

Hydrodynamic Nuclei Concentration Technique in Cavitation Research and Comparison to Phase-Doppler Measurements

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Abstract. Small particles, especially bubbles in the micro-meter range, influence the cavitation of the propellers. The prediction of cavitation inception and water quality measurements are important in cavitation research. The Hydrodynamic Nuclei Concentration (HDNC) technique can be used for reliable bubble concentration measurements in fluid flows. The HDNC technique bases on the analysis of scattered light from the cavitation nuclei in the water. The HDNC technique can distinguish between bubbles and solid particles. The particle type classification is important, because the number concentration of solid particles is often much higher than the nuclei concentration in cavitation tunnels and in seawater. Verification experiments show, that the HDNC technique reaches similar capabilities in number concentration estimation as Phase Doppler (PD) technique in much shorter acquisition time.

1. Introduction and Motivation

Cavitation processes at naval vessels causes vibrations, erosion of the propeller and rudder and impairs the efficiency. Cavitation prediction models are therefore required during the design process of vessels. Current models do not represent the complexity of the cavitation process exact enough for a reliable cavitation prediction of a full scale vessel. Therefore ship model basins and propeller designers are interested in the improvement of their numerical cavitation prediction models to obtain valid results early in the design process.

The cavitation inception behaviour of a ship propeller is influenced by the water quality and especially the bubble count concentration. At low pressure regions near the propellers surface bubbles expand (fig. 1). The expanded bubbles are collapsing at high pressure regions and cause the cavitation effects. The prediction of cavitation inceptions and the determination of the scale effects include the experimental measurement of the nuclei count concentration and the nuclei size distribution in the wake flow of model and full scale. The results are applied as boundary condition for experimental and numerical prediction.

In the framework of the KonKav project, founded by the Federal Ministry of Economics and Technology (BMWi) in Germany, cavitation prediction with focus on the influence of water quality was investigated. Model scale and full scale measurements of velocity fields, cavitation observation and nuclei concentration were performed. Project partners are the Flensburger Schiffbau-Gesellschaft (FSG), Hamburg Ship Model Basin (HSVA), Technical University of Hamburg Harburg (TU-HH), Potsdam Model Basin (SVA) and the University of Rostock. First results of nuclei measurements by Phase-Doppler (PD) technique and the concept of full scale measurements were presented on the previous CAV conference in 2012 [1,2] and the further development was documented in [3].

Therefore a robust measurement technique is necessary to determine the cavitation nuclei properties in the wake flow of a ship. The developed Hydrodynamic Nuclei Concentration (HDNC) technique combines a robust, calibration free setup with moderate hardware effort and the ability to measure particle count concentrations with bubbles in the micro-meter range. Previous measurements by PD technique [3] show, that the estimation of concentration and nuclei spectra is strongly influenced by solid particles. The concentration of solid particles in navel applications is often 10 times higher than nuclei concentration. The separation of gas bubbles and solids is therefore essential for a reliable cavitation nuclei distribution statistics and is also solved by HDNC technique.



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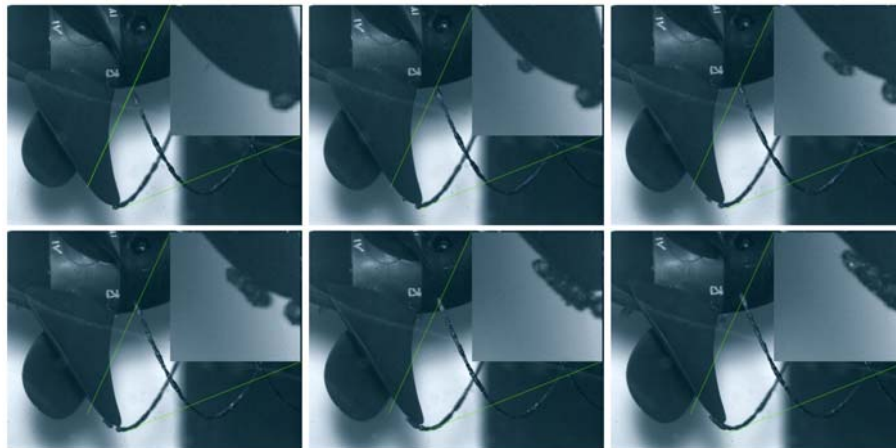


Figure 1. High speed recording of an expending cavitation nuclei near the propeller blade surface which causes tip vortex cavitation

2. Measurement principle, Setup and Image Processing

The HDNC technique uses a single laser beam which illuminates the nuclei in the wake flow and a camera for imaging the particles (fig. 2). We used a 532nm 300mW cw Nd:YAG DPSS laser. The incident laser light is scattered by the particle. A spherical bubble has two glare points in the right scattering angle of about 90°. These are imaged out of focus. An interference fringe pattern occurs. The spacing between the fringes is proportional to the bubble diameter. The exact proportionality between fringe spacing and particle diameter has to be calculated for each individual optical setup, depending on observation distance, focal length, f-number and aperture of the optics.

