Experimental Characterization of Thermodynamic Effect on Two-Bladed Inducer Alternate Blade Cavitation

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Abstract: The thermodynamic effect on alternate blade cavitation of two-bladed inducer has been experimentally investigated using a Seoul National University (SNU) water tunnel test facility. Non-dimensionalized thermal parameter has been varied from 0.12 (low) to 1.05 (high). Flow coefficient and Reynolds number have been held constant for all cases to control the angle of attack and viscosity effects. The cavity length on each blade has been investigated as a function of the cavitation number. The intensity of the alternate blade cavitation (the difference between long and short cavity) has been also examined. It is shown that the intensity of the alternate blade cavitation does not vary much as thermal parameter changes. Furthermore, as cavitation number drops below a certain value, the effect of thermal parameter on the cavity length becomes negligible.

Keywords: Two-bladed inducer; Alternate blade cavitation; Thermodynamic effect

1. Introduction

Inducer cavitation has gained much attention because of its unfavorable effects such as noise and blade erosion. Also, in certain range of cavitation number, it was shown that cavitation instabilities exist in the inducer, which are caused by cavity oscillations. Apart from the unfavorable effects caused by cavitation, cavitation instabilities themselves can lead to undesired excitation of the propulsive system and even failure. For example, Tsujimoto et al. [1] categorized cavitation instabilities which can occur in a three-bladed inducer. Hence, the behavior of the inducer cavitation (average cavity extent or inducer cavitation instability) at various cavitation number has been studied. With the usage of cryogenic fluids as a working fluid, however, it was shown that the cryogenic fluids exhibit lesser extent of cavitation than water due to 'thermodynamic effect' (also known as 'thermal effect') even though they are subjected to the same cavitation number. To make the water tunnel experiment valid and to fully exploit this favorable thermodynamic effect, the thermodynamic effect on the cavity extent and the amplitude of cavitation instabilities has been studied [2].

However, thermodynamic effect on a two-bladed inducer is rarely investigated. Therefore, this paper presents the thermodynamic effect on a two-bladed inducer, especially the thermodynamic effect on cavity length and alternate blade cavitation. The cavity length is investigated for various cavitation number including both equal-length cavity range and alternate blade cavity range with three different non-dimensional thermal parameters. Also, to examine the magnitude of the alternate blade cavitation, shorter cavity length is plotted against longer cavity length to visualize the difference between two different cavity lengths.

2. Experimental Setup

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The experiments have been conducted in the Seoul National University Water Tunnel Test Facility (SNU-WT) (Figure 1). A detailed description of the facility is given in Kim et al. [3]. To visualize the inducer cavitation and measure the cavity length, an acrylic test section has been installed to provide optical access. Also, an electric heater and a vacuum pump is attached to the water tank to control the water temperature and inducer inlet pressure. By controlling inducer inlet pressure, various cavitation numbers can be obtained. Three different non-dimensional thermal parameters (0.12, 0.37, 1.05) are examined by controlling water temperature to 45, 55, and 65 degree Celsius. The non-dimensional thermal parameter is defined as follows:

$$\Sigma^* = \sqrt{\frac{C}{U^3}}\frac{(\rho_v L)^2}{\rho_l^2 C_{pl} T_\infty \sqrt{\alpha_l}} \tag{1}$$

where C and U are characteristic length and velocity, respectively, ρ_v and ρ_l are saturated vapor and liquid density, L is latent heat, C_{pl} is liquid specific heat at constant pressure, and α_l is liquid thermal diffusivity.

The two-bladed inducer used for the present experiment is shown in Figure 2. Details about the two-bladed inducer can be found in [4].

