Numerical cavitation erosion assessment of a water jet pump

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Abstract. This study investigates cavitation erosion in a commercial water jet pump through numerical methods, with comparison to experimental paint test. The multiphase flow is modelled using a mixture modelling approach within an unsteady Reynolds Averaged Navier-Stokes (RANS) framework. The erosion model used, identifies and stores the "collapse cells" that contribute to erosion together with a measure of their erosion aggressiveness. This algorithm checks all cells at the end of each time step to avoid incorrect identification of erosion areas. The comparison with experiments indicates that the proposed methodology is a reliable tool to assess cavitation erosion.

1. Introduction

Cavitation erosion is a critical phenomenon in water jet pump operations, characterized by the continuous cycle of vapor generation and violent collapse adjacent to the solid surfaces of the pump. This process leads to surface damage through micro-jetting and shockwave impacts, which cumulatively can cause significant wear on the pump materials. Over time, this degradation reduces the pump performance and accelerates its wear, leading to a reduced operational lifespan. Therefore, understanding and mitigating this phenomenon is crucial for enhancing water jet pump durability and efficiency.

Experimental cavitation erosion assessment is challenging. Firstly, since the experiments are done on model scale, and extrapolation procedures of the results to full scale condition is not well established. Secondly, even in model scale, reliably assessment of erosion risk, usually by studying wear on a soft paint, is not straightforward. Thus, there is need for precise and reliable predictive modelling approaches to effectively manage and mitigate the detrimental effects of cavitation erosion.

It is crucial to develop models that not only capture the multiphase nature of the flow but also are (relatively) computationally cheap as this is an important factor for industrial pick-up while predicting the cavitation erosion. There are few studies that numerically investigate the cavitation erosion phenomenon of a water jet pump in particular [1-3]. These studies either employ expensive methods such as Large Eddy Simulations (LES) [1] or they do not attempt to predict erosion patterns at all but focus solely on how operating conditions affect the erosivity of the cavitation [2,3].

This study numerically investigates the cavitation erosion phenomena of a water jet-pump [1]. The main purpose of this study is to examine the performance of a newly proposed numerical methodology for this type of application by making a comparison with damage pictures from model scale cavitation erosion tests [1].

2. Methodology

The multiphase flow is modelled with a mixture modelling approach and the Schnerr-Sauer model is selected to model the mass transfer rate between phases. The two-phase water liquid and water vapor are modelled incompressible. The shear-stress transport k–ω turbulence model [4] is employed within unsteady Reynolds Averaged Navier-Stokes (RANS) formulation. The Ansys FLUENT software has been used for mesh generation and flow solving purposes.

To assess the cavitation erosion, what we denote as the MAX2-algorithm is evaluated. In this algorithm, there are three conditions that needs to be satisfied to determine if each cell is a “collapse cell” and should be considered to contribute to erosion [5]. These conditions are shown in Figure 1. As a tracked parameter for the second condition, the square of material derivative, $(DP/Dt)^2$, is tracked at each time step alongside with the additional conditions (Condition 1 and 3) to prevent fake collapses. The MAX2 algorithm loops over all cells at the end of each time step.

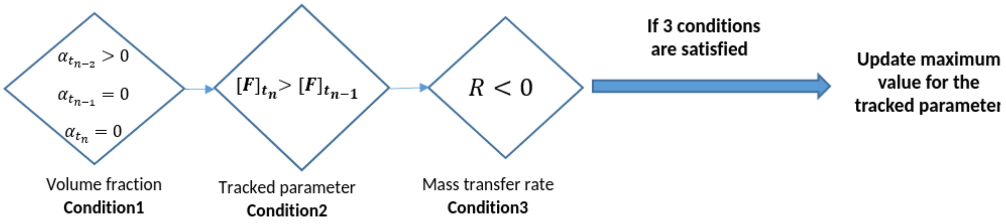

Figure 1. MAX2 algorithm and description of the variables

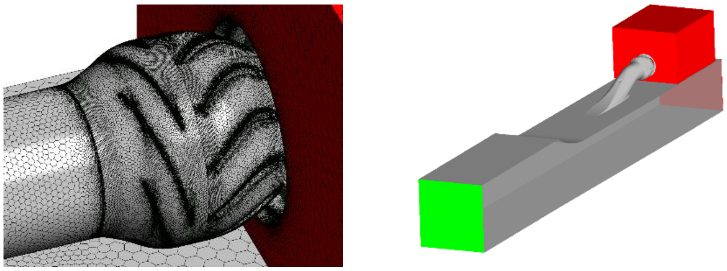

Figure 2. Representation of the computational domain with poly mesh (left) and flow topology (right)

The computational mesh has 9×10^6 cells consisting of three cell zones, which one of them is rotating rotor region. The boundary conditions are set to match the experimental condition [1]. A velocity inlet (green surface) is provided with a value of 4.58 m/s, and two outlet ports (red surfaces) are specified as pressure outlets defined as 18600 Pa with the cavitation pressure is set to 2065 Pa. Pump rotation is set as 20 revolution per second. The rotation of the rotor region is advanced with sliding mesh with a time step of 5×10^{-5} s. Flow statistics for the cavitation erosion have been collected for three revolutions after initial transients have been passed.

