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Numerical modeling and experimental investigation of a two-phase sink vortex and its fluid–solid vibration characteristics

Zichao YIN, Yesha NI, Lin LI, Tong WANG,
Jiafeng WU, Zhe LI, Dapeng TAN

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Research Background and Significance

Sink vortex is a common natural phenomenon. In the process of its formation and suction, there exists the accumulation and release of turbulent energy, accompanied by a series of shock vibration, which will bring negative effects to industrial production.

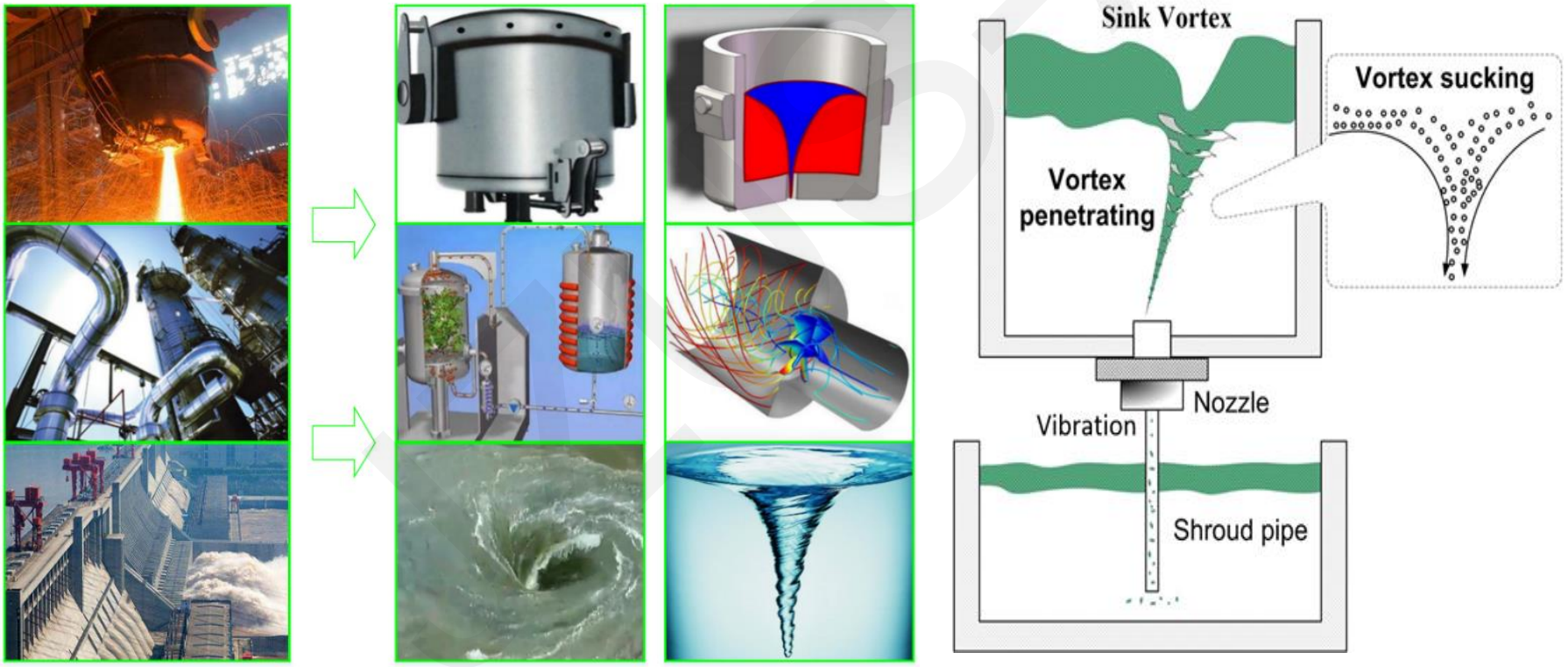


Fig. 1. The formation of a sink vortex and fluid-structure interaction in industrial production

Sink Vortex Shock Vibration Model

According to the characteristics of the sink vortex penetrating critical state, the fluid-structure interaction (FSI) boundary conditions are determined, and the multi-physical field model oriented to the vortex shock vibration is established.

