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Piping Stress Considerations and Practical Remedies to Overcome Nozzle Misalignment and Vibration Related Issue

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Abstract: *What is piping alignment? Piping alignment is to connect the piping flange to the equipment flange in decoupled condition without external loading especially in sensitive equipments like turbine, compressor, pump etc.*

Why Alignment is required? To verify the strains imposed by piping flange on equipment flange & the same should be minimized for better performance & reliability of the equipment. Many vibration problems in the equipment are amplified due to piping misalignment. Flange bolt failure might occur due to heavy external loading required for connecting piping flange with nozzle flange. Nozzle flange joints with connected piping & supporting shall be designed to qualify the alignment requirement of ASME B31.3 clause-335.1.C, when the joint is broken.

How it is affecting the cost and time due to imperfect engineering? Construction site engineer facing lot of difficulty in pipe aligning as they adjusting the supports without proper guidelines from engineering team and measuring each and every time the pipe flange bolt hole with equipment nozzle bolt hole to bring the minimum tolerance as per equipment vendor or code. Also site engineers use chain pulley arrangement and forcefully connect piping flange and equipment nozzle flange and in the process create strain on the connected nozzle which leads to flange leakage & vibration issue in future which leads to reduce the performance of the equipment. Again the reanalysis is done to understand the issue which in some cases leads to time & cost without resolving the issue.

How to overcome the misalignment? To overcome the above problems, stress engineer should play a vital role in selecting the type of supports taking care of both Operating & Installation conditions. A great deal of time & attention is required for piping alignment and it decides the overall quality of engineering & conditions of plant. Hence, in this presentation, we are going to do the front engineering defining the roles & responsibilities of the stress engineer in performing the theoretical alignment checking and also preparing the methods & ideas to be followed by the site engineer while performing the practical nozzle alignment to overcome misalignment.

Keywords: *aligning, pulley, misalignment.*

1. INTRODUCTION

To reduce the likelihood of piping strain, adherence to existing standards, guidelines, and good design practices is critical. In the authors' experience, the most commonly referenced standard and recommended practices in the compression industry are ASME B31.3 Process Piping and API RP 686. A summary of the guidance in regards to pipe strain is as follows:

1.1 ASME B31.3 PROCESS PIPING

Section 335 describes the requirements for assembly and erecting.

i) As it relates to alignment the specification prohibits introducing strain into the piping or equipment by forcing piping into alignment. Specific tolerances for flanged joint alignment are further defined as the following:

   a)Flange faces aligned to plane within 1/16"per foot as measured across any diameter and

   b)Flange bolt holes should be within .0125" maximum offset. [1]

ii) The Standard also provides methods for doing a flexibility analysis for a piping system and calculating displacement stresses.

1.2 API RP 686

Recommended Practice for Machinery Installation and Installation Design 2nd edition. Chapter 6 provides guidelines for piping alignment as well as guidelines associated with measurement of components that could identify pipe strain having effects to connected machinery.

i) Like ASME B31.3 the Standard specifically prohibits forcing piping into alignment.

ii) In terms of piping and flange alignments the following are defined as (a) machinery and piping flange faces are considered and should be parallel to within .001 in/in of pipe flange diameter with a maximum allowable of .030" for flanges larger than 10" in diameter. (b) For flanges smaller than 10" in diameter the requirement is to be parallel with 0.010" or less and (c) Flange face separation is required to be within ± 1/16" taking into consideration gasket spacing. [2]

iii) An additional requirement for measurement of pipe strain is provided for verifying that shaft movement of coupled equipment does not exceed .002" in horizontal or vertical directions when in final installation state. [2]

iv) Reciprocating compressors have an additional requirement for verifying that piston rod run out before and after installation are within the compressor manufacturer or API 618 allowances.

Concerns with existing standards are that they are not specifically written with consideration for aspects related to reciprocating compressor installations and, as a result, may not be adequate. Specific areas of concerns as they relate to reciprocating compressors are multi-cylinder nozzle pulsation bottles (more so on 3 nozzle bottles), and close coupled scrubber and suction pulsation bottle configurations.

