Pipe Stress Analysis of Pump System in Process Plant

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Abstract- Every process and LNG plants operate many pumps and compressors in the processing unit. Performing the pump stress Analysis is immensely critical. The Pump's high vibration on the process plant will seriously affect the pipe and equipment's smooth operation. The resonance effect between pipe and equipment will create a severe additional desecration. Before installation or formal process, we need to perform static analysis, and dynamic analysis (modal, forced response analysis) is mandatory for the pump system. The pump vendor must perform a Pulsation analysis on the piping system for reciprocating machinery subject to pulsation flow. In this study, flexibility analysis of pump piping system as per process piping code B31.3 using CAESAR-II programming followed by placing of diverse pipe supports. The support type and position of the supports as per the output get from static and dynamic examination. By the software analysis of CAESAR II, the efficiency of pipe flexibility and expansion of the piping system's natural frequency is authenticating by include more oriented and load-bearing support to the elbow and Valve, which prevents the resulting of resonance successfully. The stress analysis, modal analysis, pulsation analysis, and vibration analysis method proposed in this paper will increase the lifespan and operation reliability of pipe and equipment.

Keywords: Acoustic study, ASME B31.3, CAESAR-II, Frequencies, Modal analysis, Pulsation analysis.

1. Introduction

A pump is one of the most critical pieces of equipment in the process plant. Pumps are mainly being used to transfer the service fluids or gases from one location to another. In the case of upstream oil and gas field applications, pumps play an essential role in pumping the wells' oil or gas and transferring them to the onshore storages or pipelines. The standard type of pumps is a centrifugal pump, reciprocating pumps, screw pumps, etc., which are used universally. In each process or LNG plants have stand by pump to assure continuous operations in case of maintenance of the first pump. High-temperature service pump piping is the most critical system to perform the stress analysis. The stress analysis is the most important stage of the pipe design to restrict failure and cause mishap. It is associated with high degree of responsibility [1]. Apart from the stresses caused by the pipe dead weight, fluid density and isolation piping systems are also subjected to thermal changes, operating and design pressure and occasional condition like water hammer, Wind, Seismic etc. Generally, the piping stress analysis's greatest challenge is to provide the is to provide the system sufficient flexibility to absorb the thermal expansions. In the present day, pipe stress analysis plays much critical role to fix the piping layout. It is still one the challenging task for engineers to work in this field. The piping shall be routed initially, considering flexibility. Then it will be easier for the stress engineer to do the stress analysis and avoid back and fro communications within the piping department. This paper aims to present a stress analysis of pump piping systems to limit the nozzle loads within the allowable limits. [2-4]
2. Literature Review

Some researchers worked on many parameters related to pump piping. It includes finalization of nozzle allowable, modification of pump piping, etc. Payal Sharma et al [5] have mentioned that the design of the piping system is governed by the international code and standard ASME B31.3. The author also highlights about the basic concept of flexibility and SIF. The Appendix-P of ASME B31.3 is the guideline provide for doing stress analysis of the piping system. The author has presented the stress criteria background and explains why Appendix P is formulated based on confusing logic that may lead to the piping system's unsafe design. The researchers' studies mainly focus on overcoming the low nozzle allowable provided by manufacturers [6]. L.C. Peng [7] had raised concerns about the change in equipment reliability due to connecting piping. So, the piping shall be designed so that minimum loads shall be transferred to the connecting equipment so that the pumping efficacy can increase the equipment's reliability. Simizu [8] studied the nozzle load analysis for process pumps. They have found that the Pump may require to withstand nozzle loads under extreme conditions, which often exceeds the criteria stated in API610. They have gone into detail of shaft end displacement of centerlines mounted Pump under nozzle loads. A research has stated that the current permissible loads for piping loads on rotating equipment nozzles specified by manufacturers are too low. To accommodate the design specification of connecting piping system, the pump manufacturer must increase the allowable loads. Literature work does not adequately specify the design modification. The Pump allowable can be kept within limits by systematic improvement in pump piping and to satisfy the latest edition requirement of API 610 [9]. Therefore, there is a requirement of modification in piping routing and supporting to reduce the nozzle loads of pumps.

3. Experimental analysis

Piping system are very much critical system in different process parameter such as pressure, pipe material specification, temperature, surge, seismic loads, wind loads etc., acting concurrently. Mainly two types of analysis are usually preferred in oil and gas industry a) static examination and b) dynamic examination. The static loads are due to thermal, pressure, equipment displacement, fluid weight, etc. The dynamic loads are seismic, wind, water hammer, surge, two phases, etc., which usually create upset. Apart from the method of flexibility analysis and mechanical stress analysis traditional method: 1) Approximation process 2) Exact analytical methods 3) Modal tests.