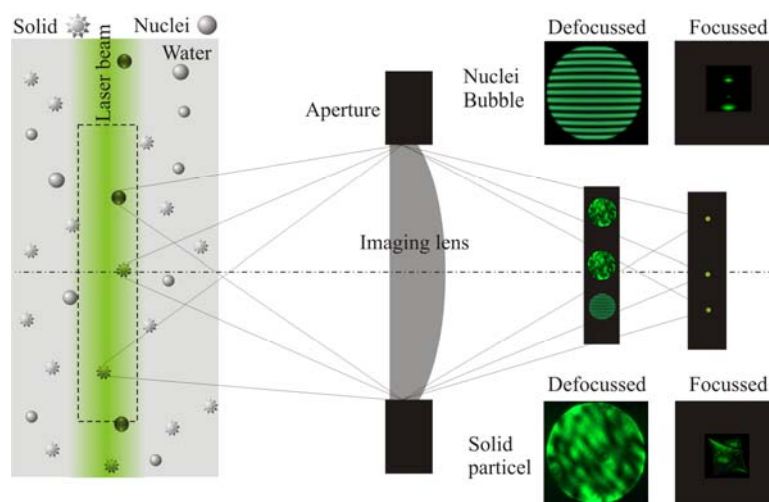


Figure 2. Schematic configuration and image generation of HDNC technique [4].

An elongated region of interest with reduced number of pixel can be used. The low required laser light energy (no pulse laser is required), the well separated and aligned defocused particle images along the imaged laser beam, the reduced hardware effort, the moderate expense alignment and the straightforward detection volume definition (required for a corrected nuclei count concentration) are the advantages of the HDNC technique (compared to PD [5] and standard IPI/ILIDS [6, 7]). A disadvantage is the higher required frame rate to reach the same statistical confidence compared to the standard IPI. Because of the significant reduced number of pixels and simpler image processing the particle rate is increased and real-time processing is possible.

An important parameter of the HDNC setup is the scattering angle between the laser beam and the imaging optics. The scattering angle decides about the imaged scattering behaviour of the nuclei. The

calculations of the light scattering of spherical bubbles in water were performed for different scattering angles, two polarizations and different sizes of the receiving aperture by using the algorithms described in [5]. We found scattering angles between 80 deg and 102 deg are suitable for measurements [4]. A scattering angle of 90 deg is preferred, because of minimized optical aberrations. The processing steps for nuclei concentration estimation are shown in Fig. 3. After pre-processing for background removal and noise suppression, the particle detection is based on template matching by different masks, based on the aperture shape. The interference structure can be used for classification of bubbles, because the spectral image characteristic of a solid particle differs from spectral characteristic of bubble images [8]. A speckle pattern appears by imaging non-spherical or inhomogeneous particles, whereas bubbles generate parallel interference fringes. After classification the nuclei or bubble diameter can be estimated from the fringe number by a spectral analysis. Classification and size calculation leads to the nuclei count concentration in advance. It is necessary to correct the obtained particle size distribution because of the inhomogeneous laser illumination and the nuclei size dependence of the scattered light intensity. Small particles are underestimated compared to larger ones.

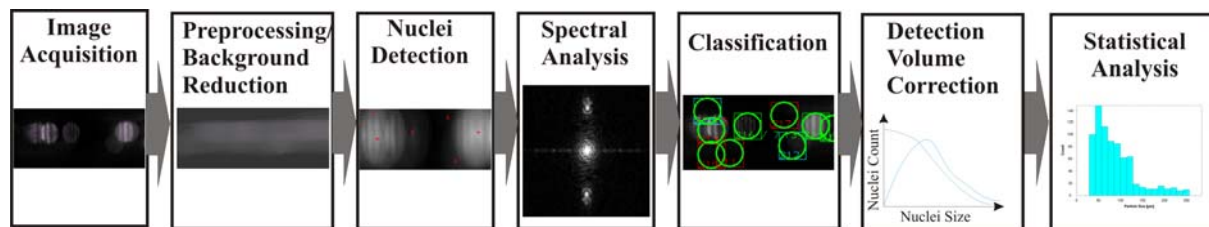


Figure 3. Processing steps for HDNC technique.

3. Measurement Results

Measurements in different cavitation tunnels (K15a SVA Potsdam and HYKAT HSVA) and full scale measurements (vessel “Amandine”) were performed. The setups and the results for full scale were already presented in [8]. The following discussion focusses on the reliability of the techniques.

