Politechnika Śląska

Instytut Maszyn i Urządzeń Energetycznych

Eksperymentalne i numeryczne badanie zjawiska kawitacji dla różnych warunków przepływu

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Rozprawa doktorska

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Abstract

The topic of dissertation is numerical and experimental investigation of cavitation phenomenon in the flow. Cavitation is a complex process that includes both forming and collapsing of vapour bubbles in the liquid flow. The vapour bubbles can form cavitation structures of complex shapes which change dynamically. As far as turbomachinery performance is concerned, the effects of cavitation in the flow are negative ones. It is connected with the cavitation accompanying phenomena such as: shock waves propagation in the flow, generation of vibrations, noise, damage of the machine elements (blades, casing, etc.) due to the cavitation erosion. Cavitating flow in pumps or water turbines rotors can lead to drop in performance curves and in case of developed cavitation can result in breaking flow continuity and machine breakdown.

In the dissertation the process of cavitation structures forming, developing and collapsing was analysed. The structures were treated as a whole; the dynamic of a single bubble was not taken into consideration. The investigation was focused on cavitation that occurs during flow over a foil. This flow is typical for turbomachinery such as pumps and water turbines. Moreover, the flow in the convergent – divergent nozzle (Venturi nozzle) was analysed.

The experimental investigation of cavitating flow on ClarkY 11.7% foil was described. The results of measurements were presented. The pictures of the cavitating flow obtained during the flow visualization were depicted. The characteristic phenomena of cavitating flow were observed: the reentrant jet occurrence, structures detachment from the foil surface and the collapse of structures in the trailing edge region. It was noticed that the lower cavitation number, the longer cavitation structures became and lower frequency of changes was observed. The frequencies varied from 37.5 Hz to 15 Hz. Different types of cavitation structures were obtained during the experiment: incipient cavitation, periodically changing partial cavities and developed cloud cavitation.

In the dissertation the results of cavitating flow simulations obtained with different cavitation models and different solvers are presented. The 2D calculations of cavitation on the foil were conducted in both OpenFOAM and FLUENT software.

In OpenFOAM the comparison of two cavitation models: Schnerr-Sauer model and Kunz model were performed. Kunz cavitation model was chosen for further analysis due to the better quality of obtained results and lower computational cost. The calculations stability was strongly dependent on the simulations sequences. The numerical scheme was very vulnerable to the value of time step. In the pictures of flow obtained numerically the characteristic phenomena of this type of flow were observed, which proved that the numerical model was properly applied. The frequencies of changes in case of numerical and experimental investigation were of the same magnitude. The discrepancies in the results can proceed from both the simplifications assumed in the calculations and the method of frequency assessment on basis of flow pictures taken by high speed camera. The areas occupied by the vapour structures were bigger in case of experimental investigation. Due to the limits of the measurement equipment the analysis of cavitation structures was performed only qualitatively.

In FLUENT software the simulations of cavitating flow were conducted with use of Singhal cavitation model. This enabled to take into account the level of non-condensable gases (NCG) in the liquid. The cavitating flows with different values of NCG mass fraction were examined. The influence on frequencies of changes was slight. With the increase of NCG mass fraction the amplitude of changes became higher, but there was some limit value of NCG mass fraction at which the oscillations were damped down and the structure became stable. The averaged values of lift and drag coefficients were similar for all investigated values of NCG mass fractions. However, the shapes of cavitating structures were different. With the increase of NCG mass fraction in the flow the gas cloud became shorter and higher and the gas-liquid interface became misty. The results of the calculations are in good agreement with the effect of smearing the phase interface due to the high level of dissolved air in the flow, reported in the literature.

The flow in the Venturi nozzle was also examined. The turbulence models test was conducted. The Schnerr-Sauer cavitation model was used in calculations. It was observed that the small amount of air added to the flow improved the compatibility between numerical and experimental results.

Cavitating flow in the complex geometry was also analysed. The simulation of cavitation occurrence and development in pump rotor was performed. As a result the H(NPSH) curve was obtained. The critical value of NPSH was determined on the basis on 3% pressure head drop criterion. The conducted calculations proved the utility of the used numerical tool to assess the potential effects of cavitation in pump flow.

Modelling of cavitating flow with regard of its whole comprehensiveness requires careful assessment of model constant, numerical scheme and calculations process parameters. It is recommended to further improve the model so that some modifications of turbulence model and fluid compressibility are included. However, the more complex the cavitation model becomes, the calculations stability will be more difficult to keep.