International Journal of Multiphase Flow 89 (2017) 290–298

Contents lists available at ScienceDirect

International Journal of Multiphase Flow

journal homepage: www.elsevier.com/locate/ijmulflow

Experimental investigation of the global cavitation dynamic behavior in a venturi tube with special emphasis on the cavity length variation

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ARTICLE INFO

Article history:
Received 10 May 2016
Revised 30 September 2016
Accepted 13 November 2016
Available online 18 November 2016

Keywords:
Cavitation dynamics
Venturi tube
Cavity length
Cloud cavitation

ABSTRACT

Experiments were conducted to investigate the global cavitation behavior in a venturi tube. Images of various cavitation stages were captured and analyzed to study the development characteristics of the cavity length and the factors influencing the cavity growth. The results show that once cavitation occurs, the flow rate remains almost constant regardless of the outlet pressures variations, and the pressure ratio and cavitation number are linearly related. Cavitation occurs each time regardless of the inlet or outlet pressure at the same critical pressure ratio of 0.89, which corresponds to a critical cavitation number of 0.99. The cavity length is only the function of the pressure ratio or the cavitation number independent of the inlet pressures. The development tendency of the cavitation structure and the cavity length can be divided into two sections by a transition pressure ratio of 0.47 (corresponding to a transition cavitation number of 0.51). When the pressure ratio is greater than the transition value, the upper and lower parts of the cavity cloud do not touch each other yet and the cavity length increases relatively slowly as the pressure ratio decreases. Below the transition value, the upper and the lower parts of the cavity cloud meet along the centerline and the cavitation becomes more sensitive to the decreasing outlet pressure resulting in the cavity length increasing faster. However, the cavity lengths in the both parts are linearly related to the pressure ratios or cavitation numbers.

1. Introduction

Cavitation is generally defined as the inception, growth and subsequent collapse of micro-bubbles or cavities due to very low local pressures or high pressure fluctuations in a liquid (Franc and Michel, 2006; Luo et al., 2016). Many studies have been conducted with various methods to further understand this complex two phase phenomenon. A wide range of experiments have investigated many aspects of cavitation, such as the inception mode (Katz and O' hern, 1986; Kravtsova et al., 2014; Tsujimoto et al., 1997), instability (Long et al., 2009), vapor fraction (Aeschlimann et al., 2011; Hassan et al., 2014), cavitation structure (Arndt et al., 2000; Coutier-Delgosha et al., 2006; Peng et al., 2016), etc. Numerical methods have also been used to achieve more detailed information about the cavitation which cannot be seen by experiments (Ji et al., 2015, 2016; Wu et al., 2015).

One of the most important reasons why cavitation has attracted so much attention is its frequent occurrence and undesirable effects such as vibration and noise, surface erosion and performance reductions (Chen et al., 2008; Dular, 2016; Hutli et al., 2016; Park et al., 2009; Xiao and Long, 2015). The parameters contributing to cavitation damages such as the vibration frequency, the region suffering from erosion and the effect of pressure impact all vary significantly in different cavitation stage, which results in different failure modes and different damage classes with cavitation. Thus, it is very important to develop some methods to predict the cavitation stage. The cavity length is a key parameter during different cavitation stages that is used as the characteristic parameter to represent the different cavitation stages (Sato et al., 2002). Nevertheless, the cavity length is difficult to measure, so flow parameters such as the flow rate and pressure are used in real applications. Therefore, the relationship between the flow parameters and the cavity length is important so that the cavity length can be predicted from the flow parameters to judge the cavitation stage and the cavitation behaviors.

Hydrofoils and venturi tubes are two of the most common fluid devices that suffer from cavitation damage. The relationship be-

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http://dx.doi.org/10.1016/j.ijmultiphaseflow.2016.11.004
0301-9322/

Nomenclature

D	diameter or distance
e	error
I	original image captured
I_c	normalized image involved in calculation
L	cavity length
L^*	dimensionless normalized cavity length
p	static absolute pressure
p_r	pressure ratio
p_v	saturation vapor pressure
Q	volume flow rate
v	cross-sectional mean velocity
W	width
Px	pixel position

Greek symbols

α	angle of convergent part
β	angle of divergent part
ρ	density
σ	cavitation number
θ	half angle of view

