Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 22, 2009

Comparison of CFD and Test Techniques for Cavitation Inception

Do Hwan Lee [a*], Sung-Keun Park [a], Sun-Ki Lee [a], Byung Kon Kim [b]
[a]*Korea Electric Power Research Institute, Nuclear Power Lab., 103-16 Munji-dong, Yusung-gu, Daejon, 305-380*
[b]*M&D Corp., Yongsan-dong, Yusung-ku, Daejon, 305-380*
[*]*Corresponding author: dhsmf@kepri.re.kr*

1. Introduction

Cavitation erosion on centrifugal pump impellers is a one of the fundamental factors that cause performance degradation and life shortening of the pumps. One approach to estimate the expected life of an impeller is to use sheet cavity length on the blade surface. While observing the cavity length is more suitable to accurately predict the impeller damage, it is not readily available in the field or on the test stand. Recently, the prediction of the cavity length by using commercial CFD codes has been tried by several authors [1,2]. As an alternative to direct measure the cavity length of an impeller, a means of estimating cavity length of an impeller based on the relation of operating NPSH to that of 3% NPSH and inception NPSH was developed by Cooper [4]. Although this method seems to be attractive, it is not easy to accurately estimate the inception NPSH without flow visualization. Some recent researchers has been paid attention to apply the high frequency Acoustic Emission(AE) technique to detect cavitation inception of pumps [3,4].

As an effort to better estimate the cavity length without relying on flow visualization, CFD calculations and experiments were performed and then the results are compared in this study.

2. Methods and Results

In this section CFD and AE techniques used to predict the cavity length are presented and results are introduced.

2.1 Experimental Methods

The cavitation experiments were conducted by using a closed loop which was designed to produce various cavitation conditions with compressor and vacuum facilities. An 11kW single-stage centrifugal pump operating at 1750 rpm was employed for the study. Two AE sensors with a relative flat response between 30 to 180kHz were located at the pump suction position and on the pump casing near the impeller eye. The AE r.m.s values were continuously calculated for a record length of 10ms. The r.m.s AE, flow rate, suction and discharge pressure signals were sampled synchronously at 10Hz.

The correlation of cavity devised by Cooper [5] used in the present study is

$$\mathbf{L_{cav}} = \frac{\pi \mathbf{D_e}}{\mathbf{n_b}}\left\{1-\left[\frac{\sigma_A-\sigma_3}{\sigma_i-\sigma_3}\right]^{1/3}\right\} \quad \text{for } \sigma_A < \sigma_i \text{ (mm)} \quad (1)$$

where $\mathbf{D_e} =$ blade inlet tip diameter
$\mathbf{n_b} =$ number of impeller blades
$\sigma = \mathbf{NPSH}/(\mathbf{U_e^2}/2\mathbf{g})$
$\mathbf{U_e} =$ blade inlet tip speed

Given the cavitation coefficient σ_i, the cavity length is calculated by using geometry and operating parameters.

2.2 Computational Method

Full 3-D simulations were performed with the finite volume code ANSYS CFX 11.0. The SST model was adopted for the turbulent calculation. Constant total pressure and mass flow rate were imposed as the inlet and outlet boundary conditions. Frozen rotor sliding interfaces were applied to the casing and impeller interfaces. A homogeneous model was used for the cavitation calculation. The three-dimensional computational domain was constructed by tetrahedral, pyramid and prism elements (about 1,300,000 elements).

Since the cavity length with the vapor fraction greater than 12.5% is known to have best correlation with visual results and actual field experience, the vapor fraction of 12.5% was used to define the cavity length [6]. The cavitation inception NPSH for predictions is determined as the point at which vapor volume is beginning to create.

2.3 Results

Figure 1 depicts the graph of NPSH along with head for the pump at a flowrate of 0.3 m^3/s obtained from experiments and numerical simulations. The calculated values show good agreement with the experimental results for NPSH > 5. However, it is noticed that NPSH of the prediction at 3% head drop is largely deviated from measured one.

AE r.m.s levels along with NPSH measured in the experiments are shown in Fig. 2. The schematic of pressure measurements by Güelich [5] is shown in Fig. 3 for comparison. Comparing Fig. 2 with 3, it is found that the shapes of curves are similar and slope changes between background and peak signal levels are shown in both curves. As claimed by Güelich [5], the noise levels increase much earlier than the visually identifiable inception point (point 2 in Fig. 4) whereas the erosion generally begins at near the NPSH where the slope of noise levels changes. Therefore, in this study, the cavititation inception NPSH is defined at the point where slope of AE r.m.s levels changes. From the definition, the cavitation inception NPSH is determined as NPSH=12 for this experiment. $NPSH_i/NPSH_3$ is found to be about 4. This value is comparable to the typical NPSH relations for normal design impellers, i.e., $NPSHi/NPSH_3$ = 4~6 [5]. Based on the expression (1), the NPSH for the cavity length of 1% of the impeller mean outlet diameter is estimated as NSH=9.4.