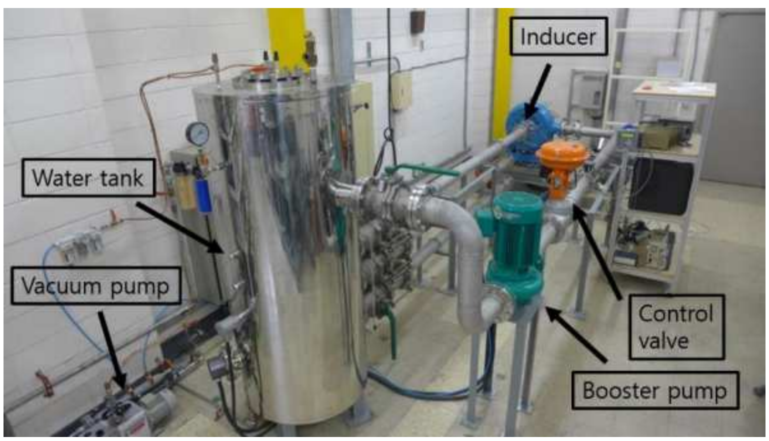

Figure 1. Seoul National University Water Tunnel.

Figure 2. Two-bladed inducer.

3. Results & Discussion

The cavity lengths for three different thermal parameters have been plotted against cavitation number in Figure 3. The cavity lengths are normalized with chordwise throat position measured from the inducer blade tip leading edge (c^*). Red, green, and blue lines correspond to low, medium, high thermal parameter, respectively. As the thermal parameter increases, it is shown that the development of the cavity is deferred. For the same cavitation number, the cavity extent is smaller with larger thermal parameter as reported in previous research [5]. However, regardless of the thermal parameter, the alternate blade cavitation starts to occur at the fixed normalized cavity length of 0.7. In other words, the alternate blade cavitation is triggered when the cavity length reaches 70% of the throat. This constant triggering length for the cavitation instability is also reported in previous research both for alternate blade cavitation and super-synchronous rotating cavitation [2]. Therefore, it can be said that the normalized cavity length of 0.7 is the general condition that the interaction between cavity and adjacent blade, which is responsible for the cavitation instability, starts. As the cavitation number gets lower and the normalized cavity length gets larger than

1.5, the cavity lengths on both blades are equal again and the alternate blade cavitation disappears. In this region, the thermal effects are negligible that the cavity length is not deferred much with increasing thermal parameter. Although this result is not consistent with the previous results [6], which shows that the thermal effects were enhanced as the normalized cavity length gets larger, a qualitative explanation can be done. While the cavity gets thinner as the thermal parameter increases, in the region of small cavitation number at near choke, the blockage effect due to cavitation decreases with higher thermal parameter. If the blockage effect is strong, the meridional velocity gets larger, and this affect the angle of attack of the adjacent blade to decrease. Hence, large thermal parameter induces small blockage effect and the angle of attack of the adjacent blade remains large. Due to the balancing between small cavity extent caused by large thermal parameter and large angle of attack caused by thin cavity, thermal effect becomes negligible in the large cavity range (small cavitation number).

To further investigate the thermal effect on the alternate blade cavitation, the length of the shorter cavity is plotted against the length of the longer cavity in Figure 4. For an equal length cavity, data points are plotted on the line y=x. From Figure 4, it can be shown that the diverging and converging pattern of alternate blade cavitation is independent from thermal parameter. Even though the evolution of cavity with respect to the cavitation number is deferred by thermal parameter, sets of long and short cavity lengths remain the same as the alternate blade cavitation triggering cavity length. The independency of alternate blade cavitation from thermal parameter can also be seen in the super-synchronous rotating cavitation [7]. While other cavitation instabilities such as cavitation surge, sub-synchronous rotating cavitation, and asymmetric cavitation are mitigated by increasing the thermal parameter [8], super-synchronous rotating cavitation and alternate blade cavitation is not affected much by the thermal parameter. Therefore, it can be tentatively concluded that the instabilities which occurs at higher cavitation number is less affected by thermal parameter due to small thermal effect at early stages of cavitation developments.

