VARIATIONS OF PERFORMANCE AND PRESSURE PULSATION DURING CAVITATION IN CENTRIFUGAL PUMPS WITH ENTRAINED AIR

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ABSTRACT

Most of the research on the cavitation with entrained air has focused on the military direction, but it ,about centrifugal pumps, which is relevant to people's livelihood, is still relatively lacking. In order to study the basic law of the development of cavitation inside centrifugal pumps under aeration conditions, a test bench suitable for cavitation experiments with incoming flow containing gas was obtained. Furthermore, a single-stage single-suction 6-blade centrifugal pump was used as the research object to conduct pressure pulsation experiments under cavitation condition when the incoming flow was 1.0% air viod fraction at 2900r/min-50m³/h. The results showed that: After cavitation happened, the greater aeration content will deteriorate the pump's anti-cavitation performance, but the head curve is more gentle in falling down compared to natural cavitation. Hence aeration has a beneficial effect on the performance degradation of the pump under the cavitation condition. At the same time, before the cavitation number drops to the fracture cavitation number of the pump, aeration has improvement in the efficiency of the pump in different degrees , especially in the situation with the ventilated rate of 1.0%. The main frequency of pressure pulsation at the inlet and outlet of the test pump after aeration is dominated by the blade frequency. The shaft frequency signal at the outlet gradually decreases with the cavitation number lessened. Moreover the amplitude of the blade frequency grows slightly with the reduction of the cavitation number. But it tends to soar when the cavitation number is less than the fracture cavitation number.

NOMENCLATURE

ρ	Fluid Density	δ	cavitation number
PSD	Power spectrum		

INTRODUCTION

Cavitation happens when the local pressure inside the centrifugal pump falls to the vaporization pressure of the fluid. Cavitation mainly occurs in the back of the blade of the centrifugal pump , or near the top of the leaf areaof the blade, etc.. Cavitation will lead to the performance of the fluid machinery degradation, vibration and noise. Moreover it will do harm to the fluid machinery overflow parts.[1]

The cavitation of fluid machinery has been criticized for a long time. But the process of cavitation can be affected by the gas flowing into the machine. A variation of air volume ration has two sides to different machines[2]. For this reason, many researchers have carried out research on inducers[3]and underwater vehicles[4-7]. Moreover, mechanism of cavitation bubbles formation and collapse would be better understood by focusing on internal flow analysis, in order to be better use of ventilation technology[8] .

Up till now, most of the research has been focused on the direction of military industry, but it is still a lack of the research on centrifugal pump which is related to people's livelihood. After Cui [9] conducted the gas-liquid two-phase flow experiment, they found cavitation phenomenon in the regions with high gas content and rotating speed, which affected the conclusion of the final experiment. So the influence of 1% air void fraction ventilated on pump cavitation is studied by using this pump in this paper.

This paper analyzes the cavitation performance of centrifugal pump with the air volume of 1% gas content in the inlet flow. Experiments have been done and provided datum comparing with a natural cavitation experiment. The purpose of this research was to learn about the interaction between vapor and gas.

ANALYSIS AND EXPERIMENT

The test rig mainly consists of four parts: liquid delivery circuit, aeration system, vacuum self-regulating system and acquisition system. The liquid delivery circuit is the core of the test bench, where the aeration system is connected to it at the inlet of the test pump. The vacuum self-regulating system is connected to the liquid delivery circuit through the top of the closed water tank as well. The layout of test rig about the centrifugal pump working under cavitation condition with entrained air is shown in Figure 1.

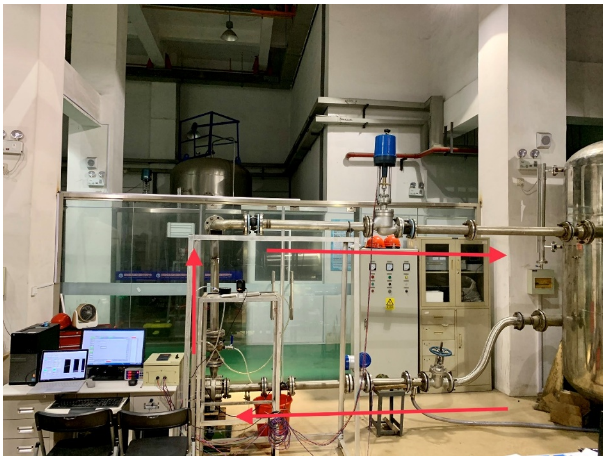

Figure 1 The liquid delivery circuit

It is composed of φ1.5×2.5m water storage tank, ball valve, 65mm inner diameter of import and export pipeline, electromagnetic flow meter, electric control valve for regulating the flow and test pump for the liquid delivery circuit . The test pump is a single-stage single-suction centrifugal pump, and its hydraulic design parameters are shown in Table 1. The motor is a Siemens inverter speed control special three-phase asynchronous motor with a nominal power of 7.5kW, and the motor speed is adjusted by using a Mitsubishi Mtsubishi F700 inverter.

