The suppression of cavitation surge in a double-suction centrifugal pump by using branch-type and slit-type accumulations installed at a pump outlet pipe.

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Abstract. Recently, cavitation surge was one of cavitation instabilities in high performance turbopumps and it damaged to a hydraulic system. In the present research, the experiments were carried out in order to investigate the influences of the branch-type and slit-type accumulators installed at a discharge pipe on cavitation surge. The experiments were conducted by the closed-type water tunnels. As a result, the occurrence region of cavitation surge in the V-shaped suction performance curve was reduced by the branch-type accumulator and the pressure amplitudes due to cavitation surge were decreased by the slit-type accumulator.

1. Introduction
In a double-suction centrifugal pump with a low specific speed, a noise due to cavitation surge has been experimentally and numerically investigated [1]. As a result, the noise due to cavitation surge occurs in the V-shape region of the suction performance curve. Kurokawa [2] have showed that the cavitation surge was substantially suppressed in inducer with large blade angle by installing many shallow grooves called “J-groove,” on the inner casing wall of turbomachine. Nakano et al. [3] have showed that the cavitation surge was suppressed in inducer by installing a backflow restriction device on the casing. Luke et al. [4] have showed several accumulator designs for suppression of POGO within the Ares I vehicle Upper Stage Liquid Oxygen System. Furthermore, Kang et al. [5] have showed that an accumulator installed in a discharge pipe has the stabilizing effect in hydraulic systems. In the present study, the suppressing effect of accumulators on cavitation surge in the double suction centrifugal pump
was investigated. The branch-type and slit-type accumulators installed at the discharge pipe were tested. In addition, the influence of the accumulator compliance on cavitation surge was investigated by comparing the result for the accumulator filled with water and air.

2. Experimental Method

Figure 1 shows (a) the overall view of an experimental facilities and (b), (c) the pressure measurement positions of the pipes. Water was used as working fluid and a tank was installed upstream from a pump. The dimensions shown in Figure 1 were written as the dimensionless values normalized by the representative length. The representative length was defined as the outlet diameter of the impeller \(D\). The numbers enclosed within a circle ① and ② are the pressure measurement points at the suction and discharge pipes, respectively. The accumulators were installed downstream from the pressure measurement point of the discharge pipe. The inner diameters of the suction and discharge pipes are 0.51 \(D\) and 0.43 \(D\), respectively. Figure 1 (c) shows the pressure measurement positions ③ and ④ of the suction part of the pump. The flow rate and the inlet pressure were used for the experimental parameters. The inlet pressure was controlled by a vacuum pump installed in the tank and the flow rate was adjusted by a butterfly valve installed downstream from the pump. In the present study, the condition without the accumulator is termed "original-type".

![Figure 1](image1.png)

Figure 1. Experimental facilities and schematic of pump.

Figure 2 shows (a) the branch-type accumulator (hereinafter, abbreviated as "branch-type"). The branch-type is the cylindrical container with the inner diameter of 0.99 \(D\) and the height of 3.28 \(D\). The air inside the accumulator was confirmed by the external tube (A) shown in Fig. 2(a).

![Figure 2](image2.png)

Figure 2. Type of accumulator.
Figure 2 shows (b) the slit-type accumulator (hereinafter, abbreviated as "slit-type"). The slit-type is the rectangular parallelepiped container with the length of 4.00 \( D \) and a height of 0.82 \( D \). In the slit-type, the partition wall (B) was installed for keeping air inside.

The flow rate, pressure, torque, water temperature and rotating speed of the impeller \( n = 1800, 2000 \) rpm were obtained by a personal computer through an A/D converter. The pressure fluctuations were obtained with the sampling frequency of 10 kHz for the original-type and the branch-type, and of 1.28 kHz for the slit-type. All measurement data were simultaneously obtained. The design flow rate of the pump is \( \phi = \nu_r/U = 0.064 \). Here, \( \nu_r \) is a radial flow velocity at the blade reading edge, \( U \) is the tangential speed at the impeller outlet. The flow rate \( \phi = 0.045 \) (design flow rate of 70%) was set in the experiment.

3. Effect of accumulator

3.1 Suction performance curve

Figure 3 shows the suction performance curves for the original-type, branch-type, and slit-type. The abscissa and ordinate show the dimensionless frequency \( f = f/f_a \), and the pressure coefficient \( \psi = (p_2 - p)/\rho U^2/2 \), respectively. Here, \( p_1 \) is the static pressure at the suction pipe (1) shown in Figure 1, \( p_2 \) is the static pressure at the discharge pipe (2) and \( p \) is the vapor pressure of water. Since the velocity and potential heads are negligible, the static pressure is used instead of the total head. The original-type, branch-type and slit-type are indicated by the circle, rectangle and rhombus, respectively. The solid symbols indicate the condition where cavitation surge peaks are relatively large.

