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Research Article

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Simulation study of gas transmission pipeline leakage signal characteristics

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Abstract Gas pipeline leaks not only lead to waste of resources but also seriously affect the safety of people's lives. In order to detect pipeline leaks more accurately, it is necessary to know enough about the leak characteristics. To this end, numerical simulations were carried out for a pipeline leak with a diameter of 50 mm, and the leak velocity, displacement and vibration frequency were studied at leak pressures of 0.01 MPa, 0.3 MPa and 0.6 MPa and leak orifices of 5 mm, 10 mm and 20 mm. The results show that the leakage velocity increases with the increase of pressure, but the magnitude of increase gradually decreases; the vibration displacement magnitude and frequency increase with the increase of leakage orifice diameter, and increase with the increase of leakage pressure.

Keywords pipeline ;leakage; fluid-solid coupling

1. Introduction

Pipeline transportation is an important mode of transportation and has an extremely wide range of applications. Gas pipelines play an important role in transporting natural gas in industry. The number of gas pipelines is huge, due to the long service life of the pipeline, the complex environment in which the pipeline corrosion, rust and other problems, which seriously affects the use and safety of the pipeline, once the natural gas leakage, light environmental pollution, serious explosion, a serious threat to the lives of the people and the safety of property. Therefore, timely pipeline leak detection is very important. Nowadays, pipeline leak detection means are mainly divided into outside the pipe detection methods, pipe wall detection methods, internal flow state detection method. Among them, acoustic emission detection method for the pipe wall detection method, with high sensitivity, high accuracy, detection speed, etc., so it is widely used in pipeline leak detection.

Many studies have also been conducted on the detection of pipeline leaks by acoustic emission techniques. To simulate acoustic emission generated by pipeline vibrations caused by leaks, A. Mostafapour et al. [1] used Donnell's cylindrical shell nonlinear theory to derive the equations of motion for simply supported boundary conditions and solved the equations of motion using the Galerkin method and the Runge-Kutta method. The results show that the continuous leakage source propagates waves in a wide frequency range of about 0-400 kHz. Jin Hao et al. [2] used the Möhring sound analogy applicable to high Mach number flow fields to simulate and calculate the aerodynamic noise during natural gas pipeline leakage, established a simulation model of natural gas leakage noise for different pressures and leakage orifice diameters, and obtained the relevant characteristics of its leakage sound source, and established a two-dimensional model of sound wave propagation in the pipeline based on this source, and concluded by comparing the simulation results with field tests that By comparing the simulation results with the field test, it is concluded that the ultra-low frequency band of the leakage sound wave can be propagated over a long distance and detected, which verifies the good prospect of the sound wave method in natural gas pipeline leakage detection. Yan Chengwen et al. [3] used the computational fluid dynamics method to calculate the gas pipeline leakage flow field, and used the Lighthill acoustic analogy method to simulate the characteristics of pipeline leakage sound source for leaky holes below 5 mm, and the results showed that the jet velocity at the gas pipeline leakage port exceeded the speed of sound, and the gas pipeline leakage sound source was dominated by quadrupole sound source, and the simulation method and results were verified through experiments.

Peng Wei et al. [4] conducted a numerical simulation study on the effects of the number of leak holes, leak hole size, location, and shape on the diffusion of leaks in buried pipelines, and concluded that the larger the leak hole the faster the diffusion rate. Wang Shaoxiong et al. [5] used numerical simulations to study issues such as the rate of gas diffusion in water at different leakage rates and water depths. Based on the VOF multiphase flow model and component transport model, Ji Hong et al. [6] conducted a numerical simulation study on the shock wave of a single-hole leak in a submarine gas pipeline and concluded that the effects of leak orifice diameter, leak rate and seawater flow velocity on the dynamic pressure of the shock wave are weakened sequentially. It can be seen that the simulation studies on gas pipeline leakage include above-ground and underground pipelines, but most of them are diffusion studies, and the simulation of acoustic emission signal of pipeline leakage is less. Therefore, this paper uses numerical simulation methods to study the effect of leakage pressure and leakage aperture on the acoustic emission signal of gas pipeline leakage.

2. Theoretical Basis

Gas pipeline leakage is a fluid-solid coupling model, in which the fluid process in the tube obeys the continuity equation, the momentum conservation equation and the energy conservation equation.

