Finite Element Simulation Analysis of Fluid Pipeline Leakage

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Abstract. Due to the harsh working environment and the inconvenient maintenance, leakages of warship pipeline often occur. When the pipeline leaks, the fluid flow and pressure in the pipeline will change. The pressure fluctuation of the fluid is one of the main sources of abnormal vibration and noise in the pipeline system. In order to locate the leaking part of the pipeline effectively, it is necessary to use sensors to collect and capture these changing parameters to facilitate real-time monitoring of the pipeline system. In this paper, ANSYS finite element analysis software is used to establish the geometric model of "I" type combined pipeline, and the pressure variation characteristics under different leakage conditions are obtained through simulation.

1. Introduction
As an important part of the ship, the safety of the pipeline system is of great significance to the vitality of the ship. In actual engineering, due to the harsh working environment and inconvenient maintenance of the pipeline system, the problem of damage and leakage often occurs. Aiming at the problem of pipeline leakage, many scholars have carried out relevant research. Mostafapour, et al [1] studied the calculation of the leakage rate when the leakage hole is a different crack through a combination of experimental and theoretical research. Zhu, et al [2] studied the problem of using acoustic emission (AE) detection technology to diagnose leakage. Han et al [3] studied the flow field characteristics of different micro leakage hole shapes, and established the simulation models of different micro leakage hole shapes. Based on numerical simulation technology, Wu, et al [4] established a physical model and a mathematical model of the slit leakage in a liquid pressure pipeline. Deng et al [5] put forward the calculation model of submarine pipeline gas leakage rate, and verified the validity and applicability of the calculation model in laboratory. Thiana A, et al [6,7] simulated the maximum erosion rate and erosion position on the outer radius of the elbow and several different flow conditions. Cai, et al [8] established a mathematical model and a finite element numerical model for gas leakage in shallow water pipeline.

The pipeline system of warship is more complex. This paper takes the "I" type combined piping model as the object, divides the leakage situation into one-end leakage and two-end leakage. Two kinds of models are established and simulated.
2. Pipe Modelling

2.1. Geometry Model
The length of the pipe at both ends is 400mm, the length of the middle pipe is 300mm, and the diameter is 54mm. The leak hole is a round hole with a radius $R=5\text{mm}$, located at the center of the junction of the two pipes. The fluid flows in from the nozzle at the left end of the upper pipe. Simulate two cases of leakage at one end and leakage at both ends respectively, as shown in figure 1 and figure 2.

![3D model](image1.png) ![Mesh generation of fluid pipeline](image2.png)

**Figure 1.** Three dimensional model and mesh generation of pipeline with single circular hole.

![3D model](image3.png) ![Mesh generation of fluid pipeline](image4.png)

**Figure 2.** Three dimensional model and mesh generation of pipeline with double circular holes.

2.2. Boundary Conditions and Parameter Setting
Find the Boundary conditions in the fluent operation interface of ANSYS finite element software, and set the conditions at Velocity-Inlet. The velocity specification method select magnitude and normal to boundary. The reference frame select absolute. The velocity magnitude set the inlet velocity to 1m/s. Supersonic/Initial Gauge Pressure set to Static pressure value. In the Turbulence area, set the
Specification method to Intensity and Viscosity Ratio, set the Turbulence Intensity to 5%, and set the Turbulence Viscosity Ratio to 10.

In order to fit the reality, diesel oil is selected as the fluid simulation material. The chemical formula is C19H30 < 1 >, the density is 960 kg/m³, the viscosity is 0.048 k/m s, and the sound velocity of the medium is 1250 m/s. The parameters of the selected pipeline materials refer to the actual pipeline materials and engineering standards, and the parameters are shown in Table 1.

Table 1. The parameters of pipeline.

| Density/(kg/m³) | Elastic Modulus/(GPa) | Poisson's ratio |
|----------------|-----------------------|----------------|
| Structural steel | 7900                 | 210            | 0.3            |

3. Simulation Analysis

3.1. One-Side Leakage

The internal flow field distribution of the "I"-shaped tube is more complicated, and the leakage modes are more diverse. Since the pipe joints are more likely to be damaged, the leakage point is selected at the center of the joint of the two pipes to observe the internal pressure distribution. First of all, when one side of the joint leaks, the pressure distribution is shown in Figure 3.

It can be seen from Figure 3 that the pressure of the "I" shaped pipe in the whole middle and lower section and the middle and rear part of the inflow pipe increases obviously, and the pressure distribution in the middle and lower section is more uniform. The pressure increase occurs in the lower right side of the leak, and the pressure drop occurs in the lower left side of the leak.

3.2. Two-Side Leakage

In order to analyze and compare the leakage characteristics of the pipe connections at both ends, under the premise of leakage at the upper end interface, a leakage point with the same size and shape of the lower end leak is added. The pressure distribution is shown in Figure 4.
Comparing one-side leakage with two-side leakage, it can be seen that there is no obvious change in the pressure distribution of the middle connecting pipeline, the pressure distribution around the upper leak is relatively uniform, and a small range of pressure increase occurs under the lower leak. For the "I" type pipeline, the location of leakage has different influence on the severity of leakage loss. The leakage at the bottom right of the interface between the inflow pipeline and the connecting pipeline is the most serious, while the leakage at the interface between the outflow pipeline and the connecting pipeline is relatively small.

4. Conclusion
The reliability of ship pipeline system is of great significance to the normal operation of various systems, the smooth operation of mechanical and electrical equipment and the life safety of crew. The research on the change of parameters during pipeline leakage can lay a foundation for real-time monitoring of system status. Considering the complexity of ship pipeline, the model of "I" type pipeline is established in this paper. The simulation results show that the impact of a leak in the inflow pipe is much greater than that in the out pipe, so it is important to take precautions.

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References

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

[2] Zhu S B, Li Z L, Zhang S M, et al. 2019 Deep belief network-based internal valve leakage rate prediction approach Measurement 133: 182-192.

[3] Han H C, He Q L, Cui J C, et al. 2018 Analysis of influence of leakage shape on leakage characteristics Electric Power Science and Engineering 34(1): 73-78.

[4] Wu H, Li L P, Liu Y, et al. 2014 Numerical simulation of flow field in pressure pipe crack leakage Turbine Technology 6: 429-431+435.

[5] Deng L Q, Yu J X, Yin B G, et al. 2019 Study on calculation method of gas leakage rate in submarine pipeline Ocean Engineering Equipment and Technology 6(5): 726-731.

[6] Thiana A Sedrez, Siamack A Shirazi, Yeshwanth R, et al. 2019 Experiments and CFD simulations of erosion of a 90° elbow in liquid-dominated liquid-solid and dispersed-bubble-solid flows Wear 426-427.

[7] Wang Y, Liu R T, Liu M, et al. 2019 Numerical investigation on erosion characteristics of coplanar elbows connection for gas-solid flow Energy Procedia 158.

[8] Cai X X, Yu Y, Yu J X, et al. 2018 Movement characteristics of gas leakage in hallow water pipelines China Offshore Platform 33(6): 56-64.