 Finite Element Analysis and Experimental Study on Elbow Vibration Transmission Characteristics

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Abstract. Pipeline system vibration is one of the significant factors leading to the vibration and noise of vessel. Elbow is widely used in the pipeline system. However, the researches about vibration of elbow are little, and there is no systematic study. In this research, we firstly analysed the relationship between elbow vibration transmission characteristics and bending radius by ABAQUS finite element simulation. Then, we conducted the further vibration test to observe the vibration transmission characteristics of different elbows which have the same diameter and different bending radius under different flow velocity. The results of simulation calculation and experiment both showed that the vibration acceleration levels of the pipeline system decreased with the increase of bending radius of the elbow, which was beneficial to reduce the transmission of vibration in the pipeline system. The results could be used as reference for further studies and designs for the low noise installation of pipeline system.

1. Introduction

The elbow not only has the function of changing the flow direction of the transmission medium, but also plays an important role in adjusting the installation position. When the fluid flows past through the elbow, the velocity and pressure will be changed greatly, resulting in separation and reflux. The flow will definitely become very heterogeneous, leading to the production of vibration. Pipeline system vibration transmission characteristic is affected by many factors, such as elbow bending radius, fluid flow, Mach number, the movement direction of the fluid, etc. In this research, we mainly aimed at observing the changes of elbow vibration transmission characteristics following the variation of bending radius. Furthermore, flow velocity, as a major factor, was also taken into consideration in the test part.

In the aspect of elbow structural parameter, Liu et al. [1] analysed the variation of the strain and amplitude in the straight tube through simulation and experiments, and summarized the vibration characteristics of the straight pipe section of the single-bend system. Although they considered some influence of elbow structure parameters in this system, the keystone of their research was the vibration characteristics of the straight pipe section. Zhang et al. [2] studied the effect of elbow wall thickness on the natural frequency of pipeline system, and concluded that the amplitude of the system decreased with the increase of wall thickness. However, the function of elbow bending radius was not considered. On the basis of the research above, researchers took the bending radius and fluid-structure coupling into account, and the results showed that bending radius had a large effect on high order natural frequency [3]. Another study illustrated the elbow bending radius from 60°- 90° bend had major influence on amplitude through the finite element method [4]. This study was of some theoretical value. The finite element model of elbow was established by Lu et al. [5], and the elbow vibration characteristics under three different flow velocities were analysed. The influence of fluid excitation was considered, but the influence of elbow bending radius was not taken into account.
In the aspects of hydrodynamics, researchers has established a fluid-solid coupled mathematical model of the 2-d single elbow pipeline system with cavitation phenomenon, and the model has been verified by experiment [6, 7]. The theoretical calculation is in good agreement with the experimental results. Yang et al. [8] simulated elbow vibration that caused by different flow velocities fluid, and illustrated the relation between fluid velocity and elbow vibration through the simulation results. But the function of bending radius was neglected. From another perspective, researchers found out the change rule and influence factors of elbow pressure field and velocity field by adopting the method of experimental contrast, and provided a theoretical basis for the future research of the elbow [9, 10].

At present, there is lack of research on the influence of elbow parameters on the vibration transmission characteristics. In this paper, the changes of bending radius elbow vibration transmission characteristics under different working conditions are analysed through simulation calculation and experiment, which will provide reference for the low noise installation and design of pipeline system.

2. Simulation
Take DN80 type pipe into consideration and establish finite element model of the elbow. The diameter was set to 88.4 mm and wall thickness was set to 4 mm. The required elbow model was simplified to shell structure and created in the part module of ABAQUS. Then the material and cross section properties of the model were defined in property module. The material parameters of the model were shown in table 1. And then Load module and boundary conditions were defined in the load module. In the left side line, there was a harmonic exciting force. The finite element model of the pipeline system was shown in figure 1. From left to right, there are different elbow finite element models of which the bending radius was 0, 1, 2, 3 times the size of the pipe diameter. These models were shown in figure 2: (a)-(d).

