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Research Article

Screening and Mitigation of Flow Induced Turbulence (FIT) in Piping Systems

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Abstract

Vibration induced fatigue failures of piping systems in a process industry are a major concern due to its association with safety, corrective action costs, production downtime and environmental impacts. Process Piping Systems have traditionally been designed on the basis of static analysis with little attention paid to vibration induced fatigue. Considering a piping system that is not designed considering these vibrations induced fatigue, can result in failure of supports, supporting structure, overstress causing cracks in pipes and fittings. Consideration of vibration induced fatigue helps in ensuring the safety and integrity of the piping system by eliminating the overstress in piping systems and supporting elements, thereby preventing practical damage to the facility. This paper allows with an opportunity to assess and mitigate the level of piping vibrations that are induced by the degree of turbulence in the flow through the main line. The piping is evaluated in accordance with the Energy Institute's Guidelines for the Avoidance of Vibration Induced Fatigue Failure in Process Pipework.

Keywords: *Flow Induced Turbulence, Caesar II, Piping Systems, Small Bore Connections, Natural Frequency, etc.*

1. Introduction

Vibration in piping systems is an essential phenomenon vis-à-vis flow or acoustics. Generation of turbulent energy lies in any piping systems when fluid flows past significant flow discontinuities in that system. Most of the turbulent energy concentrates at low frequency this is typically below 100 Hz and the level of excitation is higher at lower frequencies.

Flow-Induced Turbulence (FIT) is a function of flow rate and can excite lower frequency vibration modes of piping. FIT exists in most of the piping systems with straight pipes generates turbulence primarily via interface with pipe wall and flowing medium, also known as the turbulent boundary layer. Dominant sources of FIT in any piping system are major flow discontinuities in the system this includes tees, reducers, bends, equipment, partially closed valves, etc. Majorly excitation concentrates at low frequency typically below 100 Hz. The higher level of turbulence is governed by this lower level of frequency, leading to excitation of the low frequency modes of the piping system. In many cases FIT also causes visible motion of the pipe and even pipe supports.

FIT generated in the piping system may lead to high cycle fatigue of components especially at the small-bore connections and in some extreme cases also leads to failure of welds in the main piping line itself.

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The extent of FIT excitation depends on the kinetic energy of the flowing fluid and support arrangement [1].

For the piping systems those are prone to vibration induced failures requires a screening followed by a mitigation strategy. Piping system vibration assessment is based on the Energy Institute (EI) AVIFF Guidelines. FIT analysis done on any piping system considers the interaction between low-frequency piping modes and turbulent energy generated from the disturbed flow and makes recommendations to mitigate such vibrations in piping support and structure.

2. Case Study

For process piping system, taking into account a single-phase gaseous fluid flowing in 14" STD Schedule seamless carbon steel pipe at pressure and temperature of 1.22 bar(a) & 29°C, respectively. Piping System is designed as per ASME B31.3 and piping stress analysis is carried out using Caesar-II.

2.1 Initial Screening

2.2.1 Determining Kinetic Energy of Flow

Kinetic Energy for a single-phase gaseous flow having density 0.84 kg/m^3 and flowing at velocity of 262 m/s using (eq. 1) is 57660 kg/ms^2, which is well above the threshold valve of 20000 kg/ms², the same is classified under high Likelihood of Failure (LoF) in accordance with Table T1-1 of EI AVIFF Guidelines.

$$\rho v^2 = (actual\ density)x(actual\ velocity)^2 \quad (1)$$

Since initial screening indicates that piping system is prone to vibrations due to FIT, thus requires a detailed calculations of LOF for further analysis.

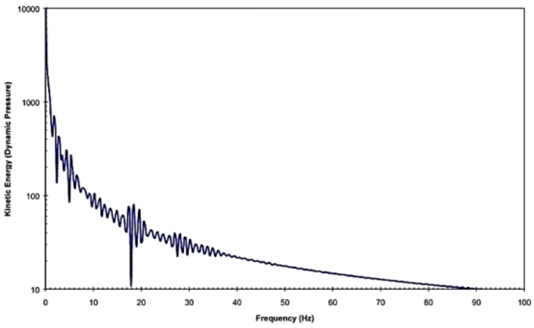

Figure 1: Turbulent Energy as a function of frequency

2.2.2 Determining Fluid Viscosity Factor (FVF)

FVF serves for the amount of turbulent energy that partially depends upon the fluid viscosity. FVF is 1.0 for liquid and multiphase fluids.

