater profitability.

5.1 Previous Installation

The equipment was originally installed approximately three decades prior to the decision to perform the remediation. Epoxy grout was used in the initial installation and maintained its integrity. The epoxy grout encapsulated the entire top of concrete foundation block, which extended beyond the footprint of the steel baseplate approximately 300 mm (Please see Figure 10). Due to the exposure of the foundation system to the harsh environmental elements, including extreme temperature changes, edge lifting occurred within the concrete below the bond line with the epoxy grout (Please see Figure 11).

Figure 10: Original Equipment Installation

Figure 11: Edge Lifting on Foundation

In the course of regular maintenance inspections, it was identified that the anchor bolts were unable to achieve designed tension. The remediation was not performed for many years due to budgetary constraints and not wanting to take the equipment off-line. The lack of proper anchor bolt tension resulted in high vibrations during equipment operation.

5.2 Problem Identification and Proposed Solution

The asset owner decided to investigate opportunities to achieve proper anchor loading of the fan without the downtime associated with removal and entire foundation rehabilitation.

Since the original concrete foundation extended significantly beyond the footprint of the equipment baseplate, an innovative solution was proposed to use a custom fabricated baseplate extension to house new anchor bolt assemblies. New anchor bolt pockets would be core drilled into the concrete foundation using industry accepted best practices with epoxy grout.

5.3 Remediation Process

The first step was to core drill new anchor bolt pockets through the epoxy grout and into the concrete foundation. The new pockets were approximately 300 mm into the existing concrete foundation. Please see Figure 12 showing the core drilling operation.

Figure 12: Core Drilling New Anchor Bolt Pockets

After adding the anchor bolt pockets, hand-held pneumatic chipping guns were used to remove as much of the existing epoxy grout as possible. This was performed to the extent possible by the reach of tooling and kept in place most of the original epoxy grout under the center of the equipment. This also allowed the equipment alignment to be maintained without requiring temporary supports. Existing epoxy grout and underlying concrete were removed until clean and sound concrete was reached and prepared per best practices for installation of a superior epoxy grout. Additionally, the edges and corners of the foundation were chamfered to help minimize the potential for edge lifting to occur in the future. Please see Figure 13 showing the surface preparation of the concrete foundation and Figure 14 showing the new anchor bolt pockets outside of the original base frame.

Figure 13: In-Process of Removal of Existing Epoxy Grout and Underlying Concrete

Figure 14: New Anchor Bolt Pockets in Properly Prepared Concrete Surface

After the surfaces were properly prepared, the formerly used anchor bolts were cut flush with the existing baseplate. In this position, they could not be tensioned and would reduce confusion for future maintenance activities. The newly manufactured baseplate extension was welded to the existing baseplate, as shown in Figure 15.

Figure 15: Baseplate Extension Welded to Existing Baseplate

New ASTM A193 B7 anchor bolts were installed in the baseplate extension and hung in the anchor bolt pockets. It was ensured that the new anchor bolts featured recommend free-stretch length, as shown in Figure 16. The original bolts did not have this free-stretch length, and it is thought that this is the primary reason why the bolts failed prematurely.

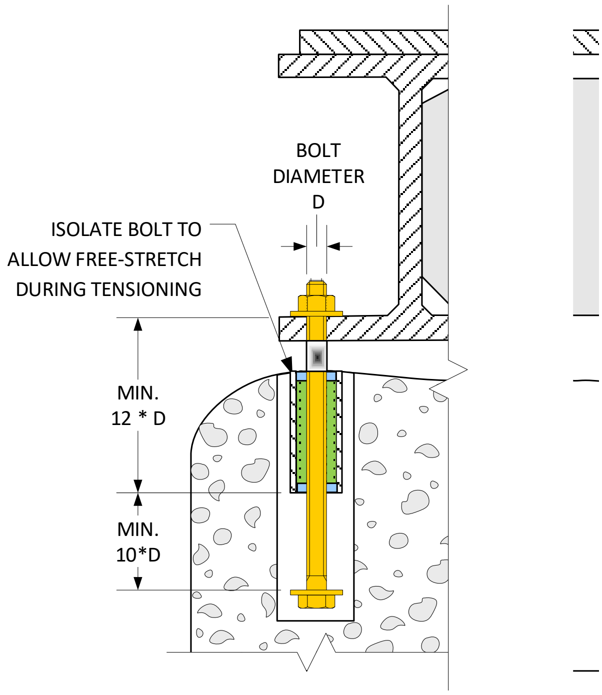

Figure 16: Proper Anchor Bolting Configuration

A superior quality epoxy grout was poured in the anchor bolt pockets and under the baseplate. The entire original epoxy grout cap was encapsulated within the new, superior epoxy grout cap. Control joints were used to segment the pour and allow for expansion and contraction of the epoxy grout due to thermal changes.

Figure 17: Superior Epoxy Grout Installed in New Anchor Bolt Pockets and Under Baseplate and Baseplate Extension

After sufficient time had elapsed, as advised per the epoxy grout manufacturer, the formwork was removed, and the anchor bolts were properly tensioned.

Figure 18: Final View of the Equipment Remediation

5.4 Follow Up

After the remediation was performed, the observed vibrations during equipment operation are minimal and greatly reduced from the original situation. The anchor bolt tension has been maintained. The entire remediation only resulted in three days of downtime for this critical piece of equipment and resulted in a significant improvement in operational efficiency.

6 Conclusion

Proper understanding of the foundation system of rotating equipment is an important aspect of overall reliability and operational efficiency. When there are deficiencies in this system, it is imperative to quickly identify and remediate these problems before they cause more catastrophic and expensive failures. By forming true partnerships with local foundation experts to properly diagnose the root causes of the problems, innovative solutions can be designed and effectively implemented, leading to great improvements in operational efficiency and a reduction in total costs. This directly results in greater asset profitability.

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