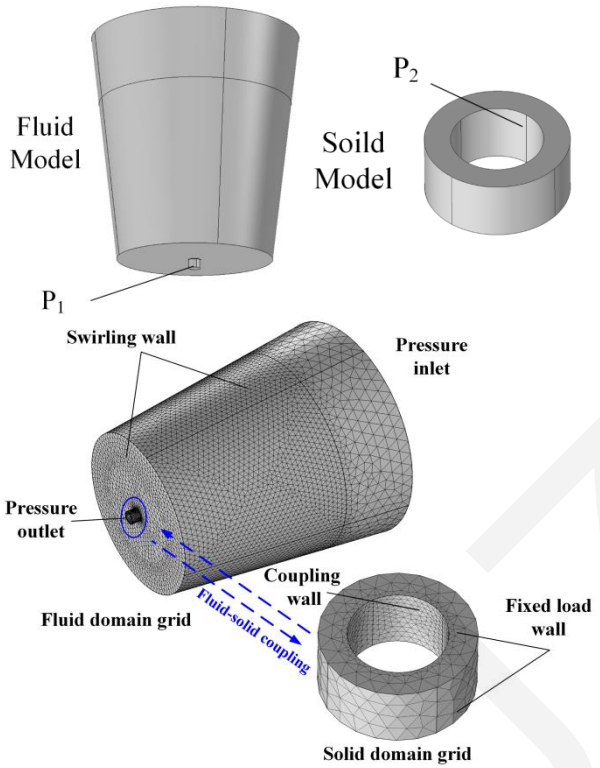


Fig. 2. Mechanic model of FSI vibration

