Development of Instrumentation and Controls for Integral Primary Systems Reactors (IPSRs)

NSTD's Advanced Reactor Systems (ARS) Group is presently collaborating with Westinghouse and Brazil's Instituto de Pesquisas Energeticas e Nucleares (IPEN) under a DOE International Nuclear Energy Research Initiative (I-NERI) to develop specialized instrumentation and controls (I&C) technologies for ISPRs. IPSRs have distinctive I&C configurations and requirements as compared to more conventional external- loop LWRs. Thus, the common element in integrating the several project tasks together is the development of specialized IPSR I&C technologies not directly transferable from external-loop LWRs.

One identified instrumentation challenge for IPSRs is accurate in-vessel water level measurement. The irregular path imposed by the shape of the pressurizer bottom plate, riser, control rod drive mechanisms, and other structural components make the use of conventional level measurements almost impossible. One of the initial project tasks is therefore to develop an in-vessel level measurement system deployable in an integral configuration. Two candidate systems are currently under development: (1) an ultrasonic, torsional waveguide-based level measurement technique by ORNL and (2) application of advanced signal processing algorithms to a cooled-fluid-based lance type probe by IPEN.

For the ORNL task and approach, the central idea underlying this type of sensor is that the density of the fluid in which a waveguide is submerged will affect the propagation velocity of a torsional wave along the waveguide. Conceptually, the speed of any torsional elastic wave propagating down a waveguide is proportional to the square root of the stiffness of the rod divided by the sum of the waveguide and the surrounding fluid inertia. A larger fluid inertia, therefore, results in a lower torsional wave propagation velocity. The fluid's apparent inertia is a combination of its density and viscosity. In the case of a water-like fluid, for realistic probe dimensions and ultrasonic wave frequencies, it has been shown that the fluid viscosity can be neglected resulting in a wave propagation delay inversely proportional to the fluid density.

For FY2005, ORNL's two principal objectives were: (1) build an experimental prototype apparatus to demonstrate the phenomena and (2) develop a computational model for the measurements. The objective for the experimental prototype was to construct and demonstrate a working extensional and torsional wave propagation and measurement assembly and to capture ultrasonic signals that correspond with a computational simulation of the experiment. This was accomplished. The present version of probe system consists of the blade and ultrasonic transducer as shown in the Figure 1 below.

The objective of the computational modeling is to optimize the overall measurement system design. Probe properties such as transitions from the shaped blade section (diamond cusp) to a cylindrical probe can be more easily optimized computationally than experimentally. The overall ultrasonic waveguide modeling was finite element based and implemented using the ANSYS™ multi-physics software package. During FY2005 the computational modeling focused on setting up the initial probe blade and coolant model and then performing ultrasonic transmission simulations that could be experimentally benchmarked to verify the model validity.

Thus, the status at this point is that ORNL has developed an initial finite element based model for the ultrasonic waveguide and has performed initial experimental benchmarking of the model predictions. ORNL is currently developing a more advanced experimental prototype suitable for deployment in more rigorous environments as well as beginning to develop the customized signal processing required to interpret the measured signals. IPEN is currently nearing completion of their experimental test facilities to enable demonstration of their probe concept in a representative environment as well as to begin to acquire measured data to train their signal processing system.

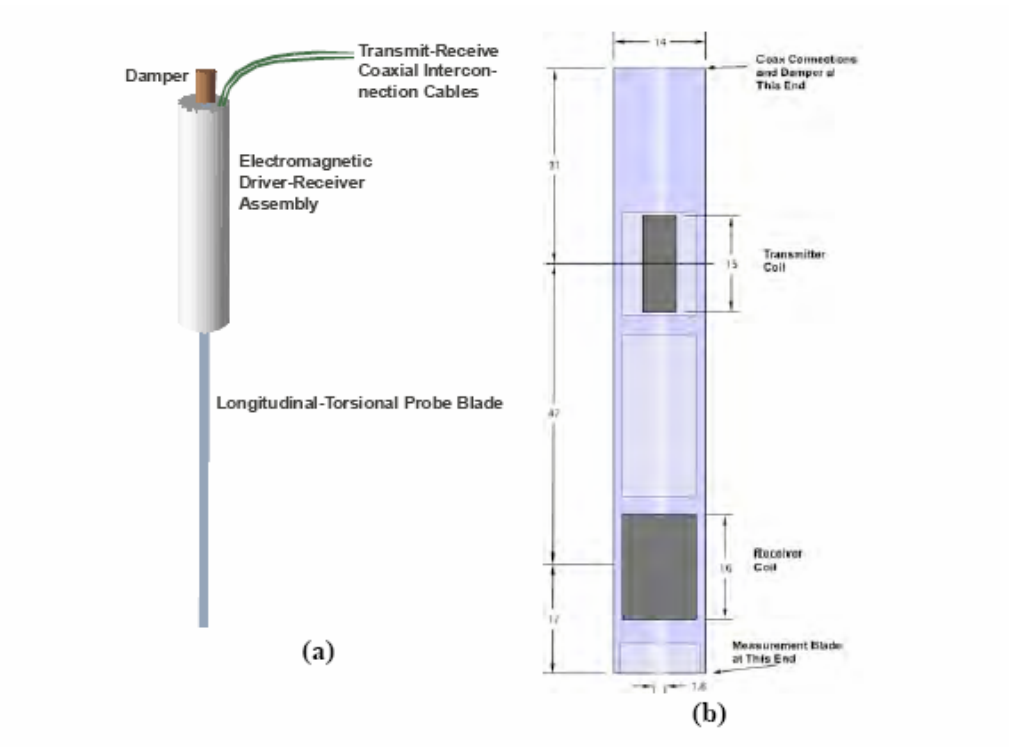

Figure 1. (a) Conceptual illustration of torsional ultrasonic probe and (b) Cross section of the driver-receiver assembly

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