One measurement campaign at K15a was intended for a comparison of the HDNC and the PD techniques. Fig. 4 shows an overview of the results (right) from this campaign. The upper graph indicates the operating conditions of the cavitation tunnel K15 during the measurements. HDNC and PD techniques were used in parallel in front of the propeller at the same position. The lower graph in Fig. 4 shows the estimated nuclei concentration. Because of the small elliptical detection volume ($< 0.016\text{mm}^3$), the applied PD technique requires approx. 12 minutes (width of the green bars) for a reliable nuclei statistics. The HDNC technique measures comparable number of nuclei in significant shorter time (width of red bars corresponds of 10s), because the detection volume was 67mm^3 . For each condition 10^4 frames were acquired by HDNC with a frame rate of 10kfps at the beginning of each PD measurements. The inevitable uncertainty from the particle counts (Poisson distribution) is shown as error bars in Fig. 4. After processing and detection volume correction the results are comparable. The first measurements (#1...13) show a quantitative discrepancy between PD and HDNC results. The deviations indicate systematic errors in the measurement process. Because of the complexity of the measurement systems and the lack of quantitative reliable methods, the systematic errors cannot be assigned to PD or HDNC technique. The authors more believe in the accuracy of the HDNC technique, because HDNC has much less parameters (Laser power, in-coupling efficiency, secondary scattering, photodetector sensitivity and gain, estimation of detection volume size) and optical components in comparison to PD-technique [5]. Furthermore the detection of solid particles is more precise for HDNC as the statistical correction in PD-technique and PD technique has generally large uncertainty (about 50%) for concentration measurements. Final statements would require well-controlled reference experiments for nuclei concentration, which are not available. Nevertheless, all experiments (especially #13...50) show same tendencies for the different working conditions and agree well by considering the complexity of the measurements.

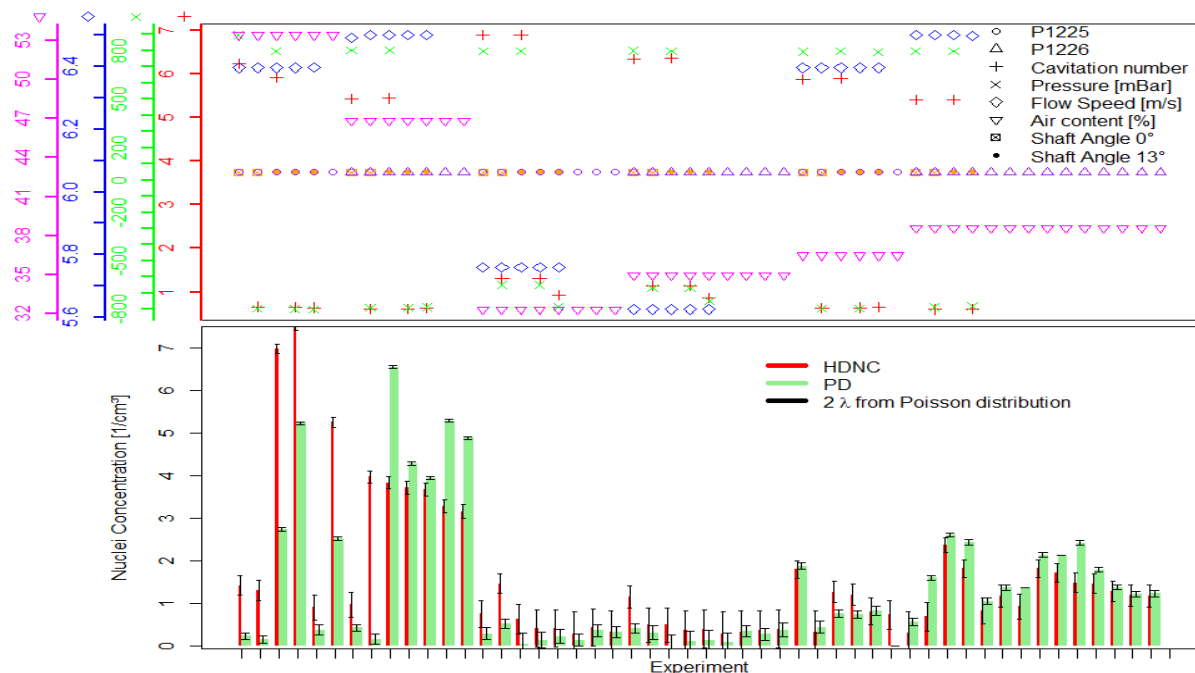


Figure 4. Operating conditions (upper graph) and comparison (lower graph) of PD and HDNC nuclei concentration measurements in K15.

4. Conclusion

In comparison to PD-technique, the HDNC technique is appropriate for the measurement of the cavitation nuclei concentration in the cavitation research. The reduced optical setup and higher data rate represent advantages. Quantitative deviations are in the order of the expected systematic errors of both techniques.

5. Acknowledgements

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