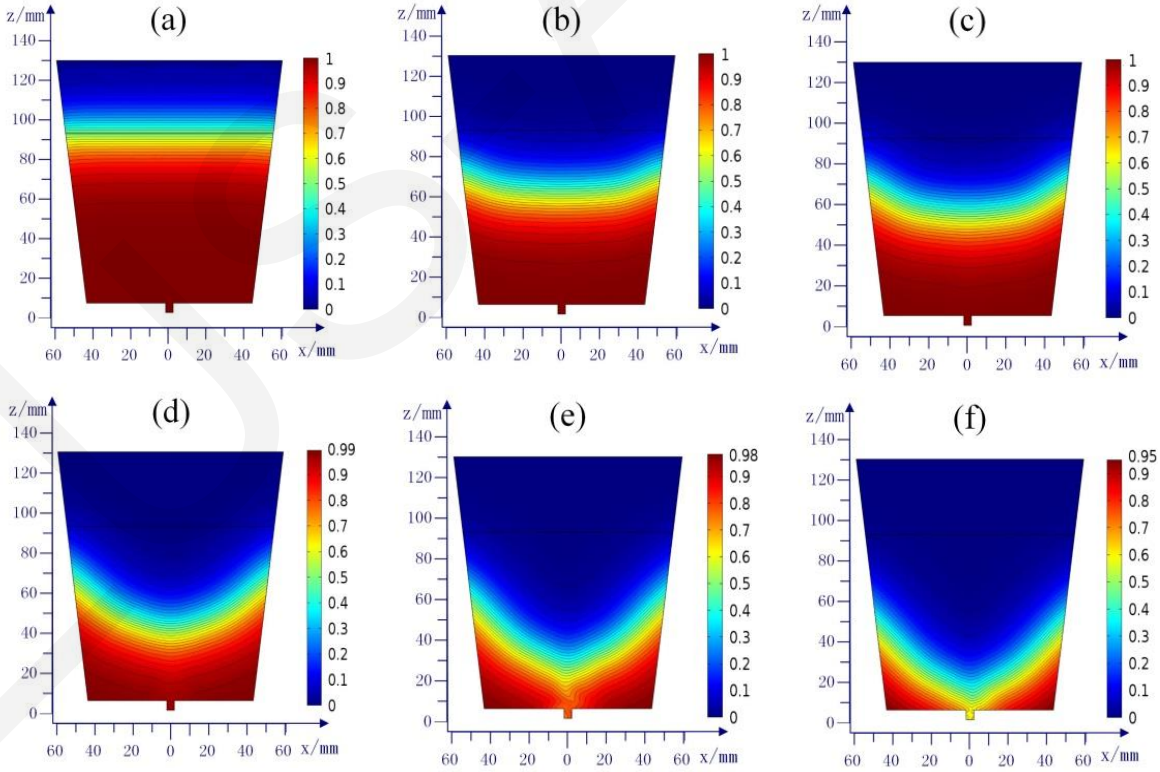
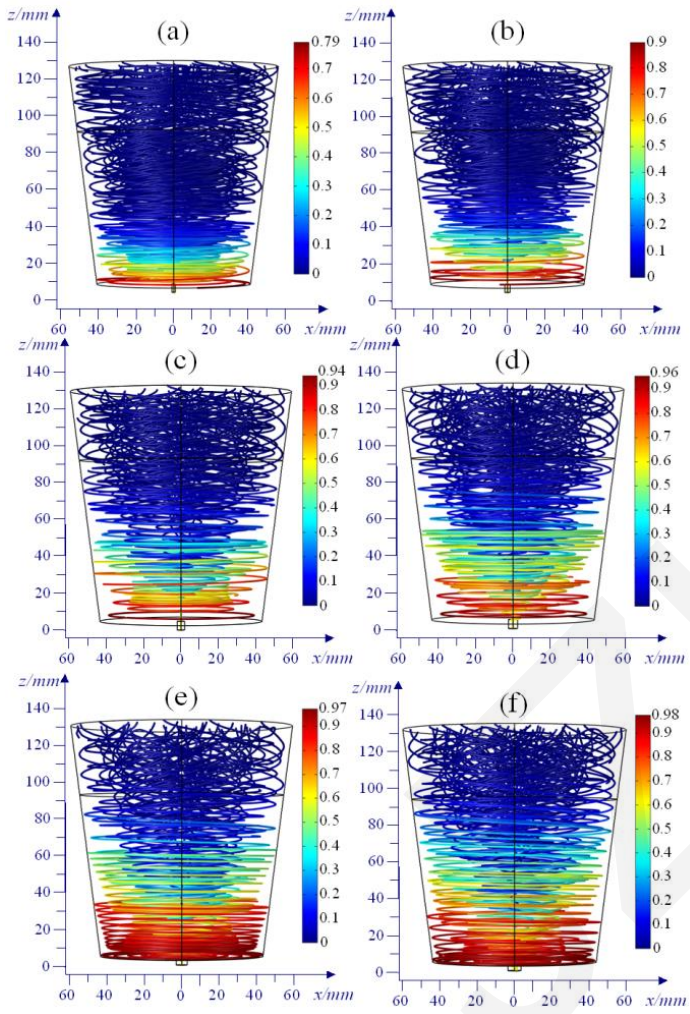
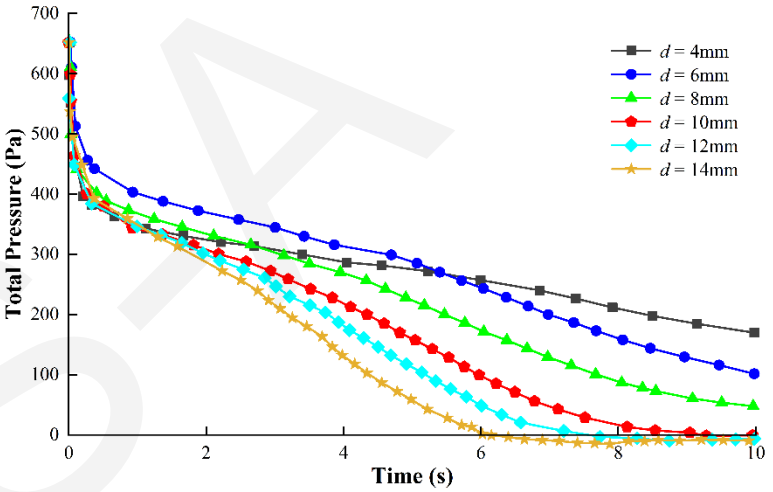