To determine FVF for a single-phase gaseous system dynamic viscosity is required. Dynamic viscosity for the fluid flowing in the piping system is $1.29x10^{-5}$ Pa-s. calculated FVF is 0.11 (using eq. 2).

$$FVF = \frac{\sqrt{\mu_{gas}}}{\sqrt{1x10^{-3}}} \quad (2)$$

2.2.3 Determining Support Arrangement

To determine support arrangement of piping system, either of the two options can be considered; first, is to calculate typical fundamental natural frequency of the piping system and second, is to calculate maximum allowable span length of the piping system.

For this paper, typical fundamental natural frequency is calculated using Caesar-II (Figure 2&3). Natural frequency of Piping is calculated as 2 Hz.

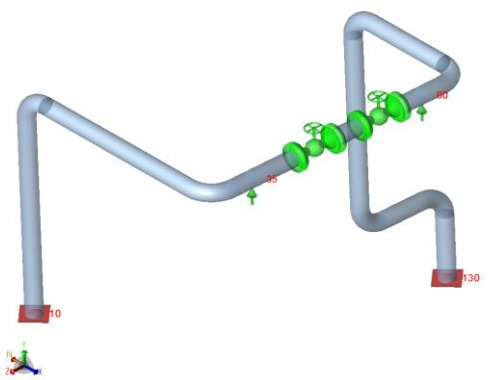

Figure 2: Piping System with support

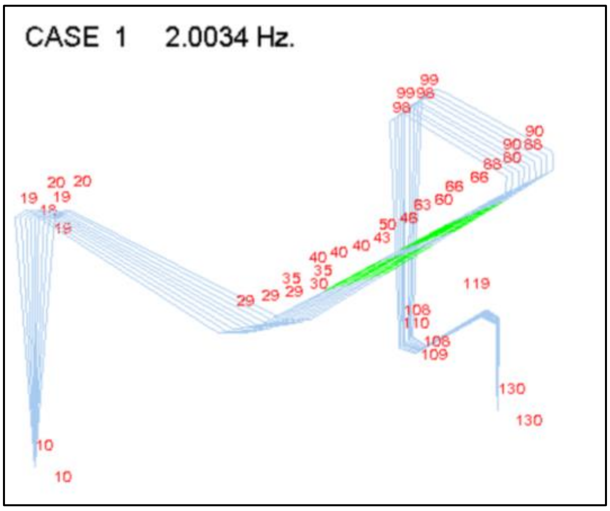

Figure 3: Mode shape for 2 Hz frequency

Referring to Table T2-1 of EI AVIFF Guidelines, support arrangements for typical fundamental natural frequency can be categorized into Stiff (14 to 16 Hz, eq. 3), Medium Stiff (7 Hz, eq. 4a&b), Medium (4 Hz, eq. 5a&b) and Flexible (1 Hz, eq. 6); this serves as the second option to determine support arrangement required in further calculation.

$$L_{span} \le -1.2346x10^{-5}D_{ext}^2 + 0.02D_{ext} + 2.0563 \quad (3)$$

$$L_{span} > -1.2346x10^{-5}D_{ext}^2 + 0.02D_{ext} + 2.0563 \quad (4a)$$

$$L_{span} \le -1.1886x10^{-5}D_{ext}^2 + 0.025262D_{ext} + 3.3601 \quad (4b)$$

$$L_{span} > -1.1886x10^{-5}D_{ext}^2 + 0.025262D_{ext} + 3.3601 \quad (5a)$$

$$L_{span} \le -1.5968x10^{-5}D_{ext}^2 + 0.033583D_{ext} + 4.429 \quad (5b)$$

$$L_{span} > -1.5968x10^{-5}D_{ext}^2 + 0.033583D_{ext} + 4.429 \quad (6)$$

2.2.4 Determining Flow Induced Vibration Factor (F_v)

Since, the fundamental natural frequency below 1Hz means piping system categorized as “flexible” referring to Table T2.2.3.3 of EI AVIFF Guidelines.

For flexible support arrangement and 273 to 762 mm range of Outside Diameter of 14” STD Schedule pipe, F_v is 2416 (using eq. 7).

$$F_v = \alpha\left(\frac{D_{ext}}{T}\right)^{\beta} \quad (7)$$

$$\alpha = 41.21D_{ext} + 49397 \quad (8)$$

$$\beta = 0.0815\ln(D_{ext}) - 1.3842 \quad (9)$$

2.2.5 Calculation of Likelihood of Failure (LoF)

Likelihood of Failure (LoF) is a calculated whole number that serves as a threshold value to determine whether a system under consideration is safe under operation or require mitigation for its safe operation.

$$LoF = \frac{\rho v^2}{F_v} FVF \tag{10}$$

For the piping system under study LoF is 2.71 (eq. 10), which is well above the threshold valve of 1 (Table 3-1 of EI AVIFF Guidelines. i.e., high potential for vibration induced fatigue failure. Now comes the opportunity to address all those failure modes via a proper mitigation strategy.

