Research on the noise induced by cavitation under the asymmetric cavitation condition in a centrifugal pump

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Abstract: An experimental investigation has been carried out to research the noise induced by cavitation under the asymmetric cavitation (AC) condition in a centrifugal pump. The acoustic pressure signals at the pump inlet and outlet were measured respectively during the development of cavitation in a closed hydraulic test rig. It could be found that both the pump inlet and outlet acoustic pressures changed obviously with the development of cavitation. The time domain and the power spectrum density of the pump inlet and outlet acoustic pressure pulsations were analyzed. The broadband pulses of the acoustic pressure pulsations were found and the reasons for the phenomenon were given.

1. Introduction
Most hydraulic machineries including turbopump inducer, turbine, hydrofoil, propeller and pump, etc. were exposed to cavity [1]. Cavitation was responsible for the noise, vibration and instability generation, for the erosive damage with the surface of flow channels, and also for the loss of performance in pumps [2-6]. The structural vibration, acoustic emissions and hydrodynamic pressures have been selected by Escaler to evaluate the detection of cavitation in actual hydraulic turbines [7]. With the pressure decreasing, the process of cavitation in a centrifugal pump could be summarized as incipient cavitation, quasi-steady cavity, and unsteady cavitation [8, 9]. While various kinds of inducer cavitation instabilities have been reported, the major ones were cavitation surge (CS), rotating cavitation (RC), asymmetric cavitation (AC) and high-order instabilities [10]. The noise generated in a centrifugal pump not only depended on its geometry structure and the operating conditions, but also induced by the flow instability which may be caused by stall, surge, and especially the cavitation in the pump [11]. Some severe instabilities were caused by cavitation under the AC condition, which would produce lots of noise. In this paper, we mainly focused on the noise induced by cavitation under the AC condition in a centrifugal pump.

2. Experimental methods
The acoustic pressure signals at the pump inlet and outlet were measured during the development of cavitation in a closed hydraulic test rig. The centrifugal pump in the rig was driven at a constant speed of 2900 r/min by an electromotor, with a blade passing frequency $f_d = 290$ Hz. The acoustic pressure pulsations were measured by four hydrophones which were installed at the pump inlet and outlet respectively. The hydrophones with the range of 0.1Hz~180kHz were produced by B&K Company, whose type was 8103. The sensitivity of the hydrophones was -211dB/1VμPa. A PXI 4472B data
acquisition module made by National Instruments Company was applied to capture the electric signals and converted them to digital signals. The test rig could meet the secondary precision of national specifications of China.

3. Results and discussion

3.1 Asymmetric cavitation

According to the reports of Y. Tsujimoto and T. Kimura, et al [9, 12, 13], in this paper it could be considered that the values of $NPSHa=1.74$ to 1.44 could be regarded as the condition of AC in the centrifugal pump.

3.2 Pump inlet noise signals

It could be found that the acoustic pressure presented a periodic fluctuations over the time under the non-cavitation condition that $NPSHa=9.87m$ in figure 1. However, the periodic variational regularity of the pump inlet noise signals gradually weakened under the AC condition with the development of cavitation. The periodic trends almost disappeared when $NPSHa=1.44m$. Not only had the amplitudes of the acoustic pressure pulsations under the AC condition become obviously lower than that under the non-cavitation condition, but also its intensity intensified. The explanation for this phenomenon was that on the one hand a larger cavity or sheet cavitation were produced by the single bubbles which were independent free in the pump while cavitation developed to a certain stage. The larger cavity collapsed in the downstream passages which was far away from the pump inlet. On the other hand, it was considered that the larger cavity absorbed part of the noise and shock pressure which were caused by the collapse of vapor bubbles under the severe cavitation condition [14]. The larger cavities showed a strong flexibility and no fixed shape characteristics due to the interaction between the larger cavities and the surrounding high pressure liquid which made the bubbles collapse or condense.

![Figure 1](image1.png)  
**Figure 1** Time domain signals of pump inlet acoustic pressure pulsations at $Q_a$.

![Figure 2](image2.png)  
(a) (b)  
**Figure 2** PSD signals of pump inlet acoustic pressure pulsations at $Q_a$.  

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The power spectrum density (PSD) signals of the pump inlet acoustic pressure pulsations under the AC condition was shown in figure 2. It could be found that the main frequency of the pump inlet acoustic pressure was the shaft frequency and its amplitudes were much higher than that of other frequency bands. The amplitudes of the main frequency decreased gradually with the development of cavitation. It was found that the broadband pulsations of the acoustic pressure distributed between 100 and 800Hz. With the decreasing of $NPSHa$, the range of broadband frequency gradually moved to low frequency and its intensity weakened. The broadband pulses could be apparently found between 1000 and 5000Hz and the frequency of the broadband presented no migration with the development of cavitation. Not only were the amplitudes of the broadband pulses at 1200Hz higher and its intensity relatively more severe than that of other frequency, but also the amplitude gradually increased.

### 3.3 Pump outlet noise signals

It was apparent that the periodic trends of the pump outlet acoustic pressure pulsations over the time could be found under both the non-cavitation and AC conditions in figure 3. The amplitudes of the pump outlet acoustic pressure pulsations increased gradually with the development of cavitation under the AC condition. The explanation for the phenomenon was that either the free type of cavitation or the sheeting cavitation would be flowed to the downstream of the pump with the fluid, then the cavities would collapsed near the pump outlet. So the noise produced by the vortexes and collapse of cavitation were relatively high near the hydrophones which were installed at the outlet of the pump. On the other hand, a large number of cavitation bubbles were converged and dilated as the further decreasing of $NPSHa$, which would increase of the intensity of the noise induced by the collapse of vapor bubbles.

![Figure 3](image-url)

**Figure 3** Time domain signals of pump outlet acoustic pressure pulsations at $Q_L$.

The PSD signals of the pump outlet acoustic pressure pulsations in the AC condition were shown in figure 4. It could be found that its main frequency was 2 times of the blade passing frequency. The broadband pulses distributed near the 4 and 10 times of the blade passing frequency, and also between the 700 and 900Hz. The intensity of the broadband pulses became severe with the development of cavitation. Some weaker broadband pulses distributed between 4000 and 9000Hz could be found with the further development of cavitation. It indicated that the high frequency acoustic pressure pulsations were produced by the collapse of cavitation bubbles under the AC condition. Due to the convergence and dilatation of the cavities, the intensity of the collapse was strengthened which could lead to the intensification of the noise. It could be found that the intensity of the pump outlet acoustic pressure pulsations was clearly much stronger than that of the pump inlet acoustic pressure pulsations. The main reason for the phenomenon was that the cavities moved to the downstream and the location of the
collapse was closer to the hydrophones which were installed at the outlet of the pump.

![Figure 4 PSD signals of pump outlet acoustic pressure pulsations at Q_d.](image)

4. Conclusion

An experimental investigation has been carried out to research the noise at the pump inlet and outlet induced by cavitation under the AC condition in a centrifugal pump. The results indicate that:

- Both the pump inlet and outlet acoustic pressures changed obviously with the development of cavitation under the AC condition.
- The high frequency acoustic pressure pulsations were radiated by the collapse of cavitation bubbles under the AC condition. Due to the convergence and dilatation of the cavities, the intensity of the collapse were strengthened which would lead to the intensification of the noise.
- Compared with the pump inlet acoustic pressure pulsations, the intensity of the pump outlet acoustic pressure pulsations was clearly much stronger than that of the pump inlet acoustic pressure owing to the cavities moved to the downstream.

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