Fig. 3. Two-phase fraction variation of sink vortex formation (a) t = 0 s; (b) t = 5 s; (c) t = 6 s; (d) t = 8 s; (e) t = 11 s; (f) t = 15 s.

Penetration critical state of a sink vortex



Total Pressure



Volume Fraction

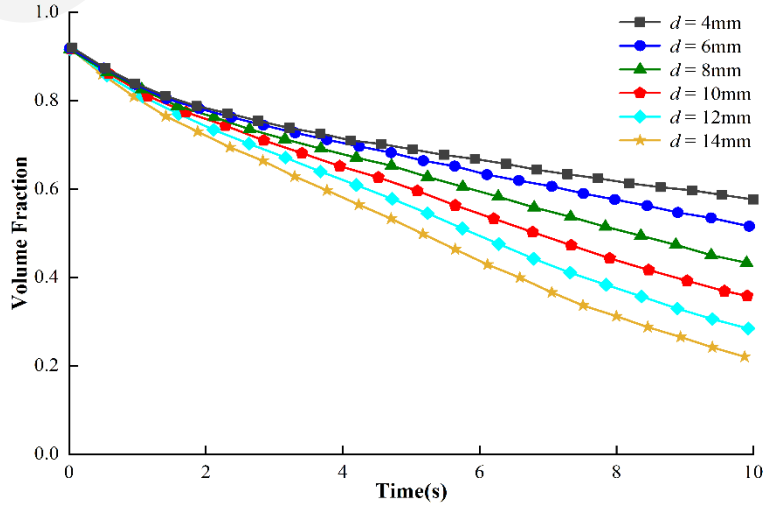
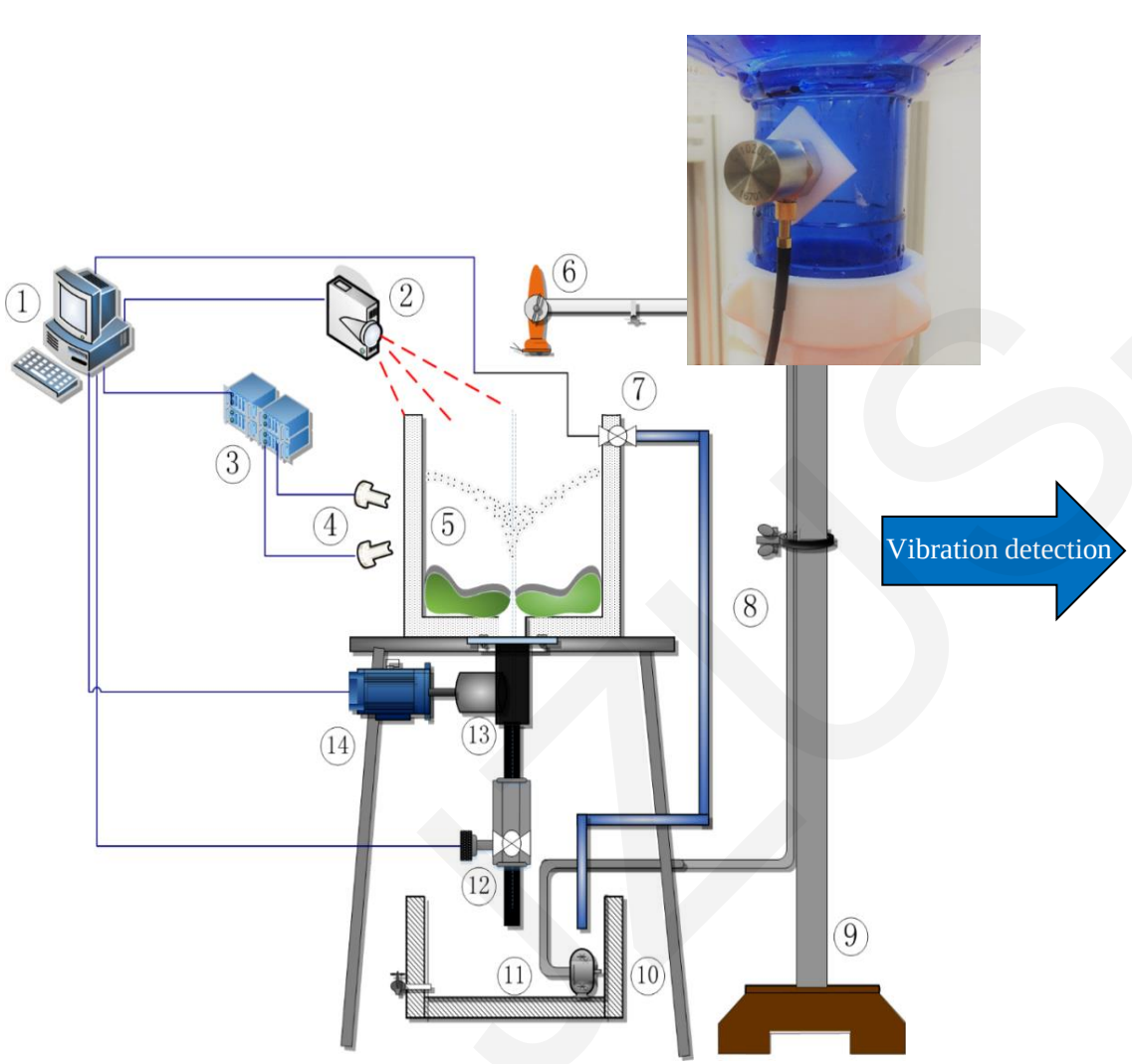