Continuity equation：

$$\frac{\partial p}{\partial t}+\frac{\partial}{\partial x_i}(\rho u_i)=0 \tag{1}$$

Conservation of momentum equation：

$$\frac{\partial}{\partial t}(\rho u_i)+\frac{\partial}{\partial x_j}(\rho u_i u_j)+\frac{\partial p}{\partial x_i}-\frac{\partial \tau_{ij}}{\partial x_j}-\frac{\partial \tau_{ij}^{-1}}{\partial x_j}=0 \tag{2}$$

Energy conservation equation：

$$\frac{\partial}{\partial t}(\rho u_i)+\frac{\partial}{\partial x_j}(\rho u_i E+u_j p)-\frac{\partial}{\partial x_j}(u_i\tau_{ij}+u_i\tau_{ij}^{-1})+\frac{\partial}{\partial x_j}(q_j+q_j^{-1})=0 \tag{3}$$

Where: u_i , u_j are the velocities of gas transport in the i and j directions (m/s), respectively; x_i , x_j are the distances of gas transport in the i and j directions (m), respectively; E is the total energy of the fluid micro-elements (J/kg); p is the gas pressure (Pa); q_j is the heat flux (J/s); t is the time (s); ρ is the gas density (kg/m^3); τ_{ij} is the viscous stress acting on the surface of the micro-elements τ component.

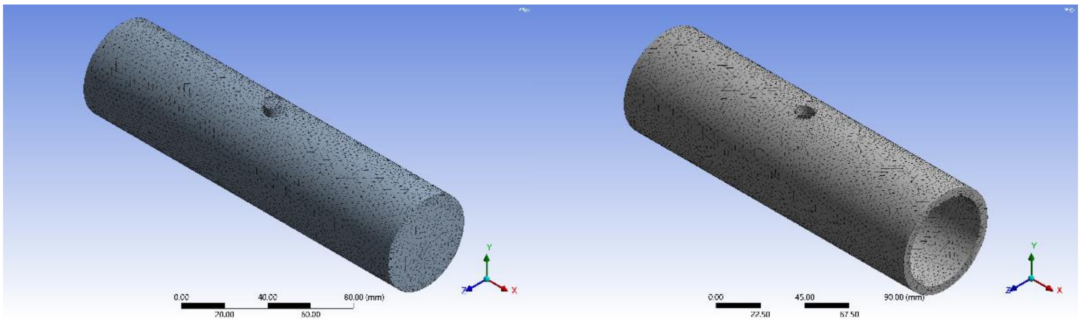
The equation of motion for the structural dynamic response of the pipe under fluid action is：

$$\frac{d^2 s}{d_t}\cdot M_s+\frac{ds}{d_t}\cdot C_s+s(t)\cdot K_s=F(t) \tag{4}$$

Where: Ms , Cs , Ks are the mass, damping, and stiffness matrices of the pipe structure as a whole, s is the structural vibration displacement vector, and F is the external excitation force of the pipe structure, i.e., the force generated by the fluid.

3. Experimental Design

ANSYS workbench software was used for this simulation study. The acoustic emission model of gas pipeline leakage uses a 200 mm long steel pipe with 50 mm inner diameter and 5 mm wall thickness. The leakage source in the middle of the pipe is designed as a circular hole with diameters of 5mm, 10mm and 20mm, and the pressure inside the pipe is 0.01MPa, 0.3MPa and 0.6MPa respectively. the inlet boundary condition is set as pressure inlet and the pressure is the set pressure inside the pipe; the leakage is set as pressure outlet and the pressure is atmospheric pressure. The calculation step length is 1000, and the total calculation time is 0.004s. The maximum mesh size is 3mm, and the generated mesh is as follows Figure 1.



(a) Fluid domain grid *(b) Solid domain grid*

Figure 1: Fluid domain and solid domain meshing

The fluid velocity monitoring point is set at the center of the leakage hole in the fluid domain during simulation, and the solid domain monitoring point is shown in Figure 2, and the monitoring data include displacement and stress.

