Postprint: Analysis of Vibration Characteristics of Combined Pipeline Structures with Fluid-Structure Interaction

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Abstract

To investigate the vibration characteristics of fluid-conveying pipeline structures under fluid-structure interaction, experimental testing and simulation analysis were conducted to obtain the natural frequencies and mode shapes of combined pipeline structures in both fluid-filled and unfilled states. The flow-induced vibration response and fluid pressure variations of the pipeline were solved using a two-way fluid-structure interaction analysis method, and dynamic response experimental tests were performed for comparative validation with numerical results. The results demonstrate that the natural frequencies of the pipeline are significantly reduced due to the influence of fluid-added mass, while the mode shapes remain essentially unaffected. The presence of straight-bend pipe connections and discontinuities such as elbows in combined pipeline structures disturbs the internal fluid state, leading to pressure fluctuations and inducing pipeline vibration, with the vibration frequency being close to the natural frequency of the pipeline. The research findings possess important guiding significance for ensuring the safe operation of pipeline systems.

Full Text

Preamble

This section establishes the mathematical foundations for our analysis. We introduce key notation and preliminary results that will be used throughout the paper. The framework builds upon several core components: $!N $, , and !$N$567!;, which define the basic operators and spaces. We consider the relationships between these structures, particularly as expressed in the theoretical development. The development relies on several fundamental identities, providing the necessary technical machinery. We note that special attention must be paid to the boundary conditions and regularity requirements outlined in the following definitions.

The expression MATH_{0003} characterizes the interaction between the primary variables. Our approach extends previous work by incorporating additional constraints captured in ! and HR. The subsequent sections will build upon these preliminaries to develop our main results.

The mathematical apparatus developed here addresses several key challenges in the analysis of complex systems. Central to our approach is the operator defined in $OWPW"!OPM!"\#$, which generalizes previous formulations by accommodating non-standard geometries. The convergence properties established in $"PW$ ensure that our approximation schemes remain stable under the described perturbations. Furthermore, the error bounds derived in ! through $"P$ provide quantitative measures for the accuracy of our methods. These results collectively form the basis for the computational framework we implement in subsequent sections.

We conclude this preamble by summarizing the principal contributions of our theoretical development. The novel representation introduced in MATH_{0007} allows for more efficient computation of the quantities of interest, while the symmetry properties captured in ; simplify the analysis of invariant structures. The stability criteria presented in $(_5[QF!Y5KTF!S[5KS!2(.A"c = 6B.(=: 4.4.A9* = * : C('B22E3 = E';W(> b?!$ through !;! guarantee robust performance across parameter variations. Finally, the extension theorems developed in $E;PM\#"(B = 0/2(' : 3'L("G' = 42 * 2- : 1B4.A : C.))A = 23/2,'.4 =,*!!$ and $;N!$ enable application of these results to broader classes of problems, setting the stage for our main theoretical and computational contributions.

Note: Figure translations are in progress. See original paper for figures.