Fig. 4. The total pressure and volume fraction in the penetration critical state of a sink vortex

FSI Shock Vibration Experiment and Analysis



Vibration detection

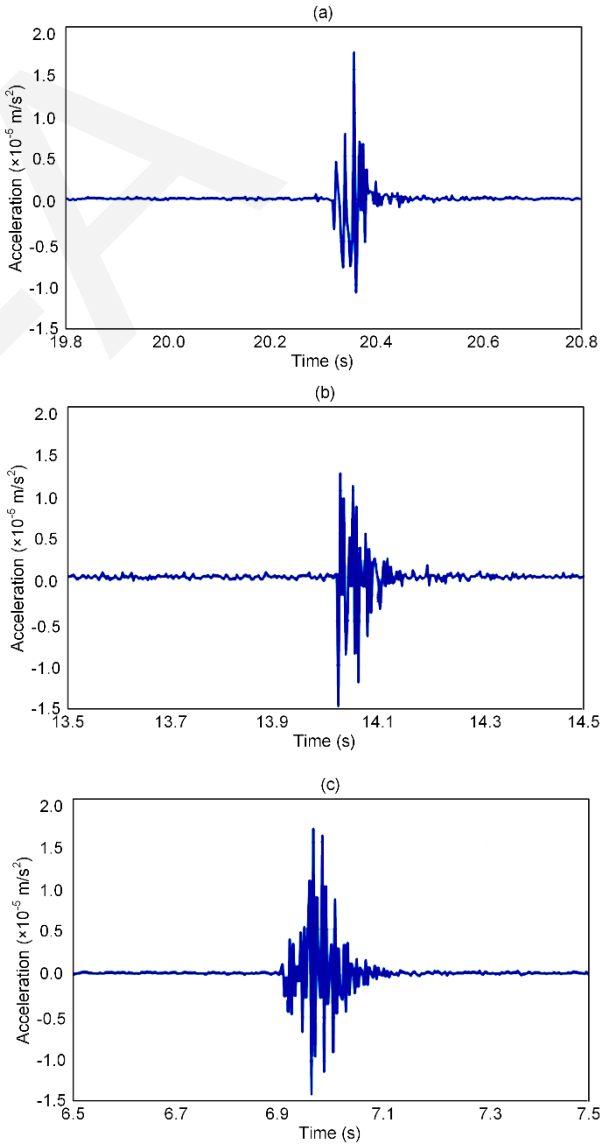


Fig. 5. FSI vibration experiment platform and shock vibration amplitude

FSI Vibration signal Analysis