2. STRESS ENGINEER'S GUIDELINES FOR THEORETICAL ALIGNMENT CHECKING

There is no standards to specifically explain the guidelines the stress engineer should follow for theoretical alignment checking for all Rotating Equipments like Centrifugal Compressor, Steam Turbine, Centrifugal Pumps, Gear Pumps etc, Few procedures are to be followed as mentioned below while carrying out static analysis:

1. Ensure correct weight of the pipe (with proper thickness), Support weight (dummy pipe), Weight of valves, flanges and any in-line items.
2. Consider Insulation density carefully (equivalent insulation density to be correctly fed with insulation & cladding weight, Check insulation on dummies for cold insulated lines).
3. Model all branch piping (like drip legs etc.) greater than 2 inches.
4. Discuss with piping lead engineer for requirement of any maintenance flanges (Normally for steam turbine or centrifugal connected lines the maintenance flange is recommended) and include it if required.
5. Minimize the sustained load on equipment nozzle as much as possible during static analysis run.
6. Make the equipment nozzle anchor flexible or remove the displacement if anchor was not modeled.
7. Wherever spring support is used, define spring rate and cold load in case of variable effort spring & Constant effort support load in case of constant effort spring.
8. After performing the above create one additional load case in Caesar II as mentioned below:

   WNC+H SUS System with spring hanger

   WNC SUS System without spring hanger
9. Set the spring hanger as "As designed".(Two load cases can be generated for spring As designed and rigid condition)
10. Now run the analysis and check the displacements of the nozzle at the above mentioned load case and limit them within below mentioned values:
11. Vertical deflection (Normally DY): +/- 1.5 mm
12. Horizontal displacement (sqrt sum of DX and DZ): +/- 1.5 mm
13. Parallelism (sqrt sum of RX and RZ): 0.0573 degree.
14. In case the above limitations are not met then re-analyze by readjusting the spring and other supports and do the simulation.

Alignment check is to be performed for both inlet and outlet lines.

Alignment check must be performed with spring under "As designed" and in "locked" conditions.

To avoid small misalignment in vertical direction first support from rotary equipment nozzle is used either a spring support or an adjustable type support.

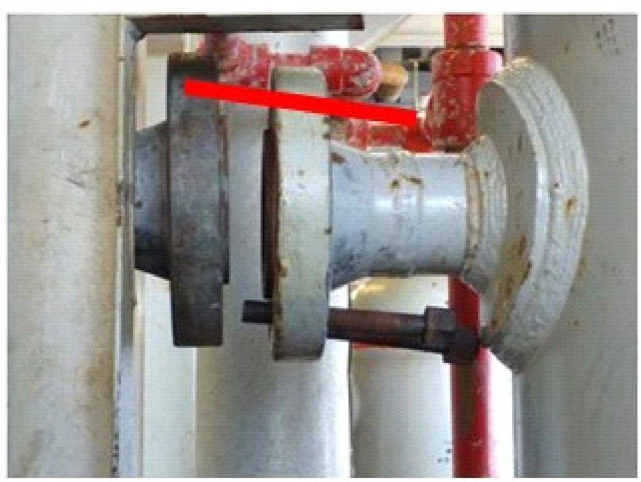

Fig. 1. Flange Alignment Problem (discovered after removing bolts)

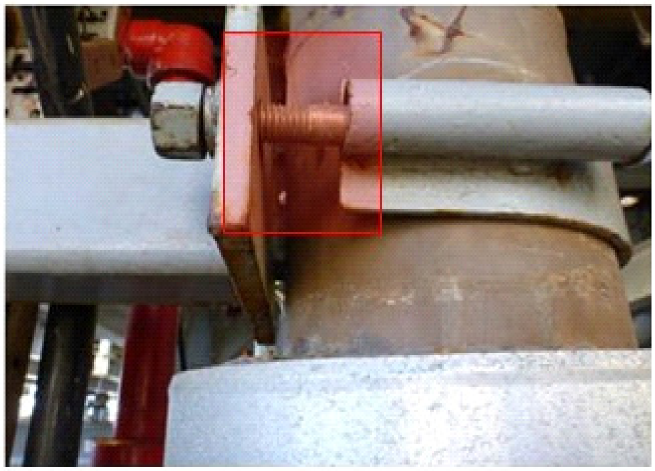

Fig. 2. Gap in piping due to improper installation (pipe strain will occur when bolts are tightened)