![Figure 1. Pipeline system finite element model.](image)

| Material parameters | Elastic modulus (pa) | Density (kg/m³) | Poisson ratio |
|---------------------|---------------------|----------------|--------------|
|                     | 1.47×10¹¹           | 7300           | 0.25         |

![Image](image)

**Figure 2. Different bending radius elbows finite element model.**

Figure 3, 4 and 5 presented the vibration acceleration level spectrums of four different bending radius elbows under the x, y and z axial unit excitation force that applied to the left end of the pipeline system finite element model. The frequency range was 0-500 Hz, and the unit of vibration acceleration level was dB (the reference level was 10⁻⁶).
As seen in figures above, the four vibration acceleration level curves of elbow shown a trend of decreasing at the 0-250 and 400-500 Hz frequency bands, so we could say that in both frequency bands, elbow bending radius had a great influence on the vibration transmission characteristics. However, in 300-400 Hz frequency band, the peaks of four curves were similar. Consequently, elbow bending radius made little difference for the vibration transmission characteristics in that frequency range. From figure 3, we could draw the conclusion that the bending radius had the greatest influence on the vibration transmission characteristics of the pipeline system under the X-axis excitation. 3 times bending radius vibration acceleration level was lowest than other elbows. Therefore we draw the conclusion: the increase of bending radius contributed significantly to reducing the vibration transmission in the pipeline system to some extent. Though the vibration acceleration levels under mechanical excitation in different directions have been proved by simulation analysis, further researches conducted in the experimental part were necessary.

3. Experiment research
Based on the results of finite element analysis above, further experimental research was taken at the last part of the paper. We took the flow velocity into consideration and explored the vibration of different bending radius elbow under different flow velocity. From left to right, there were four kinds of elbow which bending radius were 0, 1, 2, 3 times the size of the pipe diameter and shown in figure 6.
Figure 6. Four types of bend pipes.

The bend pipe vibration was measured with a three-way accelerometer mounted on both ends of the flange shown in figure 7.

Figure 7. The bend pipe to be tested.

The comparison results of the horizontal, axial and vertical vibration acceleration level were shown in figure 8(a)-(f).
Figure 8. The corporation curve of the acceleration at the downstream of the elbow is with the change of velocity.

It is shown by these figures that the total vibration acceleration level in any direction of the bending tube increases with the increase of velocity when the diameter ratio is certain. When the bending radius is 0 times the size of the pipe diameter, the total vibration level of the bend in any direction, upstream region or downstream region, is almost the maximum relative to other diameter ratios. Moreover, the difference becomes larger and larger with the increase of flow velocity. When the bending radius increases from 1 to 3 times the size of the pipe diameter, the total vibration level in any direction of the elbow is almost the same, only small gradually decreasing. For the upstream and downstream of the elbow, the acceleration of the vertical vibration is generally the maximum, the axial second and the horizontal minimum. The vertical vibration of the elbow is consistent with different diameter ratio. The total axial vibration is more consistent when the diameter ratio is larger than 0. But only when the flow velocity is greater than 5m/s, it is slightly higher in the downstream region than in the upstream region. When the diameter ratio is 0, the result is opposite. For the horizontal vibration acceleration level, it is a little bit higher in the upstream region than in the downstream region. On the contrary, it is slightly lower in the upstream region than in the downstream region in other elbow bending radius.

4. Result
Finite element method in this paper can simulate the vibration response of the elbow under different excitation characteristics, but greatly depends on the accuracy of finite element model. Sometimes the model is not accurate enough which will have an impact on the simulation results. In the calculation process, the size of the mesh will also affect the accuracy of the calculation. In the finite element software, how to establish accurate elbow finite element model still needs further complement, improve and verify.

The results of the test show that the replacements of large bending radius have certain effect on tube fluid in irregular flow. However, the modification of the single bend does not affect the vibration of the whole piping system. Therefore, in practical engineering applications, it is possible to consider minimizing the number of elbows and optimizing the radius of the elbow composition in the piping system. At the same time, it is suggested that the bending radius of metal pipe shall be no less than 2D (D is 0 of outer diameter of pipe). If there are some difficulties to install the components, the bending radius shall be less than 2D, but the minimum shall not be less than 1.5D.

5. Reference
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