High frequency signal enhancement obviously during the vortex penetrating period

A positive correlation between the rising proportion of high frequency signal and the outlet diameter

The coupling strength of gas-liquid can be reflected

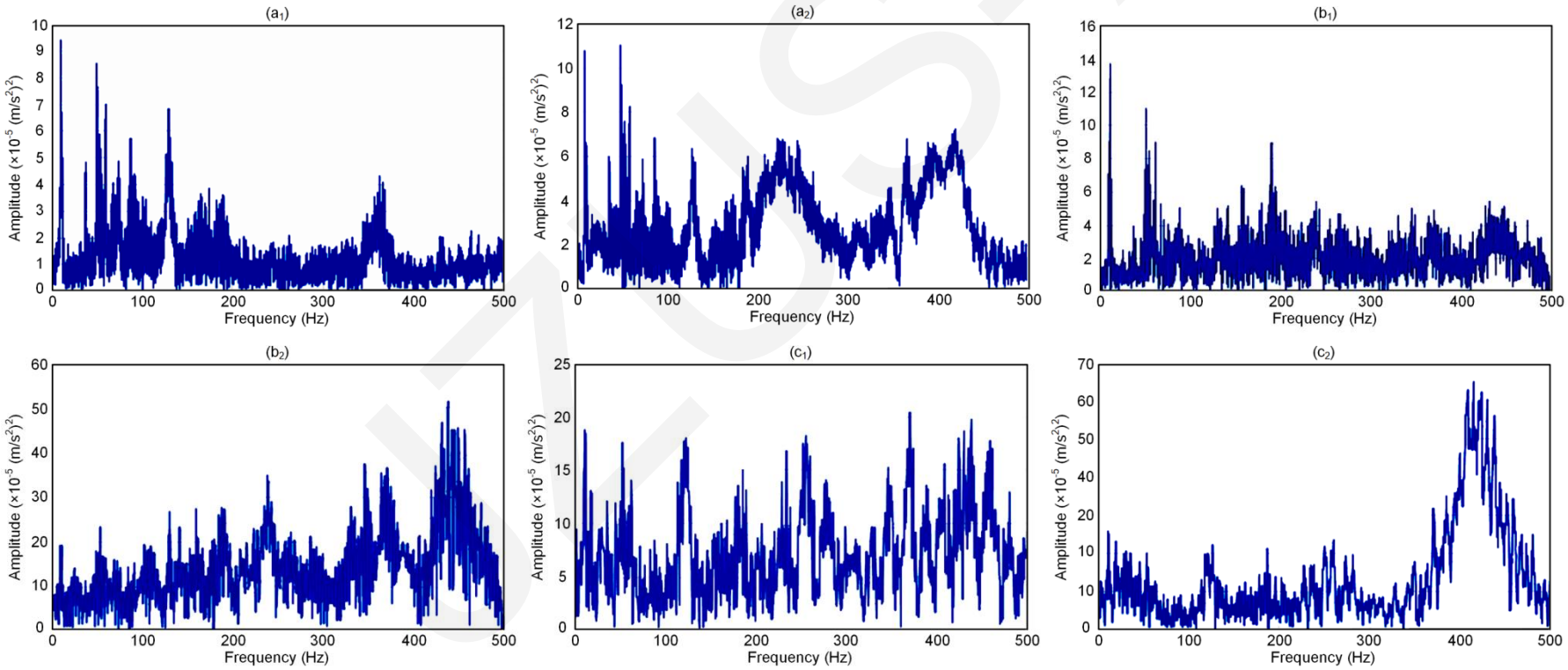


Fig. 6. Shock vibration frequency-domain signal at different outlet diameters.