Table 1 Hydraulic parameters of model pump

Parameter	Numerical	Parameter	Numerical
Design speed ($n/r\ min^{-1}$)	2900	Impeller inlet diameter (D_1/mm)	74
Design head (H/m)	34	Impeller outlet diameter (D_2/mm)	174
Design flowrate ($Q_d/m^3{\cdot}h^{-1}$)	50	Blade outlet width (b_2/mm)	12
Blades (Z)	6	Pump inlet diameter (D_s/mm)	65
Specific speed (n_s)	88.6	Pump outlet diameter (D_d/mm)	65

The aeration system is displayed in Figure 2. It contains a φ0.5×1.8m compressor, a pressure stabilizing tank, a gas mass flow meter, a air filter, Bürkert gas flow controller, gas pressure regulating valve, check valve, gas-liquid mixer, gas transmission pipeline, pumping pipeline and so on. The gas is supplied by a Denel DA-7A screw compressor with a maximum discharge volume of 1.03 m³/min and a maximum working pressure of 1 Mpa. The venting port is arranged close to the inlet of the centrifugal pump. Additionly the diameter of the venting hole can be changed to adjust the size of the bubbles by means of a self-designed structure.And Figure 3 is presented the vacuum self-regulating system, which includes a vacuum pump、a electronic valve and a tank.

Figure 2 Aeration system

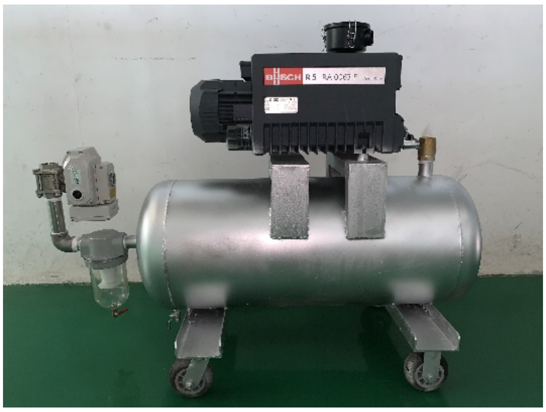

Figure 3 Vacuum self-regulating system

there are the method of the experiment of Centrifugal pump ventilating under cavitation condition: the preliminary work is opening the vacuum pump vacuum self-regulating system after the pump operation is stable. Secondly, start the compressor. when the pressure of the pressure stabilizer to reach more than 2 atmospheres, set the air volume fraction on the Bürkert gas flow controller. Thirdly, open the ventilation valve. Then repeat the steps mentioned with different inlet pressure. Finally get the external characteristics of the test pump under cavitation with entrained air, pressure pulsation data and image. Repeat the above steps to carry out experimental results of different air void fraction.

RESULTS AND DISCUSSION

Figure 4 illustrates the cavitation performance curve of the test pump at 2900 r/min at three kind of rates with entrained air compared with the natural cavitation curve. As shown in the figure, the cavitation under non-aerated conditions is incipient at cavitation number δ=0.075, deteriorates at δ=0.0625. Then the head drops sharply to only about 12m at δ=0.04. When the content of entrained air is 0.3%, the head starts to drop steeply from δ=0.08397, which is much earlier than the natural cavitation head steep drop point, but the trend of head drop is smoother than the natural cavitation condition. Moreover, the lowest head of the test pump is 14m under the limit condition of flow rate of 50m³/h, which is higher than 12m under natural cavitation. Meanwhile, the inlet pressure under this condition is slightly higher than the inlet pressure under normal cavitation. Compared with the 0.3% entrained air content, the cavitation occurs earlier with the content of 0.7% and 1% aeration. What's more, the steep head drop point is obviously moved forward, which proves that the ventilation under these two conditions will worsen the anti-cavitation performance of the pump and the steep head drop is more gentle compared with the natural cavitation. The head of the ultimate condition under the rated flow rate of 50m³/h , in additon, increases with the increase of the aeration rate. The final inlet pressure is 5000 Pa higher than that of normal cavitation because of the inlet gas. In terms of the efficiency of the pump, the test pump is increased to different degrees by the aeration content before the cavitation number drops to the fracture cavitation number, which is most obvious at 1.0% incoming gas content.

