Experimental study on nonlinear phenomenon of liquid sloshing in a circular cylindrical tank with spherical bottom

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Summary In order to study the nonlinear phenomenon of liquid sloshing in a circular cylindrical tank with spherical bottom,the time variation of wave height in liquid damply sloshing with the first lateral mode is measured by laser displacement sensor，and the whole relative information of the measurement plane at the same moment is noted by PIV. After data processing the time variations of frequency and damping ratio are obtained. It was founded primarily that the nonlinear sloshing with large amplitude shows softening behavior and the relationships between damping ratios and amplitudes are complex.

Introduction

The phenomena of the liquid sloshing attracted most attention of many scientists during last century. Some of the representative literatures are NASA research report by Abramson[1] in 1966, the bookmaking by Moiseev and Rumjantsev[2], and《Liquid Sloshing Dynamics: Theory and Applications》by Ibrahim at the near time. In 1976, the weak nonlinear theories of liquid sloshing were proposed by Miles[4,5], but the strong nonlinear sloshing has not been investigated in detail.

In this paper, the liquid sloshing forced by vertical excitation in a cylindrical tank with hemispherical bottom were investigated by experiments.

The liquid sloshing forced by vertical excitation in a cylindrical tank with hemispherical bottom

The experimental apparatus

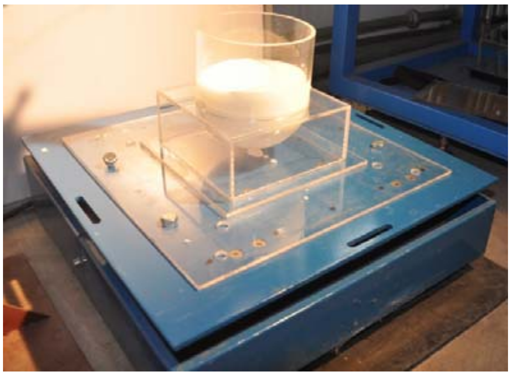

Fig.1 Experiment equipment

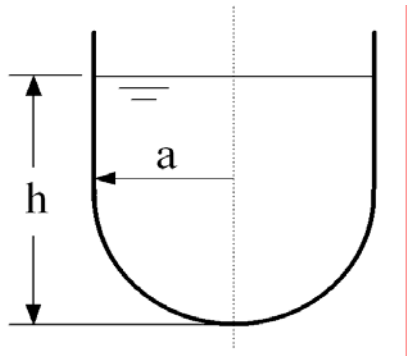

Fig. 2 The sketch map of plexiglass container

The experimental system is composed of Plexiglas’s container, vibration test instrument and recording device as shown in Fig. 1. Fig. 2 is the sketch map of Plexiglas’s container.

In order to investigate the phenomena of droplet ejecting, the experiments of liquid nonlinear sloshing forced by vertical excitation in a cylindrical tank with spherical bottom were carried out. The status of liquid sloshing was recorded by the High Speed Camera and PIV.

Results and discussion

In the situation with the exciting frequency 5 Hz and the amplitude 1 mm, the surface of the liquid oscillates with large amplitude and droplets are ejected incidentally. Fig. 3show the situation of the droplets ejecting which is recorded by the High Speed Camera.

When the exciting frequency is 10 Hz, with the amplitude unchanged, the amplitude of liquid sloshing is larger, and droplets ejecting happens more frequently, which is shown in Fig. 4.

When the exciting frequency is 25 Hz, with the amplitude unchanged, the liquid surface becomes more irregular, and droplets ejecting happens very frequently, which is shown in Fig. 5.