2.2 Mitigation

Since, LoF of the piping system is greater than 1, so the piping system shall be re-designed or re-supported to bring LoF value below 0.3; or perform a detailed FEA analysis to rule out any possibility of fatigue failure due to vibration in piping system. Also, need to ensure that two plane (perpendicular) bracing is provided for all small bore connections to avoid failure due to fatigue and vibration.

Table 1: LoF for different support arrangement

Support Arrangement	α	β	F_v	LoF
Stiff	717139	-0.79	41602	0.16
Medium Stiff	415493	-0.85	19061	0.34
Medium	224732	-0.8482	10429	0.63
Flexible	64051.3	-0.9055	2416	2.71

It can be noticed that LoF for stiff piping is less than 0.3, to achieve the stiff category for the piping system under study, the fundamental natural frequency must be above 14 Hz as per Table T2.2.3.3 of EI AVIFF Guidelines.

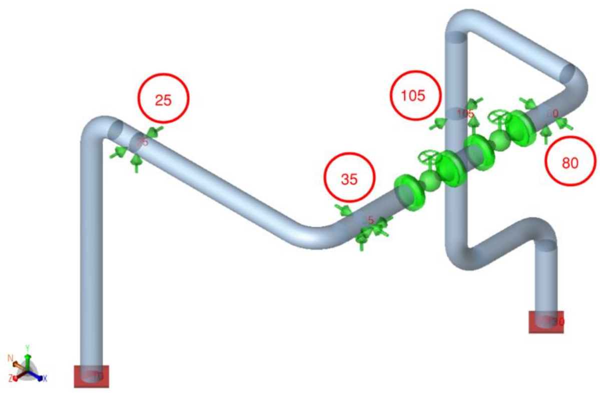

Figure 4: Piping System with modified supports

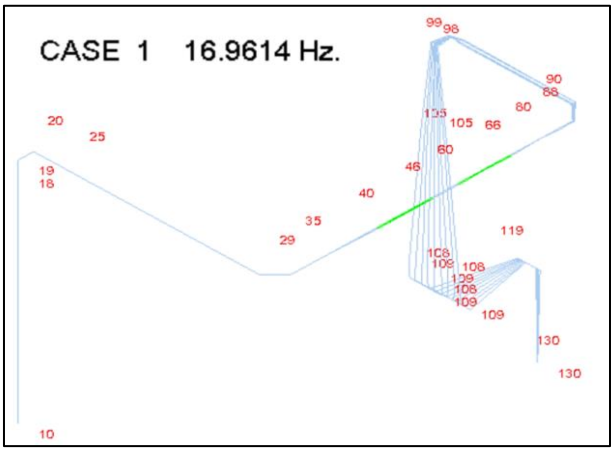

Figure 5: Mode shape for 16 Hz frequency (modified support)

In order to achieve above stated 14 Hz fundamental natural frequency in the piping system, some supports are added and modified at the nodes as en-circled in Figure 4. It can also be observed that the fundamental natural frequency of the piping system (Figure 5) is 16.9 Hz, thus the piping system under study is considered as stiff piping.

Conclusion

Post analysis it can be stretched upon that the effect of FIT in piping systems cannot be ignored and in order to ensure safe operation of piping systems and process plants vibration studies vis-à-vis screening of FIT in flow induced vibration prone lines to be carried out and mitigated to avoid any fatigue failure, thus ensuring safe operation of process plant.

In gas processing, refining and petrochemical plants, it is the joint responsibility of the process and piping engineers to verify the occurrence of vibrations due to FIT.

Nomenclature

ρ = density (kg/m³)
v = fluid velocity (m/s)
μ_{gas} = fluid dynamic viscosity (Pa-s)
L_{span} = maximum un-supported length (m)
D_{ext} = External pipe diameter (mm)
T = Nominal wall thickness of pipe (mm)

Acknowledgements

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References

[1] "Guidelines for the avoidance of vibration induced fatigue failure in process pipework," Energy Institute, 2nd edition 2008.
[2] CAESAR-II Version 12, Hexagon, 2019.