Numerical Simulation of Various Mechanisms of Cavitation Erosion

Long Abstract

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Introduction

In the past, cavitation shedding process and its relation to the erosive potential of cavitation was frequently discussed. Currently the most widely accepted general explanation of the phenomenon is that the potential energy contained in a macro-cavity is transformed into the radiation of acoustic pressure waves, and further on into the erosive power contained in the micro-scale cavitation structures or single bubbles that implode in the vicinity of the material boundaries.

Recently Dular & Petkovsek [1, 2] performed several experiments where they have attached a thin aluminum foil to the surface of a transparent Venturi section using two sided transparent adhesive tape. The surface was very soft – prone to be severely damaged by cavitation in a very short period of time. Using high speed cameras, which captured the images at up to 30000 frames per second, they simultaneously recorded cavitation structures (from several perspectives) and the surface of the foil. Analysis of the images revealed that five distinctive damage mechanisms exist (Fig. 1) – spherical cavitation cloud collapse (H), horseshoe cavitation cloud collapse (L), the "twister" cavitation cloud collapse (O) and in addition it was found that pits also appear at the moment of cavitation cloud separation (E) and near the stagnation point at the closure of the attached cavity (C).

In the present study we show fully compressible, cavitating flow simulations which resolve the formation of the shock waves at cloud collapse – these are believed to be directly related to the formation of the damage. We have successfully simulated all the experimentally observed erosion mechanisms. The work shows a great potential for future development of techniques for accurate predictions of cavitation erosion by numerical means only.

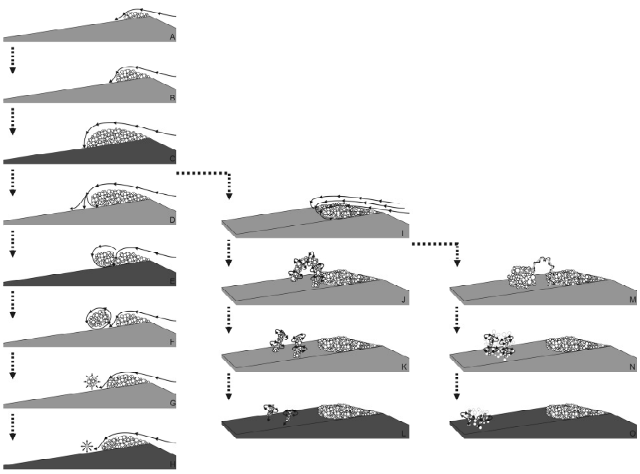

Figure 1: Schematic representation of observed mechanisms that lead to occurrence of cavitation erosion. The instants of damage appearance are denoted by the darker colour [2].

1. Methods

The applied governing equations were based on the conservation form of the Reynolds averaged Navier-Stokes equations, including mass continuity, momentum equation and energy equation.

The liquid phase and vapor phase are treated as a homogeneous mixture based on the volume of fraction. The mixture density and viscosity are defined as a function of vapor volume fraction.

Since the standard k-ε model is over-estimating the eddy viscosity in the mixture region, it cannot effectively resolve the detachment of the cavity from solid surface and excessively attenuates the cavitation instability. Therefore a modified RNG k-ε model was employed in this work.

Based on our previous positive experience, a precise cavitating prediction performance and a good convergence behavior the Zwart-Gerber-Belamri model was applied to model evaporation and condensation.

As compressible approach was adopted. The vapour obeyed the ideal gas law and the liquid density variation was described via Tait equation.

The commercial CFD code "ANSYS-Fluent" was used to solve the URANS equations summarized above. A mass flow rate and static pressure boundary conditions are imposed on the inlet and outlet respectively, strictly following the experimental data.

On the premise of ensuring the temporal accuracy, all the simulations were initiated by running the calculation under upwind scheme based on COUPLED algorithm for four shedding periods until a time-periodic solution has been reached, with a time step of 1.6×10-7 s.

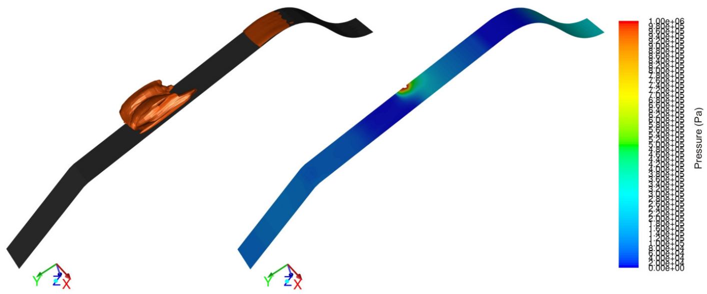

Figure 2: Pressure peak, with an amplitude exceeding 10 bar, occurring during a small scale cavitation structure collapse.

References

[1] M. Petkovšek and M. Dular. Simultaneous observation of cavitation structures and cavitation erosion, *Wear* **300** (1/2) (2013) 55-64.

[2] M. Dular and M. Petkovšek. On the Mechanisms of Cavitation Erosion – observing them at 30000 frames per second. Submitted to *Experimental Thermal and Fluid Science*, (2015).