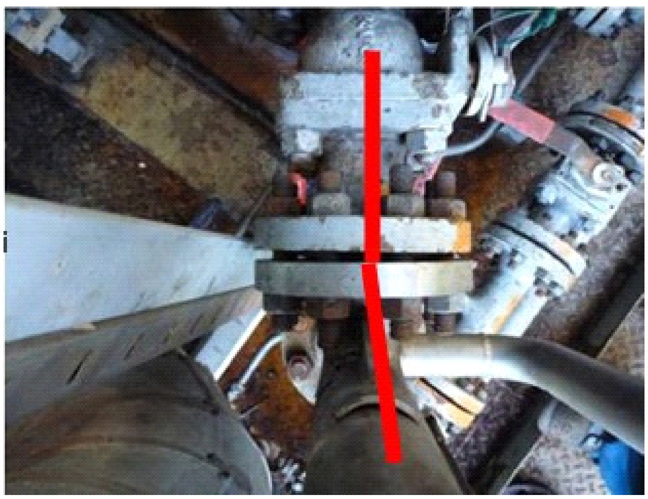

Fig. 3. Angular Misalignment of Flange (creating pipe strain)

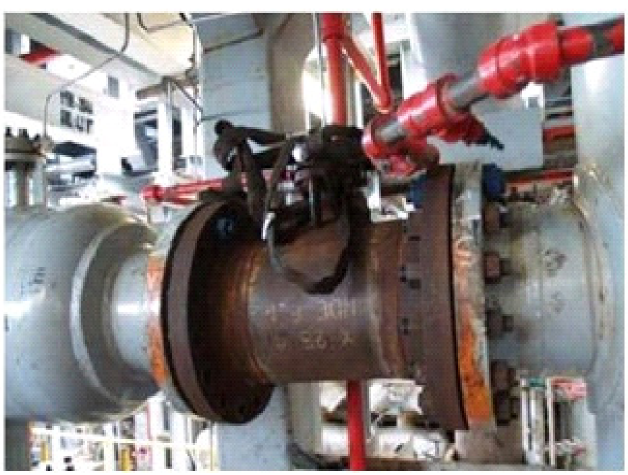

Fig. 4. On-site fabricated spool piece to address pipe strain concerns

3. SITE ENGINEER'S GUIDELINES IN PRACTICAL ALIGNMENT CHECKING

Although most of the guidelines are mentioned in API-686 standards, we are giving some of the guidelines based our experiences:

1. Ensure that piping is not forced into alignment with mating flanges or support locations using force such as hydraulic jacks and chain falls during assembly.
2. Design pipe supports with at least ¼" gap between piping and support to allow for shimming after installation is in hot (operating) condition.
3. Pipe clamp bolts and pipe supports should line up without forcing piping to line up with the support. Slotting of support holes may be a good practice to allow for variability due to construction tolerances and on-site thermal growth during operation.
4. Angular alignment of mating flanges should be as near to parallel as possible.
5. Ensure multi-cylinder nozzle pulsation bottles have flange faces on the same plane and are tolerance to mate with cylinder nozzles without stressing the nozzles.
6. Implement custom orifice plate thickness if axial misalignment between flanges is too great, rather than drawing the flanges together with bolting and Provide support for large process valves.
7. Implement sufficient pipe supports at adequate spacing intervals to prevent induced mean stresses from the piping weight.
8. Ensure skid is designed appropriately for the installation to reduce the likelihood of deflection of the skid in transit to final site versus the manufacturing location.
9. Final fit up of piping near machinery by field welding of pipe spool pieces.

4. CASE STUDIES

4.1 OVERVIEW OF PIPE STRAIN

Pipe strain, for the purpose of this paper, is considered to be the load introduced into the piping due to static deflections. One of the major contributors of controllable pipe strain is piping misalignment. The root cause of misalignment can be attributed to deficiencies in design, fabrication, assembly, and installation practices. By itself, pipe strain may not be sufficient to cause failure, but when combined with the dynamic stresses related to reciprocating compressors, pipe strain becomes an element critical to the reliability of piping systems. The three figures below show examples of geometries that resulted in pipe strain. Two pipe strain examples are presented below to illustrate the magnitude of vibration problems and the types of solutions employed to resolve the issue. These examples include one case relating to static stress problems and the other relating to dynamic stress problems.

4.2 STATIC STRESS RELATED TO PIPING MISALIGNMENT

In this case, bolt failure occurred between the pedestal support and the distance piece. The problem was due to increased static loading of the bolts of the support connecting the distance piece to the pedestal caused by short coupled scrubber and pulsation bottle, Spool piece (Figure 4) for inlet screen was too short, Loads transferred to the pedestal support bolts were concluded to have exceeded bolt preloads and subsequent vibratory loosening of the fastener occurred. It is important to note that flange alignment actually met the requirements defined in ASME B31.3. Custom fabricated new spool piece and custom thickness plate for inlet screen installation. Without analysis, standard practice of increasing the pedestal bolt torques would have potentially moved the stresses being caused by misalignment and dynamic loads to compressor components.

