Mitigation of Cavitation Damage in the Spallation Neutron Source Mercury Target: An Acoustic Resonator for Determining the Gas Volume Fraction in Mercury-helix Two-phase Flows

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Abstract

Details of an acoustic waveguide for measuring the void fraction of two-phase mercury-helix fluids are discussed. The resonator assembly’s waveguide is a stainless steel cylinder with 5.06cm ID, 1.27cm wall thickness and 40cm length. A 2.54cm thick stainless steel plate at the bottom supports the enclosed fluid, provides a rigid acoustic boundary condition, and is the mounting point for a hydrophone. A port near the bottom is the inlet for the fluid of interest. A spillover reservoir welded to the upper portion of the main tube allows for a flow-through design and provides a large free surface for larger bubbles to rise out. A cover on the reservoir supports an acoustic shaker which provides the acoustic excitation of the waveguide. The shaker is driven by a linear chirp that excites the tube in a broadband fashion. A bubbly injection flow loop circulates fluid through the resonator. The hydrophone captures the frequency response of the waveguide. The sound speed of the flowing medium is calculated, assuming a linear dependence of axial mode number on modal frequency (plane wave). Assuming that bubble-bubble interactions are insignificant, that the medium has an effective mixture sound speed, and that it contains bubbles which are much smaller than the resonant sizes (Wood’s limit), the void fraction of the flow is calculated. Results for water and bubbly water of varying void fraction are presented. [Supported by the ORNL Spallation Neutron Source, which is managed by UT-Battelle, LLC, under contract DE-AC05-00OR22725 for the U.S. Department of Energy]

Motivation / Introduction

The Spallation Neutron Source (SNS) is an accelerator-based neutron source located at the Oak Ridge National Laboratory in Tennessee. At full power, the SNS will provide the most intense pulsed neutron beams in the world for scientific research and industrial development. The incoming GeV proton beam is absorbed in a liquid mercury target (right), losing energy in a series of collisions which release both neutrons (spallation, see right) and heat. The rapid rise in temperature produced by the proton beam results in an intense acoustic wave which travels in the mercury. The large amplitude (~50 MPa) and long duration (~50 ns) of the negative portion of the wave serve to grow vapor nuclei generated by the proton and neutron collisions to macroscopic size (mm) cavities. These cavities subsequently collapse violently when the pressure is no longer negative. When cavities collapse in the vicinity of the stainless steel walls of the target chamber, they implode asymmetrically, resulting in a high-velocity (500 m/s) liquid mercury jet impacting the target chamber. The resulting cratering damage seriously limits the lifetime of the target chamber.

B destroy bubble: highly reflective
Bubble Fluid Waveguide

\[ \frac{1}{c_{\text{eff}}} = \left(1 - \frac{n^2}{c_0^2} \right)^2 + \frac{\lambda^2}{c_0^2} + \frac{1}{c_0^2} \frac{\rho g \rho_\text{L} c_\text{L}^2}{\rho \rho_\text{L} c_\text{L}^2} \]

where \( \lambda = \frac{V_{\text{gas}}}{V_{\text{total}}} \)

Acoustic Resonator Design

In order to measure the void fraction (gas content) of the Hg flow in the SNS target, a vertical flow-through resonator tube method can be employed. The flow design ensures the injected small bubbles remain entrained in the flow, and a collection reservoir provides a large free surface for any “rogue” large bubbles to rise out. A thin plate at the bottom will provide a pressure-release boundary condition as well as provide a mounting point for a hydrophone. A spillover design at the top surface will provide another pressure release boundary condition. A piston inserted from the top and driven by an electrodynamic shaker excites the tube. By examining the effect of various injected void fractions, the “optimal” void fraction for cavity damage mitigation can be determined.

Resonator Results

- Resonator is able to measure sound speed and subsequently calculate void fraction of pure water and bubbly water flows

Next step
- Conduct preliminary Mercury experiments at BU
- Transport apparatus to ORNL SNS for implementation into their testing facility

Acknowledgements

The support of ORNL via contract # 4800053931 is gratefully acknowledged.