3.1. Inputs for piping stress analysis

Stress Isometric from piping designer, P&ID & Line Designation Table (LDT from process department, Equipment GAD and other vendor data from the mechanical group,PFD /datasheet if required from the process department, Specification of piping (PMS) from the piping material group, All control valves and other valve data from Instrumentation. Project-specific nozzle allowable standard, overall plot plan, and area plot plan for finding HPP elevation and equipment orientation from piping layout group.

3.2. Governing codes and standards for pipe stress analysis

ASME B31.3: Process piping Code
Centrifugal Pumps: API 610
Centrifugal Compressors: API 617

3.3. Stress analysis of pump piping system

The analysis of pump piping consists of suction and discharge piping. The static analysis and modal analysis of suction and discharge lines of Pump existing in the refinery are considered in the current paper.
One of the piping unit's refinery systems consists of 2 pumps with two suction and discharge nozzles. The pump piping loads exerted on the pump discharge nozzles have exceeded the pump manufacturer's limit. It is required to bring the nozzle loads within the limit by stress analysis (static) of the pump piping system. The static analysis of the complete system is performed in finite element analysis software (CAESAR-II). It includes finalizing the piping system routing and supports. The pump nozzle loads are within allowable limits, suggesting the changes or modifications in the piping system such that the system is optimal in terms of cost.

**Figure 1.** Process and instrumentation diagram for pump system. The yellow highlighted pipeline is pump suction and discharge line.

### 3.4. Optimization of piping

The design and cost comparison among the cases mentioned above shall be the ideal approach to present the design's optimization. However, these are not being used in consultancies due to many drawbacks like time, cost, etc. For this project, the optimization is achieved mainly by material optimization and engineered support, resulting in cost optimization. Even if we save on a few of the fittings or spring support, it will save a large amount of commodity, welding, handling, test & inspection cost.

If we consider a reduction in the number of supports or the simple supports rather than specially designed supports, it will be a cost saver. The standard support is usually fabricated and welded at the site. However, in special supports, these are required unique design, manufacturing, and installations. Thus, the first choice should be simple supports, and in extreme cases where simple supports are not practical or not acceptable considering design analysis, SPS shall be used. The problem cases are being analyzed in terms of the cost of material used in the piping. The best and optimum is design, which is safe in terms of allowable limits and cost-effective [10].

### 3.5. Stress evaluation

The standard-purpose FEA codes will not consider the supports' geometric properties, valve data, and engineered support. Constructing the analytical models for each load case scenario is of utmost critical. Moreover, the evaluation of allowable stresses for each load case is very strenuous. So, CAESAR-II program was used in this research, which is used in all the process industry. From the below figure, software modelling is done as per stress isometric. Procedure of the piping modeling (1) piping system part; (2) Node and coordinates of the piping system; (3) Piping parameters” (like
length, diameter, and schedule); (4) Provide process and insulation. Firstly, complete the equipment modelling and then start modelling the piping based on piping isometric drawing. Always make a closed system to get the correct results. Typically, pump lines are connected to heat exchanger, horizontal or vertical vessel and tank. So, it will create a closed secure network. Then run the Caesar-ii piping model to check code stresses, displacements, loads on nozzle and support, natural frequencies etc.

**Figure 2.** The geometry of operating-Stand by Temperature profile for a two-pump system isometric view. Pump-A is in working condition and pump-B will be in stands by pump.

**Figure 3.** General arrangement drawing for pump. All the calculation related details (nozzle allowable, anchor location, pump type, size and rating of pump mentioned).
3.6. Load cases

For each stress calculation the following load cases are required as minimum for pump piping system. So, considering T1 as operating temperature, T2 as maximum stress and T3 as minimum stress, the following load cases are required. The load cases combination is as per ASME B31.3, process piping specification.

| Loads Defined in Input | Drag a column header and drop it here to group by that column |
|------------------------|---------------------------------------------------------------|
| W - Weight             |                                                                 |
| T1 - Thermal Case #1   |                                                                 |
| T2 - Thermal Case #2   |                                                                 |
| T3 - Thermal Case #3   |                                                                 |
| T4 - Thermal Case #4   |                                                                 |
| T5 - Thermal Case #5   |                                                                 |
| P1 - Pressure Case #1  |                                                                 |
| HP - Hydro. Pressure   |                                                                 |
| H - Hanger Loads       |                                                                 |
| U1 - Unif Load Case #1 |                                                                 |
| U2 - Unif Load Case #2 |                                                                 |
| WIN1 - Wind load Case #1|                                               |
| WIN2 - Wind load Case #2|                                               |
| WIN3 - Wind load Case #3|                                               |
| WIN4 - Wind load Case #4|                                               |
| WW - Water Filled Weight|                                             |
| WNC - Weight No Contents|                                             |