Cavitation surge occurs in 0.021 < \( \sigma < 0.042 \) for the original-type, in 0.030 < \( \sigma < 0.034 \) for the branch-type and in 0.031 < \( \sigma < 0.042 \) for the slit-type, shown in Figure 3. This shows that the occurrence region of cavitation surge is reduced by the branch-type. The cavitation number \( \sigma = 0.059 \) starting to degrade the pressure coefficient for the slit-type is larger than those for the original-type and branch-type. Furthermore, with respect to the shape of the suction performance curves, for the original-type, the V shape with the dip of \( \sigma = 0.036 \) is observed in 0.030 < \( \sigma < 0.051 \). For the slit-type, the W shape with the dip of \( \sigma = 0.045 \) and the peak of \( \sigma = 0.042 \) and the dip of \( \sigma = 0.040 \) is observed in 0.038 < \( \sigma < 0.065 \).

3.2 FFT analysis result

Figures 4 ~ 6 show FFT results of the pressure fluctuations at the measurement point (3) shown in Figure 1. The abscissa, ordinate, depth show the dimensionless frequency \( f' = f/f_a \), the dimensionless pressure amplitude \( \bar{\psi} = \bar{p}/(\rho U^2/2) \) and the cavitation number \( \sigma \), respectively, Here, \( f_a \) is the rotational frequency. The results for the original-type, the branch-type and the slit-type are shown in (a), (b), and (c), respectively.

For the original-type, in 0.036 < \( \sigma < 0.042 \), the dominant peaks are observed at the dimensionless frequencies \( f' = f/f_a = 0.126, 0.429 \) and 0.717. Here, the phase differences of these dominant peaks were investigated by the pressure fluctuations at (3) and (4) in Figure 1. As a result, we confirmed that the dominant peaks at \( f' = f/f_a = 0.126, 0.429 \) is caused by cavitation surge and that the dominant peaks at \( f' = f/f_a = 0.717 \) is caused by rotating cavitation.

Therefore, it is understood that cavitation surge and rotating cavitation occur simultaneously in 0.036 < \( \sigma < 0.042 \). On the other hand, in 0.021 < \( \sigma < 0.034 \), only the dominant peaks due to cavitation surge at \( f' = f/f_a = 0.126 \) is observed. The occurrence region of cavitation surge for the branch-type is the same as that for the original-type. For the slit-type, the occurrence region of cavitation surge is almost the same as that for the original-type. The amplitude for the slit-type, however, is smaller than that for the original-type. Here, the surging occurrence was not judged and only the amplitudes of the oscillation spectrum peaks are examined.
3.3 Suppression effect of accumulator on cavitation surge

Figure 7 shows the frequencies of the peaks due to cavitation surge for each accumulator shown in Figure 4 to 6. Since several peaks due to cavitation surge were observed, the frequency near $f^* = f/f_n = 0.140$ was selected. The abscissa and ordinate show the cavitation number $\sigma$ and the dimensionless frequency $f^* = f/f_n$, respectively. The original-type, branch-type and slit-type are indicated by the circle, rectangle and rhombus, respectively. For the original-type, the frequency decrease as the cavitation number is decreased. For the branch-type, the frequency $f^* = f/f_n = 0.141$ is constant. For the slit-type, the frequency $f^* = f/f_n = 0.128$ is almost constant.

Figure 8 shows the pressure amplitudes due to cavitation surge in each accumulator shown in Figures 4 ~ 6. The abscissa and ordinate show the cavitation number $\sigma$ and the dimensionless amplitudes $\bar{\psi} = \bar{p}/(\rho U^2/2)$, respectively.

For the original-type, the amplitude curve has the $\Lambda$ shape with the peak at $\sigma = 0.032$. For the branch-type, the amplitude curve has the $\Lambda$ shape with the peak at $\sigma = 0.032$, as well as the result for the original-type. For the slit-type, the amplitude curve has the $\Lambda$ shape with the peak at $\sigma = 0.038$ although the increment is smaller than other results. With respect to suppression of the pressure fluctuation due to cavitation surge, the pressure amplitude due to cavitation surge is reduced by 34% at $\sigma = 0.030$ for the branch-type and by 80% at $\sigma = 0.031$ for the slit-type.

From the above, as the cavitation number is decreased, the frequency decrease for the original-type. For the branch-type and slit-type, the frequencies are almost constant. With respect to suppression of the
pressure amplitude due to cavitation surge, the pressure amplitude is reduced by 34% at $\sigma=0.030$ for the branch-type and by 80% at $\sigma=0.031$ for the slit-type.