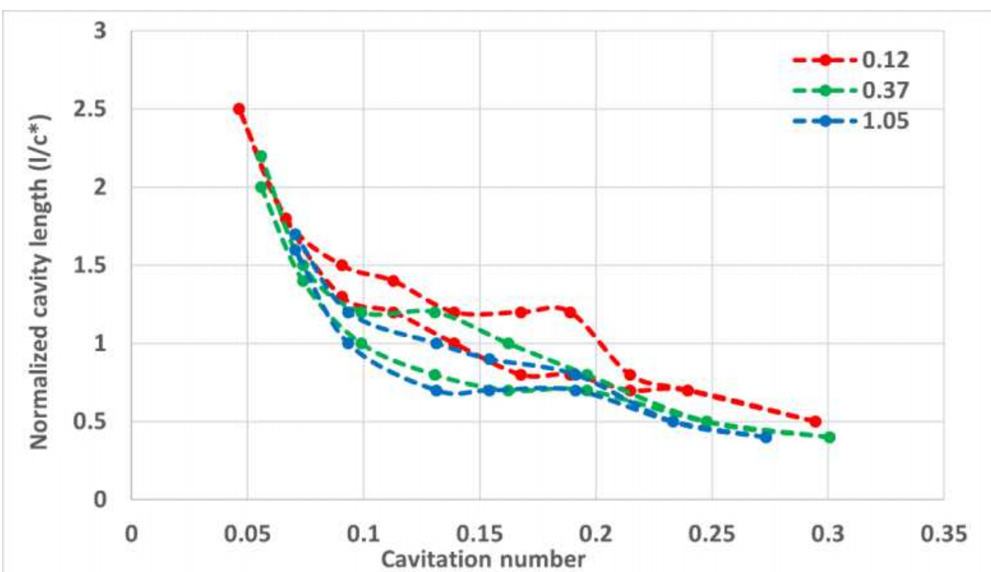

Figure 3. Normalized cavity length for three different non-dimensionalized thermal parameters.

4. Conclusion

By experiments with two-bladed inducer at different non-dimensional thermal parameters, the following points regarding the thermal effect of alternate blade cavitation were clarified.

(1) Regardless of the thermal parameter, alternate blade cavitation starts at constant cavity length.

(2) The difference between long & short cavity lengths remains the same even the thermal parameter varies.

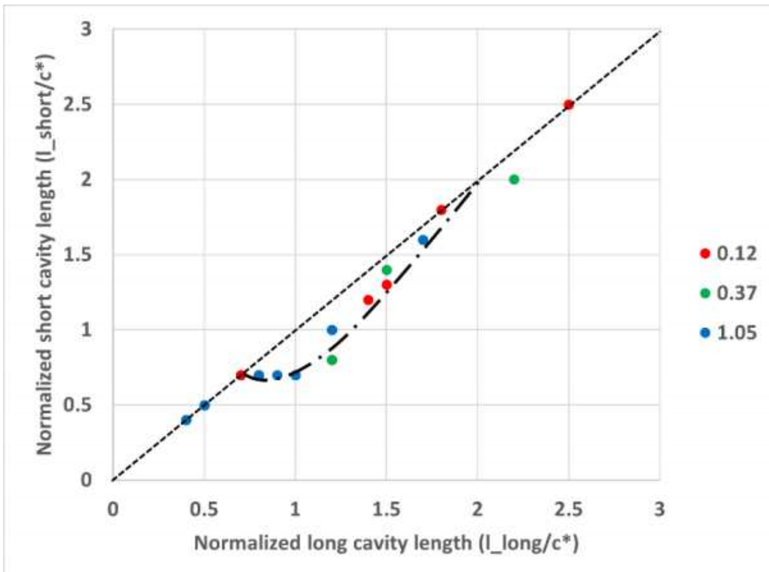

Figure 4. Cavity length difference between long cavity and short cavity.

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