Subscripts

c	critical
l	liquid
in	inlet
out	outlet
ref	reference
s	sight
t	transition
th	throat

tween the cavity length and the flow parameters on a hydrofoil has been investigated by some researchers. The experiments of Le et al., (1993a, b) show that the non-dimensional cavity length (l/c) is the function of the non-dimensional parameter $\sigma/(\alpha-\alpha_i)$, where l is the measured cavity length, c is the foil chord length, σ is the cavitation number, α is the angle of attack and α_i is the inception angle of attack. All the experimental points collapsed well around an L-shaped curve. The experimental results agreed well with the theory of Tulin (1953) for supercavitation and the theory of Acosta (1955) for partial cavitation. The experiments of Kjeldsen et al. (2000) on a 2D hydrofoil with an NACA 0015 cross section combined with the equivalent 2D data adjusted from 3D data for a NACA 0015 hydrofoil with an elliptical planform by Arndt et al. (1995) represented a similar law that the non-dimensional cavity length (l/c) almost increases almost linearly with the decrease of the non-dimensional parameter, $\sigma/2\alpha$, when $2° \le \alpha \le 8°$, this also indicates that the quasi-2D theory of Watanabe et al. (1998) gives reasonable estimates of the cavity length for elliptically loaded hydrofoils.

On the other hand, the prediction of the cavity length based on the flow parameters in a cavitating venturi geometry is not as well understood. Rao and Chandrasekhara (1976) found a similar law of cavity length on a cylindrical inducer in a venturi to that of the hydrofoil. However, the cavitation on a cylindrical inducer is essentially the external cavitation like that of a hydrofoil, not like the internal or confined cavitation in a venturi geometry. Mishra and Peles (2006) observed the cavitation in a micro-venturi with a rectangular cross section and measured the cavity length variation with the cavitation number, but the data was for only one inlet pressure and there was only a small amount of data. Dular et al. (2012) investigated the scale effect on cloud cavitation in a rectangular venturi geometry. They used the pressure of the throat to calculate the cavitation number and found that the non-dimensional cavity length and the cavitation number had a very precise one-to-one correspondence regardless of the test section size variation. Sayyaadi (2010) concluded from the snapshots of cavitating flow in a venturi that the operating pressure had negligible effect on the cavity length for a given cavitation number. However, cavitation is inherently unstable, so the conclusions based on the snapshot were not that much reliable. Abdulaziz (2014) studied cavitation with infra-red light source and found that the vapor formation distribution in a small venturi along the axis were nearly the same when the pressure ratio was 0.5.

Despite many studies, there is still no general relationship between the cavity length in a venturi tube and the various flow parameters or operating conditions. The cavity length cannot be predicted from the flow parameters yet. This study tries to solve that problem based on experiments. Comprehensive tests are conducted on a venturi tube for various inlet and outlet pressures. Images of various cavitation stages are captured and analyzed based on the image post processing proposed to relate the cavity length to the flow parameters. The development tendency and the influence of the cavitation structure were also analyzed.

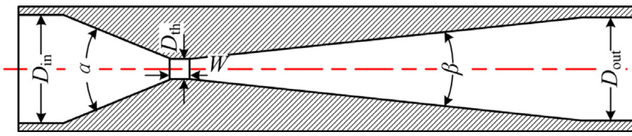

Fig. 1. Schematic drawing of tested venturi tube.

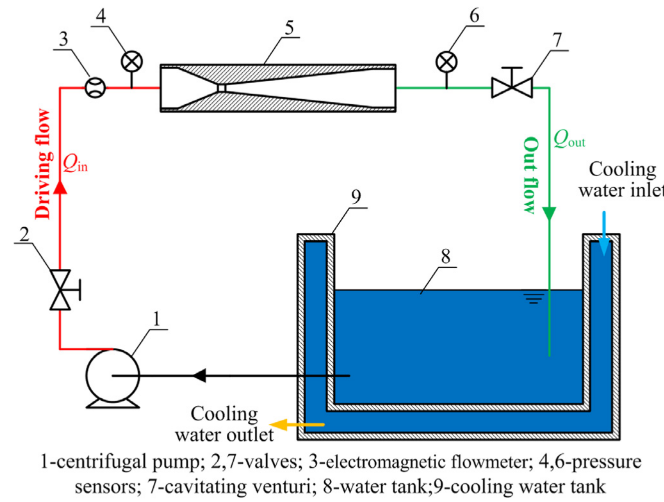

Fig. 2. Sketch of the experimental rig.

2. Experimental rig and procedure

2.1. Experimental rig

Fig. 1 shows a schematic drawing of the tested venturi tube. The convergent part angle, α, was 45° while the divergent part angle, β, was 12° The inlet diameter, D_{in}, and the outlet diameter, D_{out}, were both 50 mm. The throat diameter, D_{th}, and length, W, were both 10 mm. The venturi tube was made of transparent organic glass for the convenience of visualization of the cavitation process and its outside was made quadrate to reduce the influence of refraction and reflect for the purpose of obtaining better images.

The experimental system is schematically illustrated in Fig. 2. The volume flow rate was controlled by valves and measured by electromagnetic flow-meter mounted in the upper stream of the venturi tube. The lengths of the long straight pipes upstream and downstream the electromagnetic flow-meter were both 12DN, i.e.