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Innovative numerical fatigue methodology for piping systems: qualifying Acoustic Induced Vibration in the Oil&Gas industry

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Abstract

Acoustic Induced Vibration (AIV) refers to the high acoustic energy generated by pressure-reducing devices that excite pipe shell vibration modes, producing excessive dynamic stress. Analysis of this risk is an important part of Asset Integrity Management systems as AIV can cause catastrophic piping failure. Existing guidelines address this risk through an analytical assessment. However, these methodologies are not fully known and input parameters are limited. Some limits to the guidelines are pointed out with recommendations to improve them.

The approach presented for identifying AIV damage is based on a dynamic stress evaluation at pipe discontinuities (welded connections and supports). This evaluation is performed through a fluid-structure coupling Finite Element Analysis. Pressure fluctuations inside the pipe are predicted and coupled with a pipe structural analysis. This methodology is provided with its validation through measurement on an actual AIV field case, corresponding to a crack initiation due to AIV on an FPSO flare network tail pipe.

To conclude the paper, the method is then applied to quantitatively assess the mitigation actions' efficiency on an actual case. Different solutions have been individually tested to end up with a final solution that reduces the damage to acceptable levels in the most cost-effective manner.

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Keywords: AIV ; Acoustic Induced Vibrations ; Oil&Gas Piping ; Piping fatigue ; Acoustic Fatigue

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1. Introduction

Acoustic Induced Vibration (AIV) in piping systems refers to high acoustic energy that excite pipe shell vibration modes, producing excessive dynamic stress that could lead to pipe failure.

The source of this high acoustic energy is a pressure-reducing device (valves, restricted orifices…) with a high pressure drop and important mass flow rate. In such devices, the amount of energy dissipated is quite high and even if most of the energy is converted to heat, a significant part is converted to sound or pressure waves that will excite the pipe wall. This broadband and high-frequency excitation propagates through the pipe, amplified by transverse acoustic pipe modes, and comes to excite the pipe's shell vibration mode. While running along straight pipes, the impact of vibration is limited due to axisymmetry of the pipe shell mode shape. However, when the excitation comes to a non-axisymmetrical discontinuity (branch, small bore, support…), vibrations are amplified, leading to high dynamic stress that can cause fatigue failure of the pipe. As these vibrations occur at high frequencies, i.e. with a high fatigue cycle rate, fatigue failure occurs within a few minutes to a few hours.

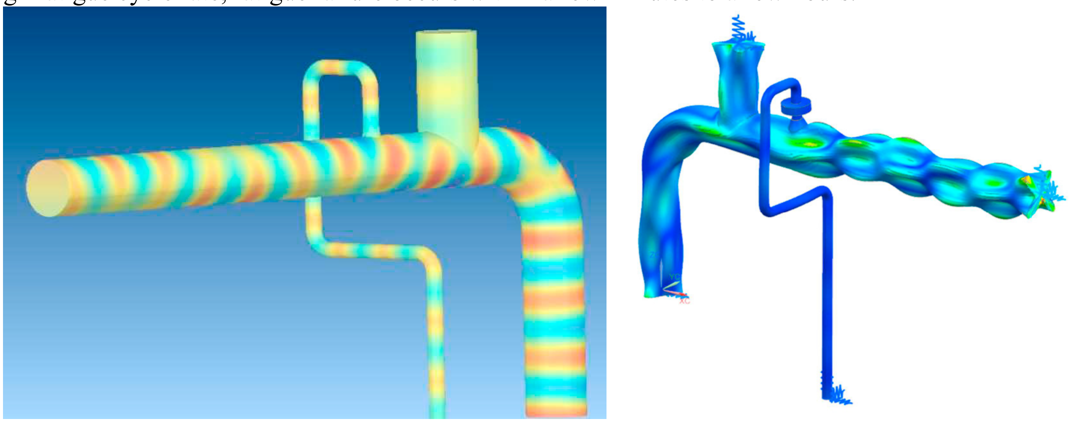

Fig. 1. (a) Fluid Acoustic mode; (b) Pipe shell mode.

The major risk associated with this phenomenon for offshore plants is related to flare systems. Blowdown valves, restricted orifices and pressure safety valves encountered in these systems are usually with large pressure drops and important mass flow rates. As the acoustic energy generated by these devices propagates downstream with small attenuation, the whole flare network is impacted by the risk of AIV failure. As flare systems are gas associated systems and safety-related, pipe failure would have catastrophic consequences. Therefore, assessing and controlling the AIV risk is an essential part of Asset Integrity Management.

AIV has been an on-going research subject since initial publications in the late 70s and methodologies have been developed to help engineers assess this risk. The dominant methodology for the Oil & Gas industry is that published by the Energy Institute. In its guidelines, the Energy Institute addresses this risk through an analytical assessment methodology. This tool is very efficient in performing a quick screening of large numbers of pipes. However, when it comes to mitigation measures, the limited number of input parameters used to quantify the Likelihood of Failure (LOF) reduces the range of possible mitigation measures, since the efficiency of certain mitigation measures are not LOF calculation parameters and therefore cannot be assessed. The LOF is calculated with the following formula:

$$LOF = -0.1303\ln(N) + 3.1 \text{, N representing the number of cycles before failure} \quad (1)$$

To overcome this limitation, a new detailed Finite Element methodology has been developed using coupling between fluid and structure, making it possible to predict dynamic stress for complex piping models. This methodology is introduced in the next chapter and includes validation through measurements on an actual AIV field case.