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Ultrasonic Pulse-Echo Measurement of Bubble Diameters in Suppression Pool

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Suppression pools allow decreasing the pressure in a nuclear reactor or in the containment during an accident by condensing steam and also by venting the gas filtered by the pool. Radioactive particles are removed from the gas via a scrubbing effect, the efficiency of which depends on bubbles parameters such as the bubble diameter. The thesis describes the development of an ultrasonic technique that is capable of measuring bubble diameters. The performance of the technique was tested and examined. As a result, the uncertainty of the technique was understood both for its application in low-temperature environment and in the environment of a suppression pool. This allows obtaining experimental bubble size data to improve the understanding of scrubbing efficiency. Follows a short summary of each chapter.

Chapter 1: “Introduction” explains the problematics of the scrubbing effect in suppression pools and introduces the methods of predicting the scrubbing effect efficiency and explains the importance of bubble diameter data. It also introduces measurement techniques capable of measuring the bubble diameters and the advantages of ultrasonic measurement.

Chapter 2: “Development of the ultrasonic pulse-echo with tracking technique” introduces a novel measurement technique capable of measuring the position of bubble surfaces while overcoming the limitations of traditional pulse-echo techniques: the inability of ultrasound to propagate around and behind bubbles with typical measurement settings and the inability of the signal processing to distinguish between multiple bubbles measured at the same time. The first issue was addressed by examining the shadow cast by a bubble both experimentally and numerically and by choosing suitable transducer (TDX) parameters so that reflections from multiple bubbles can be recorded by the TDX. The second issue was addressed by implementing a suitable pulse-echo signal processing scheme and developing a tracking technique capable of distinguishing between multiple bubbles. The developed technique was validated in an ideal experiment where the flow condition was simplified to allow easier comparison between the measured bubble surface positions and those measured by a high-speed camera (HSC). It was discovered that the technique is sufficiently accurate and while it does not detect all the bubbles which pass the measurement volume, the difference between a number of bubbles detected by the developed technique and by the HSC was sufficiently low in the tested range. The difference grows with the void fraction and this shows the limitation of the developed technique to low void fraction bubbly flows.

Chapter 3: “Measuring bubble diameters using the pulse-echo with tracking technique” introduces a method for measuring bubble diameters with the ultrasonic pulse-echo with tracking technique. The method was validated by measuring diameters of metal cylinders as well as diameters of air bubbles in realistic experimental settings where HSC was used for a reference measurement. The experiment required improving upon the video processing used for analysing videos recorded by the HSC. The main improvement was including an algorithm for recognition of overlapped bubbles on the video frames and separating them. Another improvement was adding a second HSC to evaluate the 3D position of bubbles, which was important in order to decide whether the bubbles are in the measurement volume or not. The uncertainty analysis was conducted for the diameter measurement and the results agreed within the

predicted uncertainties. It was analysed how there are two types of errors of different scales. When all bubbles are affected by the small errors, only a few bubbles are affected by the large errors. However, this number increases with the void fraction in the measurement volume.

Chapter 4: “Measuring bubble diameters with resistant transducers” focuses on the problematics of applying the technique with resistant TDXs developed for high pressure and high temperature. While those TDXs can be deployed in the full-scale conditions of the real suppression pool, they are much less sensitive and the measurement has to deal with higher levels of noise. The condition of the ultrasonic pulse was tested for different settings and the methodology to decide which pulse is the most suitable was introduced. With this, the diameters of metal cylinders were measured and the performance of the technique was confirmed. A new filtering scheme was introduced with the goal of decreasing the noise level. The scheme was tested by measuring single bubble diameters with results compared to a reference HSC measurement. Finally, the bubble diameters were measured in realistic experimental settings and two HSCs were used for a reference measurement. The HSC video processing was further improved taking advantage of two frames obtained under different angles in order to recognise overlapping bubbles and correctly separate them. The comparison showed worse agreement than for regular TDXs, but it was still acceptable at 0.5 mm for up to 3.5% of void fraction.

Chapter 5: “Application of the pulse-echo to suppression pool experiment” introduces a suppression pool experiment and its instrumentation in detail. The experiment allows injecting a mixture of steam and air into a pool of water through a vertical downcomer. Some parameters of the experiment, such as the downcomer diameter, gas flow rate or pool volume were downscaled, while other parameters, such as pool water temperature and pressure, downcomer submergence and others were similar to real suppression pools deployed in nuclear power plants. The effect of temperature on the measurement results and on the measurement uncertainty was analysed and calibrated for. Finally, the resistant TDXs were used to measure bubble diameters under various experimental condition. The results show the capability of the developed measurement technique and provide a useful insight into the bubble hydrodynamics in suppression pools and thus the efficiency of scrubbing.

Chapter 6: “Conclusion” sums up the content of each chapter and recapitulates the achievements of the dissertation, namely the development of a novel ultrasonic pulse-echo technique, the examination of the developed technique performance for both regular and resistant transducers, the extended analysis of the effect of bubbly flow conditions on the performance of the developed technique and the application of the technique to a bubble diameter measurement in a suppression pool experiment.