Comparison of Simulation and Experiment

Both simulation and experiment came to the consistent conclusion that high-frequency signal intensity will increase correspondingly when vortex penetrates the outlet.

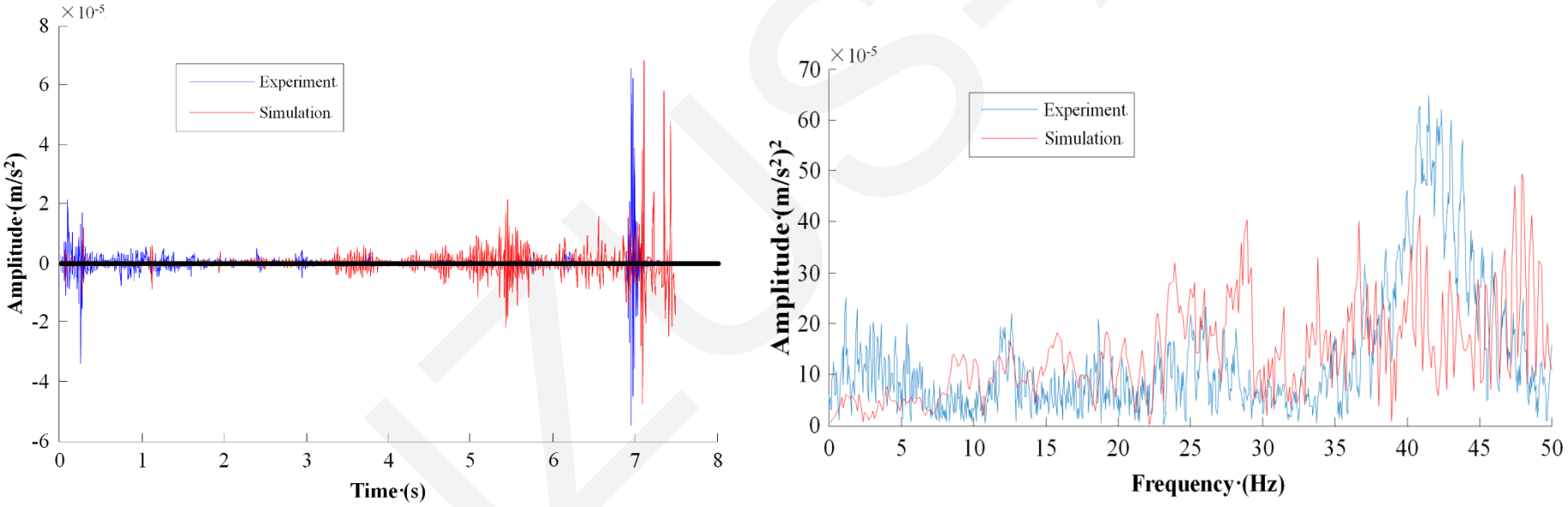


Fig. 7. Vortex shock vibration time-domain and frequency-domain signal

Conclusions

(1) The study on the shock vibration of sink vortex is of great significance to metallurgy, chemical industry, water conservancy and other engineering fields. In view of this problem, a FSI dynamic model for vortex shock vibration is proposed, and the vibration characteristics of the wall surface are obtained.

(2) Based on the results of numerical calculations, the frequency signal is weak and stable before the sink vortex penetrates the outlet. When the sink vortex reaches to the critical state of penetration, the pressure oscillation caused by two-phase coupling leads to the enhancement of each frequency signal, and some high frequency band is particularly obvious.

(3) Based on the hydrokinetics similar theory, the experimental platform of vortex shock vibration detection has been set up, and the experiments of FSI shock vibration detection have been completed.