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The Research Progress on Vibration Analysis of Liquid Filled Pipeline

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Abstract: ***Pipeline plays an extremely important role because of its wide range of applications in many industrial fields. However, the vibration of the pipeline has a negative impact on industrial production and residents' lives. In this paper,the current research progress is reviewed, through summarizing the research results of many scholars, introduced many kinds of fluid-structure interaction vibration analysis methods of liquid filled pipesin detail and the future development trends are analyzed and predicted.***

Keywords: liquid filled pipeline; vibration analysis; fluid-structure interaction; research progress

1. Introduction

The fluid flow in liquid filled pipes caused by the dynamics of pipeline vibration has a broad background in engineering applications, its research results can be directly used for submarine pipeline engineering, power engineering, water biological engineering, aerospace engineering and nuclear industry. The harmonic resonance caused by fluid-structure interaction will not only cause serious damage to the pipeline system, but also produce a disturbance which is difficult to control.

Since Brillouin first observed the phenomenon of fluid induced pipe vibration in 1885, the study on the vibration of liquid filled pipeline has been studied for more than a centuryand has always attracted people's attention. In 1939, Bourrieres deduced the equation of motion of the liquid filled pipeline, which made people know more about the vibration of the cantilever pipe system. Based on Bourrieres' study, Paidoussis gave a penetrating exposition of the vibration of the pipeline and pointed out two kinds ofnotableinstability phenomena-Divergence instability and flutter instability. Nearly half a century, due to the rapid development of science and technology and the deepening of understanding, people have made great progress in the analysis of liquid filled pipe vibration.The main research contents include: liquid filled pipes linear and nonlinear fluid solid coupling vibration model; linear and nonlinear fluid solid coupling vibration analysis method; experiment research of flow pipe vibration coupling study on vibration control of the pipeline.This paper mainly elaborates the analysis method of fluid-structure interaction (FSI) vibration of pipe.

2. Modeling of Pipeline System

The vibration analysis of liquid filled pipeline depends on its model. For the modeling of pipeline system，there are two kinds of basic model-beam model and cylindrical shell model. In engineeringAccording to the needs of the application, the structural characteristics analysis, numerical calculation and analysis, dynamic stability analysis are carried out on the basis of the model.

2.1 Structural Characteristics Analysis

In the practical application of the pipeline, the pipe diameter is much smaller than the length of the pipeline. The analysis of the structure of the liquid filled pipeline will affect the natural frequency and wave velocity of the pipeline. In 2008, Tijsseling analyzed the Skala expansion water hammer theory, the classic water hammer theory describes the spread of fluid filled pipes pressure wave, the theory correctly predicts the cycle limit of pressure wave, but it cannot accurately calculate scattering damping and wave fronts, especially in actual measurement, compared to standard corresponding to the calculation of water hammer damping and large scattering is obtained. This is because the standard of water hammer by the way of theory does not take into account the unsteady wall material damage, non-elastic characteristic factors, acoustic radiation etc.

On the basis of the 4- equation model, Skalak used the Laplace transform method and the Fourier transformmethod to obtain the scattering relation of the free vibration of the liquid filled pipeline,and the following conclusions are obtained by the asymptotic method:the wavelength of wave front is proportional to the cube root of time; Because of the radial vibration of liquid and pipeline, the pressure near the peak of the wave front may exceed the classical Joukowsky value.

The effect of initial disturbance is studied on the basis of the simplified Skalak model by Simpson et al. The research shows that, the initial disturbance produces two waves, while the initial slow wave is the main disturbance.In 2008, he tested the conclusion and the results were in agreement with the theory.

Because of the difference between the straight pipe and the physical structure, the vibration characteristic is different from the straight pipe. Based on Tentarelli modeling ideas，Tijsseling put straight pipes and a bent pipe in the same pipeline system for research，then he set up two kinds of pipe models, the straight pipe is solved in frequency domain, and the whole bendingmodel is solved by using the model of pipe bendingwithout dividing unit. The influence factors of the fluid structure coupling vibration are analyzed by changing the radius of curvature and bending angle. The analysis results show that, The smaller the bending angle

and the radius of curvature, the lower the intensity of the spectral curve, the weaker the coupling vibration.

2.2 Analysing Method

The analysis method of FSI vibration of liquid filled pipeline has formed a perfect theoretical system.Due to the complexity of the vibration problem of the liquid filled pipeline, it is difficult to consider the problem from one theoretical point of view, the problemcannot solve accurately. At present, there are many methods to analyze the dynamic characteristics of liquid filled pipeline, and the emphasis of the research is different, mainly from the time domain, frequency domain and so on. In recent years, the research on fluid solid coupling vibration of liquid filled pipeline, based on the extension of the traditional analysis method, focuses on the high accuracy and reliability of numerical calculation method.