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Fig. 3 Droplets ejecting in 5 Hz

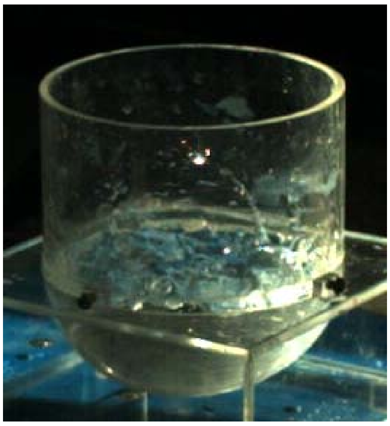

Fig. 4 Droplets ejecting in 10 Hz

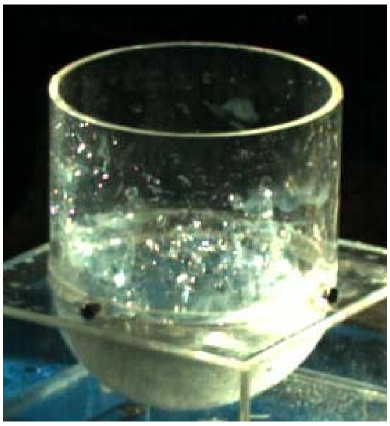

Fig.5 Droplets ejecting in 25 Hz

Differences in the droplets ejecting under different exciting frequencies can be illuminated with the theory of droplets ejecting. Investigations indicated excited frequencies and surface tension coefficients influence the droplets ejecting greatly. The droplets ejecting can happened under both conditions where gravitational wave or capillary waves is dominant. The gravitational wave formed in the situation that the exciting frequency is low, which corresponds to the cases of 5Hz and 10Hz, where gravity dominates the process of liquid sloshing. When the exciting frequency is high, which corresponds to the case of 25Hz, the surface tension is dominant in the liquid surface wave. The relationship between maximum exciting accelerations and exciting frequency is as follows

$$a_c = 0.239\omega^{4/3}(\sigma/\rho)^{1/3}$$

where a_c is the maximum exciting acceleration, w is the exciting frequency, σ is the surface tension coefficient and ρ is the density in water. We take $\sigma = 0.072 N \cdot m^{-2}$, $\rho = 1000 kg \cdot m^{-2}$ in the present computations. The critical maximum exciting accelerations are $0.986\, m \cdot s^{-2}$, $3.948\, m \cdot s^{-2}$, $8.426\, m \cdot s^{-2}$ correspond to the exciting frequency 5 Hz, 10Hz, 25Hz, but the maximum exciting accelerations in experiments are $0.987\, m \cdot s^{-2}$, $3.948\, m \cdot s^{-2}$ and $24.674\, m \cdot s^{-2}$ that are bigger than the critical values, therefore droplets ejecting happened.

Conclusion

In this paper, some experimental investigations on the nonlinear liquid sloshing were presented. The nonlinear sloshing forced by vertical excitation in a cylindrical tank with hemispherical bottom was observed in experiments, and the results demonstrated the relationships between droplets ejecting and maximum exciting accelerations. It was also indicated that the mechanism of droplets ejecting depends on exciting frequencies and surface tension coefficients, and it occurs in both cases of gravitational waves and liquid surface capillary waves.

PIV note the whole relative information of the measurement plane at the same moment, thus the instantaneous velocity vector and vertical contour of the measurement plane can be acquired.Basing on image processing technology the PIV post-process is realized by using Matlab language. The velocity vectors are extracted from the flow image of PIV successfully. On the base of basic cross-correlation algorithm of PIV digital image processing, some new methods raising the veracity of velocity vector are put forward, such as reducing the interference of background light. Good results can be acquired from the shot image with PIV equipment of Dantec Corporation. The good results can reflect the flow information of the blade passage.

References

[1] Abramson H N.The Dynamic Behavior of Liquids in Moving Containers[S].NASA Sp-106. Washington,1966.

[2] Moiseev N N and Rumjantsev V V. Dynamics of Bodies Containing Liquid[M]. Moscow,1965(in Rus.).

[3] Ibrahim R A. Liquid Sloshing Dynamics: Theory and Applications[M]. London: Cambridge Pub. 2005.

[4] Miles J W. Nonlinear surface waves in closed basins[J]. J. Fluid Mech. 1976, 75:419–448.