Steady-State Response of a Piping System Under Harmonic Excitations Considering Pipe-Support Friction With Variable Normal Loads

Dynamic loads in piping systems are mainly caused by transient phenomena generated by operating conditions or installed equipment. In most cases, these dynamic loads may be modeled as harmonic excitations, e.g., pulsating flow. On the other hand, when designing piping systems under dynamic loads, it is a common practice to neglect strong nonlinearities such as shocks and friction between pipe and support surfaces, mainly because of the excessive cost in terms of computational time and the complexity associated with the integration of the nonlinear equations of motion. However, disregarding these nonlinearities for some systems may result in overestimated dynamic amplitudes leading to incorrect analysis and designs. This paper presents a numerical approach to calculate the steady-state response amplitudes of a piping system subject to harmonic excitations and considering dry friction between the pipe and the support surfaces, without performing a numerical integration. The proposed approach permits the analysis of three dimensional piping systems, where the normal forces may vary in time and is based in the hybrid frequency–time domain method (HFT). Results of the proposed approach are compared and discussed with those of a full integration scheme, confirming that HFT is a valid and computationally feasible option. [DOI: 10.1115/1.4029403]

Keywords: piping harmonic response, harmonic excitations, support friction, HBM, HFT

Introduction

Some piping systems are subject to dynamic excitations due to process conditions and installed equipment. An example of dynamic excitation that may be properly modeled as harmonic is the excitation produced by the pulsating flow present in gas lines. In this kind of flow, pressure waves that travel within the pipe produce dynamics forces on elbows and tees. This condition is relatively common in nuclear and petrochemical industries handling oil, gas, and multiphase fluids, where there is reciprocating equipment, e.g., reciprocating compressors, screw pumps, etc.

In the design stages of such systems, a dynamic stress analysis is generally required, taking into account the external harmonic excitations, in order to verify that code regulations are satisfied. The main idea behind dynamic analysis in piping systems is to reduce the displacement amplitudes in the structure and therefore the dynamic stresses. This is done normally by modifying support types and support locations, introducing dampers or vibrations isolators, and in extreme cases, it requires the piping layout redesign.

Nowadays, it is a common practice to estimate the harmonic response of piping systems considering linear behavior, thus neglecting strong nonlinearities that can be present, e.g., pipe-support dry friction, shocks (between adjacent pipes and between pipe and supports), unidirectional supports, gaps, etc. In fact, to the authors’ knowledge, commercial piping stress programs that permit calculation of the dynamic response are formulated under this hypothesis.

If linear behavior is assumed, harmonic analysis is straightforward for a forcing frequency and not specially demanding in computational cost, since time integration of the equations of motion is unnecessary. On the contrary, if any nonlinearity is taken into account, a time integration of the equations (with explicit or implicit methods) is required until the system achieves a steady-state solution. This normally demands dealing with initial conditions, selection of appropriate numerical methods and time steps, intensive computations, and long calculation times. The considerable increase in calculation time, when using time integration methods, is related to the small time steps required for determining amplitudes with adequate accuracy.

One of the most common nonlinear phenomena presented in structures corresponds to friction between interfaces. Coulomb friction or the dry friction model is used in mechanical systems associated with friction because of its simplicity and effectiveness above other models proposed by researchers in the past [1–3]. Dry friction has been studied in some detail in structures and machinery, in general, however, very few works have focused their attention on its influence over the behavior of piping systems. This may be explained by the fact that neglecting friction between pipe and supports normally produces higher vibration amplitudes, thus being a conservative approximation. However, for some applications (e.g., large pipe diameters), this approximation may result in overestimated amplitudes, thus misleading designers, who translates into excessive cost in system construction.

One of the first works that incorporates friction in piping supports was done by Sobieszczanski [4], who devised a...