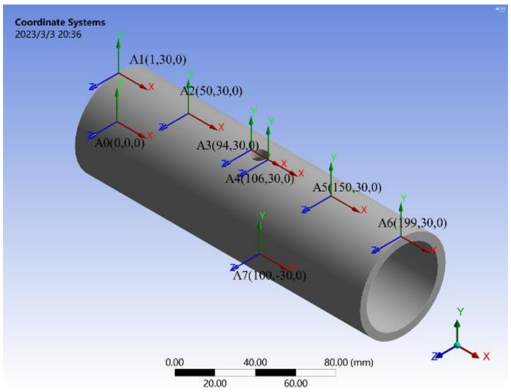
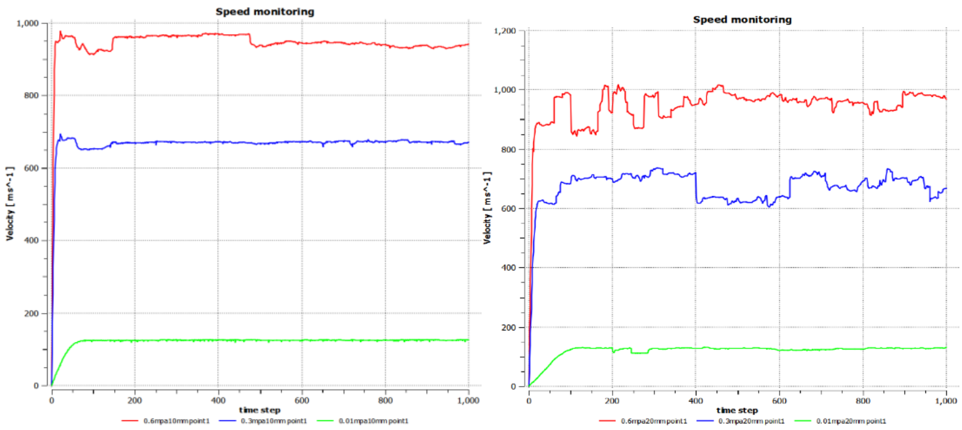


Figure2: Solid domain monitoring point setup

4 Results and Discussion

The leakage exit velocity curves of 10mm and 20mm leak holes under the leakage pressure of 0.6MPa, 0.3MPa and 0.01MPa are shown in Figure 3. It can be concluded that the overall leakage velocity at the same leakage pressure with different leak hole diameter is the same; with the increase in pressure the leakage exit velocity increases significantly, and with the increase in pressure the time to increase the leakage exit velocity from 0 to the highest velocity will become shorter; the larger the leak hole diameter the worse the stability of the leakage velocity.



(a) outlet velocity at different pressure under 10mm leak hole *(b) outlet velocity at different pressure under 20mm leakage hole*

Figure3: Leak outlet velocity monitoring curve at different pressures and orifice diameters

The leakage pressure of 0.6MPa, 0.3MPa, 0.01MPa, and the leakage orifice diameter of 5m, 10mm, and 20mm were simulated in two combinations, and the maximum leakage velocity data from the results were fitted using three spline interpolations, as shown in Figure 4. From Figure 4, the leakage curves of 5mm, 10mm and 20mm leak holes almost overlap, so it is concluded that the influence of the leak hole diameter on the maximum leakage velocity is very small; the maximum leakage velocity shows an increasing trend with the increase of the leakage pressure, but the increase rate gradually decreases.

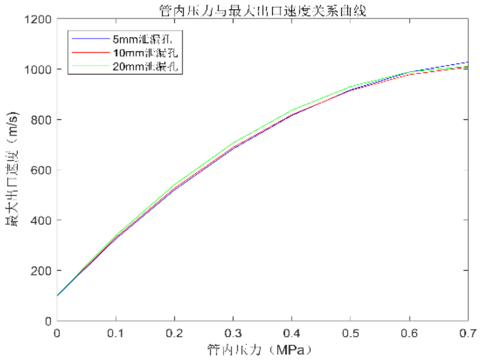


Figure4: Pressure in the tube and the relationship between the leak hole and the maximum leak rate curve

The x, y and z displacement data of monitoring point A3 on the leak model with a leak pressure of 0.3 MPa and a leak orifice diameter of 10 mm are integrated into one graph, as shown in Figure 5. It can be seen that the displacement amplitude in the y-direction is significantly larger than the displacement amplitude in the x and z-directions, i.e., the radial displacement amplitude is larger than the amplitude in the other directions when the pipe is leaking, so the radial displacement data can be used to extract the leak characteristics and locate the leak location more effectively in the actual pipe leak detection.