Li and Fanused the characteristic line method to analysis the 14- equation and 4- equation model.In order to improve the accuracy of the numerical analysis, the traditional method of characteristics of 14- model was improved,based on the determination of the time step and the number of segments, an adaptive network encryption method is proposed to modify the spatial step size to better capture the fluctuation of the liquid pressure at the boundary. 4- equation model numerical solution to the progress of the problem in 1990s has been well solved by Yang. He showed that, on the one hand, when using the characteristic line method to carry out the numerical calculation of the pipeline, the accuracy and the efficiency of the numerical calculation of the pipeline according to the minimum beam segment, on the other hand, determine structural damping effect on the response of the pipeline system, it can fast attenuation of liquid pressure response and pipeline vibration response in high frequency or high frequency harmonic component and low frequency component amplitude, damping effect is far greater than the friction between the liquid and pipe, coupling vibration increase pipeline structure damping can effectively inhibit the infusion line.

Su et al flow for moving boundary problems of solid coupling analysis, based on the quasi solid two stepmethod, he put forward a new finite element mesh updating method,the fluid grid as the quasi solid with specified displacement boundary conditions for elastic analysis, according to the calculated, using the "PSS" method, gives the principal shear strain larger unit with larger Young's modulus of the material non solid motion analysis, update the ideal grid. The new method has a strong adaptability, can significantly reduce the distortion of the unit, so that the grid to maintain good performance, suitable for large deformation of the FSI problem in the grid update calculation.

In the light of the characteristic ofnoise space transmission pipeline system, Ke et al combining the finite element method and impedance analysis method in pipeline system, in the field of pipeline system source excitation, on the basis of displacement method, the mechanical excitation of the pipe wall, the acoustic excitation of the medium, the structural damping , the elastic support and the elbow are considered, the vibration model of pipeline structure under external excitation force or vibration is established. It is characterized by using 3 translational displacementand 3 rotational displacementsof each element node as unknowns.Using the beam element, the mass element, the elastic element and the frequency characteristics of the known dynamic stiffness or impedance to simulate the pipeline structure of the vibration protection measures, the equation of motion is established to solve the dynamic response of the system.

Sun et al look the actual pipeline system which includes the equipment and accessories as the research object, in this object, he considered the interaction between internal fluid medium and pipeline structure, and established the integrated finite element model of liquid pipe coupling vibration analysis of the dynamics of liquid pipe noise.According to the model, the finite element model of the pipe system, such as the pipe unit, the spinal canal unit, the elastic concentration unit and the mass concentration unit, is established.

Transfer matrix method is one of the most effective methods for modal analysis of chain structures.Compared with the finite element method, one of the most important advantages of the transfer matrix method is that it can be realized on computer,the dimension of the system matrix increases with the increase of the grid nodes,in the transfer matrix method, the dimension of the system matrix is a constant, which is the same as the number of state parameters that describe the vibration of the system,so the calculation is much smaller than the finite element method.Li through the Fourier transform, the 4- equation model of the transverse vibration of fluid filled pipeline to transform from the time domain equations, and direct derivation,the relationship between the coordinates of the space and the frequency is obtained,the transfer matrix method is used to calculate the transverse vibration of the fluid pipeline, and the corresponding frequency domain of the liquid filled pipeline can be solved directly. Li Baohui et al based on the finite element theory and the Hamilton variational principle, considering FSI effect, derived the governing equation of transverse vibration of the current carrying pipe, And used the Galerkin method to solve the equation, the pipeline along the axial direction is discretized into several units,the dynamic equations of each pipe element are obtained.According to this equation, we can calculate the vibration frequency of fluid-structure interaction.The finite element transfer matrix method does not increase the dimension of the matrix with the increase of the number of partition elements.In the case of self-excited vibration, the dimension of the transfer matrix is kept constant by 6 dimensions, the calculation is simple, and the accuracy can be maintained.

BaoRidong, JinZhihao et alstudied on the dynamic characteristics of a general support flow pipeline with linear spring and torsion spring constraintunder the action of flow velocity, pressure pulsation, pipeline lateral bending caused by additional axial force and nonlinear harmonic motion of the base. The Galerkin equation is used to expand the motion equation in the modal space, andthe nonlinear dynamic response of the system is studied.

Stangl M et al cantilever elastic pipe as the research object, using the Newton equilibrium equation and the Hamiltion criterion derived for a class of nonlinear ordinary differential equations, the equation is introduced to approximate arbitrary order reduction method, to reduce the dimension of nonlinear equations.

Jin et al, based on the assumption that the mode shape function of the beam at both ends is assumed, derived an analytical expression for the critical velocity of both end supported flow pipeline.By using the critical velocity formula, the vibration characteristics and stability of both ends of the support beam under torsion spring are studied.