| Definition | Name       | Stress Type |
|------------|------------|-------------|
| W + H      | L1         | MGR         |
| W + T1 + P1 + H | L2       | MGR         |
| WW + HP + H | L3         | HYD         |
| W + T1 + P1 + H | L4       | OPE         |
| W + T2 + P1 + H | L5       | OPE         |
| W + T3 + P1 + H | L6       | OPE         |
| W + T4 + P1 + H | L7       | OPE         |
| W + T5 + P1 + H | L8       | OPE         |
| W + P1 + H   | L9         | SUS         |
| WNC + H     | L10        | SUS         |
| W + T1 + P1 + H + U1 | L11    | OCC         |
| W + T1 + P1 + H + U1 | L12    | OCC         |
| W + T1 + P1 + H + U2 | L13    | OCC         |
| W + T1 + P1 + H + U2 | L14    | OCC         |
| W + T1 + P1 + H + WIN1 | L15   | OCC         |
| W + T1 + P1 + H + WIN2 | L16   | OCC         |
| W + T1 + P1 + H + WIN3 | L17   | OCC         |
| W + T1 + P1 + H + WIN4 | L18   | OCC         |
| L11 - L4    | L19        | OCC         |
| L12 - L4    | L20        | OCC         |
| L13 - L4    | L21        | OCC         |
| L14 - L4    | L22        | OCC         |
| L15 - L4    | L23        | OCC         |
| L16 - L4    | L24        | OCC         |
| L17 - L4    | L25        | OCC         |
| L18 - L4    | L26        | OCC         |
| L19 - L9    | L27        | OCC         |
| L20 - L9    | L28        | OCC         |
| L21 - L9    | L29        | OCC         |
| L22 - L9    | L30        | OCC         |
| L23 - L9    | L31        | OCC         |
| L24 - L9    | L32        | OCC         |
| L25 - L9    | L33        | OCC         |
| L26 - L9    | L34        | OCC         |
| L4 - L9     | L35        | EXP         |
| L5 - L9     | L36        | EXP         |
| L6 - L9     | L37        | EXP         |
| L7 - L9     | L38        | EXP         |

**Figure 4.** Load cases table for stress summary, restraint load, displacement, and nozzle check for sustained, operating, expansion and occasional cases.
4. Results and discussion

4.1 Output results for code compliance report

Stress check for all the multiple load cases combine in a single report using the code compliance report.

| Load Case | From Node | Code Stress | Allowable Stress |
|-----------|-----------|-------------|-----------------|
|           |           | lb./sq.in.  | lb./sq.in.       |

**Figure 5.** Code compliance report.

4.2 Nozzle load check

The below load table shows that the nozzle loads are well within the API 610 code allowable limits. For rotary equipment, nozzle load qualification on design and upset condition is not recommended.
Figure 6. Nozzle loads check actual vs allowable.

4.3. Modal analysis

The Modal analysis of the inlet and outlet piping system performed independently through CAESAR II programming. In this research we observed that the minimum natural frequency of the system more than 10 Hz, which is much higher than the industry recommended EI guidelines frequency 7Hz. So, the resonance effect between pump and piping would not happen.

Figure 7. Natural frequency report of the system.
4.4. Recommendation to reduce piping stresses and optimization piping layout

Increase the fundamental natural frequency by reducing the support span, avoid SBC near turbulence source (e.g., closed valves, short radius or mitered bends, tees, and reducers), and add protection to SBC. Adequacy of Rigidity, Skirt support: Filter /scrubber/volume bottles (no legs support unless Rigidity braced) Axial stop+ guiding near pressure throttling piping, e.g., Orifice plate, Valve. [11]

5. Conclusion

The systematic study of pump piping systems is performed using FEA software CAESAR-II and process piping code ASME B 31.3-2016 for flexibility analysis. [12]

The insightful and FEA software results is observed. The pipe stress analysis is performed for the piping system is checked manually based on the process design code B31.3-2016, and the system is stress analyzed with the help of FEA software. [13]

The outcomes are breaking down and tracked down that the Piping framework is protected. In this study elaborate the procedure and special consideration to be followed for pump piping analysis. [14]

It concludes that provided with enough flexibility, this is considered in the initial stage of piping routing. Some of the means to increase flexibility are 45 deg connections; spring supports, axial stop used other than anchor supports, and overall flexibility up to the header piping. [15]

As per ASME B 31.3 and API 610 pump nozzles are within the code allowable stress, Nozzle loads, restraint loads, natural frequencies, sagging, leakage check and support loads are well within the standard.

6. References

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