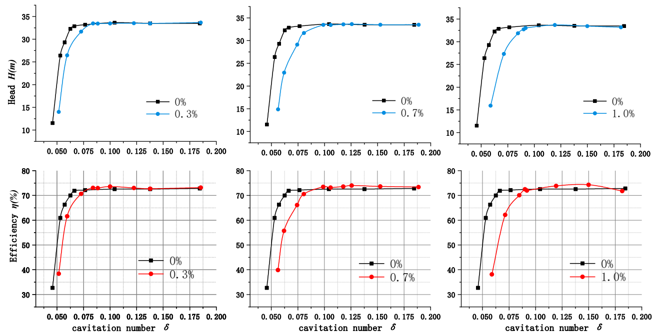

Figure 4 Comparison of performance curve between natural cavitation and cavitation with various content of entrained air

Figure 5 and Figure 6 are the frequency domain diagrams of the pressure pulsation of the inlet and outlet of the test pump when the entrained air content of the incoming flow is 1.0% at a revolving speed of 2900 r/min under cavitation inception condition. From Figure 5, it can be found that in the non-aeration stage when the cavitation number is δ=0.118, the main frequency of pressure pulsation at the inlet of the test pump is simply the shaft frequency, and the secondary main frequency is the blade frequency signal.After the start of the aeration stage, the peak of the shaft frequency disappears. Then the main frequency of pressure pulsation at the inlet is dominated by the blade frequency. Due to the location of the signal which is at the inlet, the pressure pulsation signal can only reflect the overall test pump which contains less rich and detailed information than at the outlet.

As shown in Figure 6, the main frequency at the outlet of the test pump under this condition is dominated by the blade frequency. At the same time, there is a regular pulsation signal from 1 to 9 times the shaft frequency. Additionally the shaft frequency signal gradually decreases with the cavitation number reduction. On the contary, the instability caused by the bubble blocking each flow channel makes the blade frequency signal stronger and stronger. When the cavitation number δ=0.018~0.099, it can be seen at this moment the test pump head curve is so stable that the blade frequency amplitude with the cavitation number decreases slightly combined with Figure 3. When reaching the fracture cavitation number, the pressure pulsation main frequency skyrocket. Simultaneously, the broad frequency pulsation between 8-10 times the shaft frequency is also gradually stronger. By the time the entrained air-containing bubble and the cavitationbubble keep acting and influencing each other, the broad frequency signal disappears and the unstable broadband signal appears around the main frequency signal.

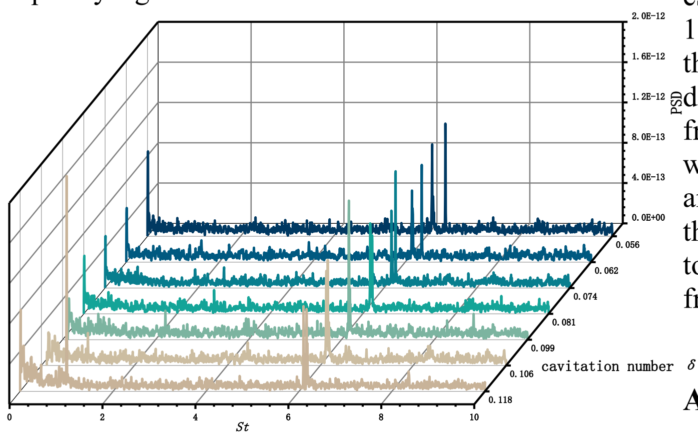

Figure 5 The pressure pulsation at the inlet of the pump under cavitation with entrained air

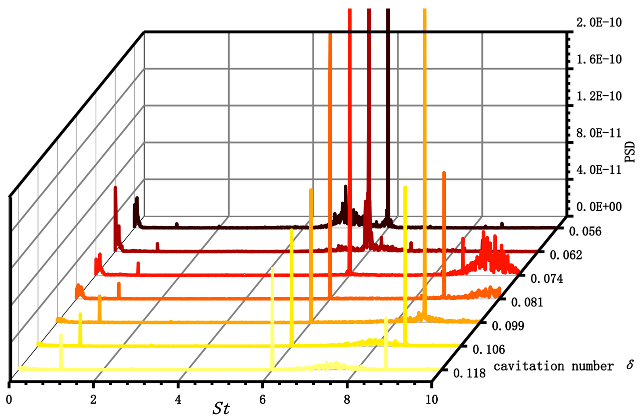

Figure 6 The pressure pulsation at the outlet of the pump under cavitation with entrained air

CONCLUSIONS

After cavitation happened, the greater aeration content will deteriorate the pump's anti-cavitation performance, but the head curve is more gentle in falling down compared to natural cavitation. Hence aeration has a beneficial effect on the performance degradation of the pump under the cavitation condition. At the same time, before the cavitation number drops to the fracture cavitation number of the pump, aeration has improvement in the efficiency of the pump in different degrees , especially in the situation with the ventilated rate of 1.0%. The main frequency of pressure pulsation at the inlet and outlet of the test pump after aeration is dominated by the blade frequency. The shaft frequency signal at the outlet gradually decreases with the cavitation number lessened. Moreover the amplitude of the blade frequency grows slightly with the reduction of the cavitation number. But it tends to soar when the cavitation number is less than the fracture cavitation number.

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For reference use ASME format, i.e., number in square bracket [1].

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