Figure 4 gives the water vapor fraction distribution of the blade at NPSH=3.7. Based on the 12.5% vapor fraction criterion, the cavitation inception NPSH is found to be NPSH=3.7~5.7. This is at least two times less than measurement estimates. Considering cavitation inception NPSHs with $NPSH_3$ estimates in Fig. 1, the CFD provide lower values than the AE technique.

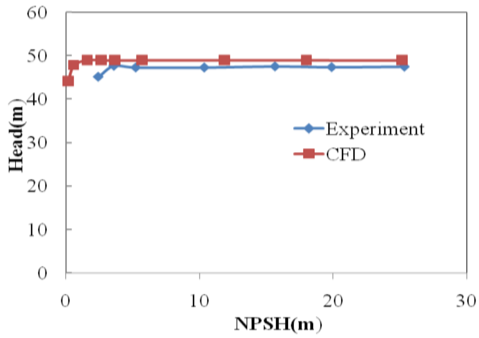

Fig. 1 NPSH versus head obtained from experiments and CFD predictions at a flow rate of 0.3 m^3/min

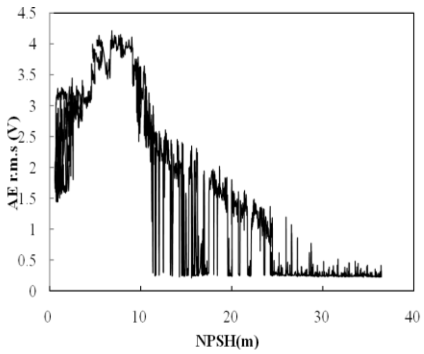

Fig. 2 Variation of AE r.m.s. values with NPSH on the pump casing at a flow rate of 0.3 m^3/min

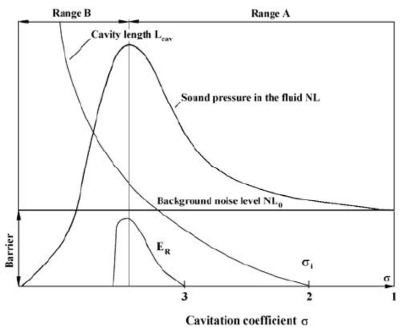

Fig. 3 Schematic of noise and cavitation coefficient relations

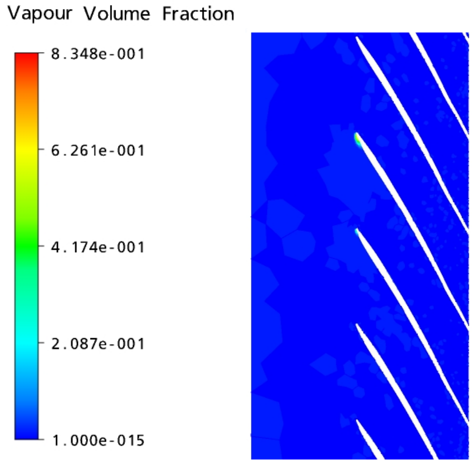

Fig. 4 Predicted vapor volume fraction at NPSH=3.7

3. Conclusions

The applicability of CFD and Acoustic Emission(AE) techniques to predict cavity length is examined. AE technique gives conservative results for the detection of cavitation inception and 3% of NPSH rather than CFD.

REFERENCES

[1] P. Dupont, T. Okamura, Cavitating Flow Calculations in Industry, International Journal of Rotating Machinery, Vol.9, pp. 163~170, 2003.

[2] F. C. Visser, Some User Experience Demonstrating the Ue of Computational Fluid Dynamics for Cavitation Analysis and Head Prediction of Centrifugal Pumps, Proceedings of ASME FEDSM'01, pp. 1~6, 2001.

[3] L. Alfayez, D. Mba, G. Dysonl, The application of Acoustic Emission for detecting incipient cavitation and the best efficiency point of a 60kW centrifugal pump; case study, NDT & E international, Vol. 38. p. 344, 2005.

[4] G. D Neill, R. L. Reuben, P. M. Sanford, E. R. Brown, J. A. Steel, Detection of Incipient Cavitation in Pumps Using Acoustic Emission, IMechE, Vol. 211 Part E. p267-277, 1997

[5] J. F. Gülich, Centrifugal Pumps, Springer, 2007

[6] D. P. Sloteman, Cavitation in High Energy Pumps – Detection and Assessment of Damage Potential, 23rd International Pump Users Symposium, Lecture 6, 2007.