![Figure 7. Comparison of dimensionless peak frequency (Original-type, Branch-type, Slit-type).](image1)

![Figure 8. Comparison of dimensionless pressure fluctuation amplitude (Original-type, Branch-type, Slit-type).](image2)

4. Influence of compliance of accumulator

4.1 Suction performance curve

In order to investigate the influence of the accumulator compliance on cavitation surge, the experiments for accumulator filled with water (without compliance) and air (with compliance) were carried out.

Figure 9 shows the suction performance curves for the original-type and for the slit-type with and without compliance. The original-type is indicated by the circle. The slit-type without and with compliance are indicated by the triangle and rhombus, respectively. The solid symbols indicate the condition where cavitation surge peaks are relatively large.

Cavitation surge occurred for the original-type in $0.021 < \sigma < 0.042$, for the slit-type without compliance in $0.030 < \sigma < 0.034$ and with compliance in $0.031 < \sigma < 0.042$. This shows that the occurrence region of cavitation surge without/with compliance is increased/reduced by comparison with the result for the original-type. The cavitation number $\sigma=0.059$ starting to degrade the pressure coefficient with compliance is the same as that without compliance. Furthermore, with respect to the shape of the suction performance curves, the W shape with the dip of $\sigma=0.042$, the peak of $\sigma=0.040$ and the dip of $\sigma=0.035$ is observed in $0.032<\sigma<0.065$ without compliance. This is almost the same as the result with compliance.

4.2 FFT analysis result

Figure 10 shows FFT analysis result of the pressure fluctuation at the measurement point ③ shown in Figure 1. The range of $\sigma$ is the same as the occurrence region of cavitation surge expressed as the filled symbols shown in Figure 9.

For without compliance, in $0.032 < \sigma < 0.044$, the dominant peaks are observed at the dimensionless frequency $f^*=f/f_n=0.052$. Here, the phase differences of the dominant peaks were examined. As a result, we confirmed that the dominant peak is caused by cavitation surge. The amplitude of the dominant peak is smaller for the with-compliance case than for the without-compliance one. Here, the surging occurrence was not judged and only the amplitudes of the oscillation spectrum peaks are examined.
4.3 Suppression of pressure fluctuation amplitude

Figure 11 shows the frequencies of the peaks due to cavitation surge in Figures 4, 6 and 10. Since several peaks due to cavitation surge were observed, the frequencies with the largest amplitude were treated. With and without compliance, $f^*/f_n=0.140$ and $f^*/f_n=0.052$ were selected, respectively. The original-type is indicated by the circle. The slit-type without and with compliance are indicated by the triangle and rhombus, respectively. For the original-type, the frequency decreases as the cavitation number is decreased. For without compliance, the frequency increases in $0.040 < \sigma < 0.044$ and it decreases in $0.032 < \sigma < 0.040$. By comparison with the result for the original-type, the frequencies are low for all cavitation numbers. On the other hand, with compliance, the frequencies are high by comparison with the result without compliance.

Figure 12 shows the amplitudes due to cavitation surge in Figures 4, 6 and 10. For the original-type, the amplitude curve has the Λ shape with the peak at $\sigma = 0.032$. Without compliance, the amplitude curve has the Λ shape with the peak at $\sigma = 0.037$. With compliance, the amplitude curve has the Λ shape with the peak at $\sigma = 0.038$ although the increment is smaller than other results. With respect to suppression of the fluctuation, the amplitude of the pressure fluctuation due to cavitation surge is reduced by 70% at $\sigma = 0.038$ with air by comparison with the results without air.
From the above, the frequency with/without compliance is larger/lower, respectively than that for the original-type. With respect to the pressure amplitudes for the original-type and for the slit-type with compliance, the amplitude curve has the Λ shape even though the cavitation number of the peak is different. For the slit type with compliance, the amplitude of the pressure fluctuation is reduced by 70% at $\sigma=0.038$ by comparison the result without compliance.

5. Conclusion
(1) In the unsteady region of the suction performance curve, the V shape for the original-type and branch-type and the W shape for the slit-type are observed.
(2) With respect to suppression of the fluctuation, the amplitude of the pressure fluctuation due to cavitation surge is reduced by 34% at $\sigma=0.030$ for the branch-type and by 80% at $\sigma=0.031$ for the slit-type. The slit-type is more effective for suppression effect of cavitation surge than the branch-type.
(3) With respect to the effect of compliance, with air, the amplitude of the pressure fluctuation is reduced by 70% at $\sigma=0.038$ by comparison the result without air.

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