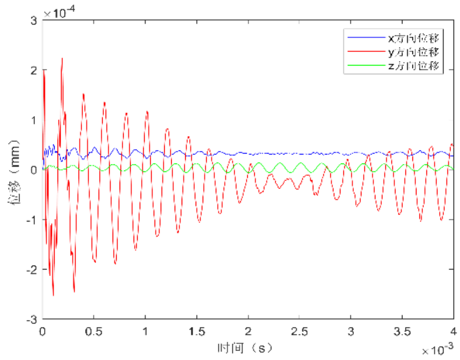


Figure 5: Comparison of displacement of monitoring point A3 in each direction at pressure 0.3MPa and 10mm hole

Figure 6 shows the radial displacement of the leak hole at 0.3MPa with 5mm, 10m and 20mm respectively, it can be seen that the larger the diameter of the leak hole, the larger the displacement amplitude at the same leak pressure. The vibration frequencies of 5mm, 10mm and 20mm are 4.75kHz, 5kHz and 5kHz respectively, and it can be seen from the frequencies that the larger the leak diameter is, the larger the vibration frequency is at the same leak pressure.

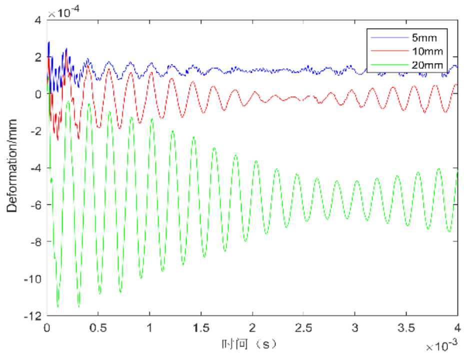


Figure 6: Comparison of radial displacement under different bore diameters at 0.3 MPa pressure in the pipe

Figure 7 shows the radial displacement data at monitoring point A3 when the leakage pressure is 0.01MPa, 0.3MPa and 0.6MPa, respectively, and the corresponding vibration frequencies are 4.75kHz, 5kHz and 5kHz, respectively, when the leakage pressure is 10mm.

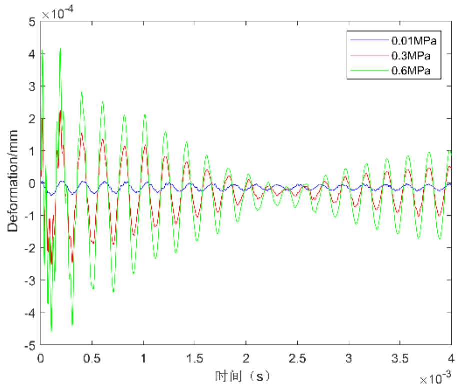


Figure 7: Radial displacement of monitoring point A3 of 10mm leak hole under different pressure

5. Conclusion

The leakage velocity and vibration characteristics of the pipeline under different conditions were studied by numerical simulation methods. The main conclusions are (1) the pipeline leakage velocity is mainly related to the leakage pressure, increasing with the leakage pressure, but the rate of increase in gradually decreasing. (2) The radial displacement amplitude is larger than the displacement amplitude in other directions when the pipeline is leaking, and monitoring the radial displacement is more conducive to detecting the pipeline leakage. (3) the same leak pressure, the larger the leak aperture displacement amplitude, the higher the vibration frequency. (4) In the same leak aperture diameter, the larger the displacement amplitude of the leak pressure, the higher the vibration frequency.

References

[1]. Mostafapour A., Davoudi S. Analysis of leakage in high pressure pipe using acoustic emission method [J]. Applied Acoustics. 2013, 74(3): 335-342.

[2]. Jin H., Zhang L. B., Liang W., et al. Simulation research on leak source characteristics and propagation mechanism for natural gas pipeline[J]. Acta Petrolei Sinica. 2014, 35(01): 172-177.

[3]. Yan C. W., Han B. K., Bao H. Q., et al. Research on acoustic source characteristics of gas pipeline leakage[J]. Technical Acoustics. 2017, 36(02): 110-115.

[4]. Peng W., Zhang J., Yuan H. Y., et al. Numerical simulation on influence of leakage hole on gas leakage in deep buried pipeline[J]. Journal of Safety Science and Technology. 2020, 16(10): 59-64.

[5]. Wang S. X., Li Y. X., Liu C. W., et al. Numerical simulation on leakage and diffusion characteristics of underwater gas pipeline [J]. CIESC Journal. 2020, 71(04): 1898-1911.

[6]. Ji H., Zhang G., Yang K., et al. Numerical Simulation on Single-hole Leakage Shock Wave of Submarine Natural Gas Pipeline[J]. Safety and Environmental Engineering. 2019, 26(03): 182-186.