4.3 DYNAMIC STRESS ON PIPING SYSTEM

Figure 3 shows a gap between the pipe and the pipe support. Once the bolts are fully tightened, the pipe will be strained. The pipe vibration problem is due to the pipe not being shimmed at the clamp and the resulting vibration response being near the MNF. A pipe strain condition could be created by tightening the clamp to draw the pipe to the clamp and result in increased static stress, shift of the mechanical natural frequency of the system, and a changing in damping. Figure 2 Gap between pipe and support prior to shimming. To solve the vibration problem, related to what is shown in Figure 6, shims were added between pipe and clamp. This resulted in reducing vibration to acceptable limits.

4.4 PUMP ALIGNMENT PROBLEM

After commission of petrochemical plant, after few weeks pump leakage near mechanical seal issue arise in one of the units. To understand the issue, we visited the site to see if all the supports are working according to design, after inspecting, we find some issue and suggest the solution to overcome the leakage issue but after making the changes no result achieved. Then proper analysis carried out in design department and reanalysis the system to understand the problem. Once the analysis was complete no much success achieved. Finally we decided to dismantle the pump suction nozzle and piping. Once we dismantle the nozzle there was huge alignment issue and nozzle joint was created by applying force and due to which bolts get loosened and leakage got started. Huge amount of manpower and cost involve resolving this issue with one pump and due to which all operation get halted.

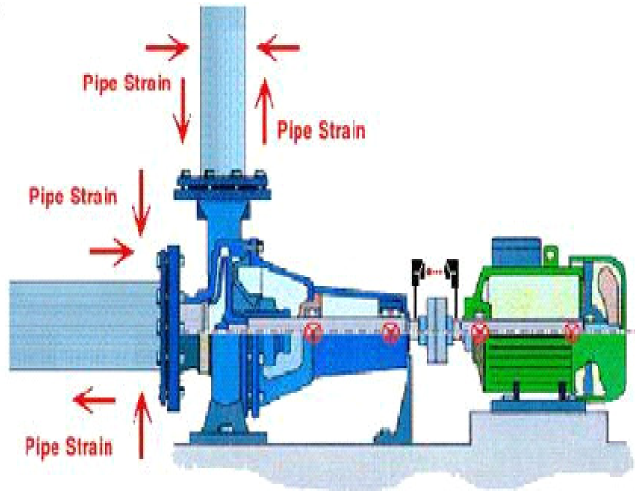

Fig. 5. Pump alignment with inlet and outlet

5. CONCLUSIONS

Good design practices as well as good manufacturing and assembly practices reduce the likelihood of problems. Proper installation is critical to ensure low vibration and reliability. Identifying root cause is complex and cannot be easily identified without the right tools and experience. Further research is needed to accomplish the following:

i) Conduct finite element analysis and field measurements to compare the change in static stresses as it relates to varying degrees of misalignment.

ii) Measure vibrations and relate the change in vibratory response to differences in initial static stress.

iii) Conduct hysteresis measurements in laboratory and at field installations with and without static stress.

iv) Develop improved alignment recommendations for installation of piping systems in strain critical applications.

Develop a field calculator able to define allowable alignment tolerances more specific to individual piping joints, with less dependence on generalized tolerances for a very wide range of installation variables.

Validate findings and recommendations through laboratory and field testing

Our ultimate goal is to bring the responsibility of the engineer not only on theoretical ideas and also focus on practical issues faced on site locality. This will result in increased safety, reducing any environmental risk, Plant cycle or life span gets increased, reduced unplanned shut down and failures. While doing any project, much of the emphasis is on engineering and due to which nozzle alignment is not given much importance due to cost involved with the analysis because of extra supporting but once the plant got into construction stage lot of wrong means are adopted for static as well as rotary nozzle alignment due to which lot of leakage and vibration issue come up after commissioning of plant. So, our suggestion is that we should be very serious about nozzle alignment during engineering stage and take proper care while doing nozzle alignment and provide extra supports for alignment as they will be used again and again during shut down and startup and overall the cost of operation minimized.

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