S.V.Sorokin, N. Olhoff, O. A. Ershova et al. Focused on the study of the vibration of liquid filled pipes from the angle of energy transfer, and analyzed the effective range and the parameters of energy transfer.

3. Research Prospect

For a long time, the domestic and foreign researchers have focused on the study of the coupled vibration of liquid filled pipeline, and some scholars have done the research on the vibration of pipeline under the condition of external excitation.With the development of pipeline application, the research on the vibration characteristics of the space motion pipeline has strong academic value and application value.

The space motion of the liquid in the tube in addition to pipeline and pipeline interactions, it will be with the external bearing movement and interaction, external bearing sports including transverse and radial shrinkage or stretching.Accordingly, the pipeline system will be subjected to lateral and longitudinal vibration under the condition of motion.There is a big difference between the vibration model of the pipeline and the vibration model of the liquid filled pipeline.On the other hand, the liquid filled pipe in different positions of the space, the vibration mode is different from the outside of it shows a very strong complexity, the corresponding system analysis method should be established according to the vibration of the space motion pipeline

References

[1] Paidoussis M P, Issid N T. Dynamic stability of pipes conveying fluid[J]. Journal of sound and vibration, 1974, 33(3): 267-294.
[2] Bourrières F J. Sur un phénomèned'oscillation auto-entretenueenmécanique des fluidesréels[M]. E. Blondel La Rougery, 1939.
[3] Païdoussis M P. Oscillations of liquid-filled flexible tubes [D]. 1963.
[4] Paidoussis M P. Flow-induced instabilities of cylindrical structures[J]. Applied Mechanics Reviews, 1987, 40(2): 163-175.
[5] Tijsseling A S, Lambert M F, Simpson A R, et al. Skalak's extended theory of water hammer[J]. Journal of sound and vibration, 2008, 310(3): 718-728.
[6] Bergant A, Simpson A R, Tijsseling A S. Water hammer with column separation: A historical review[J]. Journal of fluids and structures, 2006, 22(2): 135-171.
[7] Tijsseling A S, Lambert M F, Simpson A R, et al. Skalak's extended theory of water hammer[J]. Journal of Sound & Vibration, 2008, 310(3):718-728.
[8] Li Yanhua, Liu Gongmin, Ma Jun. Research on fluid-structure interaction in fluid-filled pipes[J]. Journal of Vibration and Shock, 2010, 29(6):50-53.
[9] FanShijuan, Yang Chao. Numerical calculation of fluid-structure coupling vibration of a water pipeline[J]. Noise of Vibration Control, 2009, 28(6):56-59.
[10] Ke Bing, XieZhiqiang, LvZongqiang. Synthetic FEM for vibration-acoustic transmission of spatial pipe system[J]. Noise and Vibration control, 2009, 29(1):49-53.
[11] Sun Yudong, Wang Suoquan, Liu Zhongzu, et al. Unified finite element method for analyzing vibration and noise in 3-D pipeling system with liquid-pipe coupling[J]. Journal of Vibration Engineering, 2005, 18(2):149-154.
[12] Li Yanhua, Liu Mingong, Zhang Yinbao. Transfer matrix method in frequency domain for lateral vibration of liquid-filled pipes[J]. Journal of Vibration Engineering, 2009, 22(6):597-602.
[13] Li Baohui, Gao Hangshan, Liu Yongshou, et al. The finite element-transfer matrix method for calculating natural frequencies of pipe conveying fluid[J]. Structure & Environment Engineering, 2009, 36(3):39-44.
[14] BaoRidong, JinZhihao, Wen Bangchun. Analysis of nonlinear dynamic characteristics of commonly supported fluid conveying pipe[J]. Journal of Vibration and Shock, 2008, 27(7):87-90.
[15] BaoRidong, Wen Bangchun. Dynamic response analysis of submarine free spanning pipeline[J]. Journal of Vibration and Shock, 2007, 26(8):140-143.
[16] Stangl M, Gerstmayr J, Irschik H. An alternative approach for the analysis of nonlinear vibrations of pipes conveying fluid[J]. Journal of Sound & Vibration, 2008, 310(3):493-511.
[17] JinJiduo, Yang Xiaodong, Zou Guangsheng. Stability and critical flow velocity of supported pipes conveying fluid[J]. Journal of Mechanical Engineering, 2006, 42(11):131-136.
[18] Sorokin S V, Ershova O A. Analysis of the energy transmission in compound cylindrical shells with and without internal heavy fluid loading by boundary integral equations and by Floquet theory[J]. Journal of Sound & Vibration, 2006, 291(1-2):81-99.
[19] Sorokin S V, Olhoff N, Ershova O A. Analysis of the energy transmission in spatial piping systems with heavy internal fluid loading[J]. Journal of Sound & Vibration, 2008, 310(4–5):1141-1166.