3. Results

Experimental results were available from previous tests performed at Kongsberg Hydrodynamic research centre. Experimental images [1] of both vapor structures (left) and erosion patterns (right) are presented in Figure 3. It is clear from the experiments that two types of cavity structures, which are sheet and root cavity, are formed during the operation. These vapor structures are continuously generated and collapsing. Due to the sheet and root cavity, two distinct damage locations, represented as A and B in right side of Figure 3, are created.

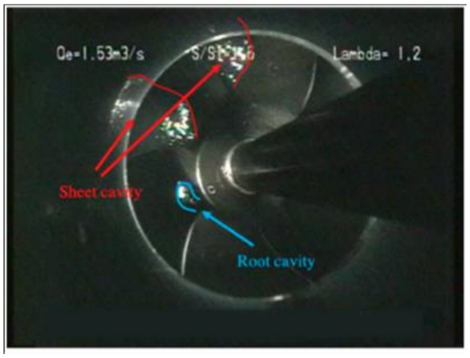

Figure 3. Experimental images of (left) vapor structures (right) erosion pattern [1]

Preliminary numerical results are depicted in Figure 4. The numerical erosion assessment is done by coloring the pump geometry with MAX2 $(DP/Dt)^2$ erosion indicator. Here, the high values of the erosion indicator (yellow color) provide an insight into the erosive aggressiveness of the cavitation. There is a good agreement with the experiments in that both A and B damage locations are well predicted, both in location and extent. The predictions indicate also a risk of erosion at the blade tip. This is not visible in this exact condition but is apparent in similar tested conditions.

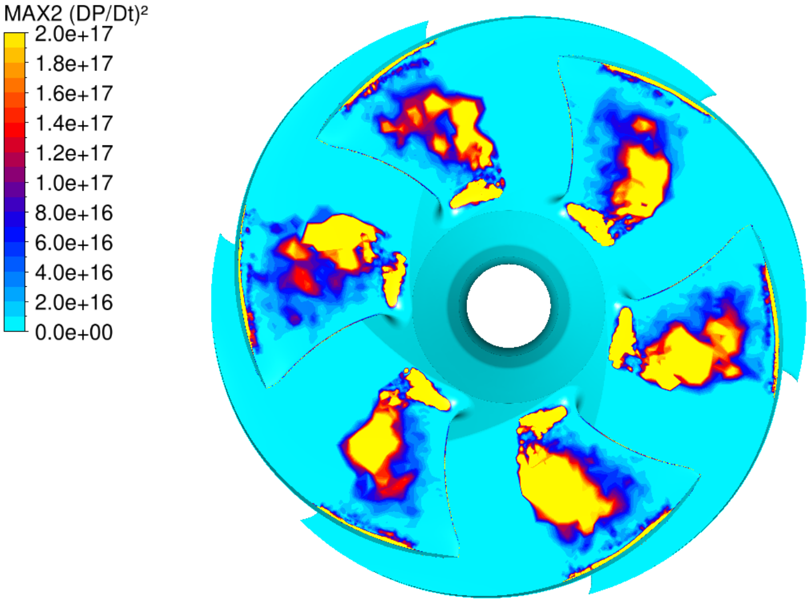

Figure 4. Cavitation erosion assessment of water jet pump with MAX2 $(DP/Dt)^2$ erosion indicator

4. Conclusions

The predictive capability of the current simulations showed that the proposed numerical methodology alongside the erosion modelling is promising. The future simulations will investigate additional operating condition that is experimentally available and previously investigated [1]. This will provide valuable insights for optimizing the performance and durability of water jet pumps.

References

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Acknowledgments

The simulations were performed on the resources provided by the National Academic Infrastructure for Supercomputing in Sweden (NAISS) and the Swedish National Infrastructure for Computing (SNIC) at Chalmers Centre for Computational Science and Engineering (C3SE) and National Supercomputer Center at Linköping University (NSC), partially funded by the Swedish Research Council through grant agreement no. 2022-06725 (NAISS) .