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A TORSIONAL ULTRASONIC TECHNIQUE FOR LWR LIQUID-LEVEL MEASUREMENT

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1. INTRODUCTION

In the late 1970's, a technique for determining the mean density of a fluid surrounding a waveguide of non-circular cross section was developed using slow torsional ultrasonic pulses. With the waveguide partially inserted in a liquid of known density, the fraction of the probe immersed in the liquid can be derived, and hence the level. (See, for example, refs. 1 through 3). The loss-of-cooling accident at TMI-2 in 1979 pointed out the need for a sensor to monitor continuously reactor vessel coolant level and density (i.e., void fractions). Devices utilizing torsional ultrasonic pulses can provide continuous readouts, in appropriate units, of level, average density (or void fraction), and temperature along the sensor in the reactor vessel, in each of a number of zones (limited to about 20 sections per probe in practice).

Additional advantages of the torsional-wave level probe include ruggedness and long life resulting from the simplicity of the waveguide structure — only a strip of stainless steel contained in a stainless steel support tube is immersed in the reactor vessel. Thus the probe is expected to have a long life in high neutron and gamma fluxes as well as being adaptable to current reactor designs.

Under normal reactor operation, the torsional-wave sensor will provide a display of level (if it exists, as in a BWR), as well as density, and temperature profiles. These indications can be correlated with measurements from other plant sensors providing confirmation of the indications of plant instrumentation. Under accident conditions, the probe would be expected to provide indications of the event to the point of destruction of the stainless steel itself. Thus, continuous readings of temperature, level, and density could be recorded to provide a log of the event for post-accident analysis.

Since 1980, the Instrumentation and Controls Division of ORNL has been involved in the evaluation of sensors using torsional ultrasonic pulses to make level and density measurements, and extensional ultrasonic pulses for temperature measurements and correction of the torsional measurements.[4,5] Work at ORNL through 1981 demonstrated the feasibility of transmitting torsional pulses in a ribbon of stainless steel and the sensor was used to measure the level of a steam/water interface at 290°C and 10 MPa. Subsequent work under the Advanced Two-Phase Instrumentation Program has been directed towards an operational prototype instrument that can be installed in functional power reactor.

For a discussion of the theory behind ultrasonic density and temperature measurements, and an extensive list of references, refer to J. E. Hardy et al., ref. 6.

2. EVALUATION OF SIGNAL ATTENUATION CHARACTERISTICS

The demonstration of transmission of stress pulses over long distances, such as would be required in a typical application, is a necessary step on the way to a fully functional device. Figure 1 shows the attenuation of the echo strength at the transducer coil as a function of sensor length. The loss was about 12%/m; however, signals of a few tens of mV are quite usable and a probe as much as 40-m long will still have an adequate echo from its far end. Attenuation in a circular rod is somewhat less — around 10%, so the portion of the waveguide leading to the active section of the probe should be circular. In a related test, the high-energy excitation pulses and the detected echo pulses were transmitted through a 120-m length of coaxial cable with no significant attenuation.

3. ELECTRONICS FOR EVALUATION TESTS

Figure 2 shows a block diagram of the instrumentation used with the probe. Work was concentrated primarily in transducer design — including means for alternately providing torsional and extensional biasing for the two pulse modes; production of fast, high-energy pulses for strong, narrow signals; a signal-conditioning circuit to detect the peak of the echo pulses; and a precise digital timer that is interfaced directly to a microcomputer. The electronics consisted of a fast filter/differentiator section, a fast digital counter, and an interface to a microcomputer. The measurement sequence consisted of setting an enable window around the two echos of interest, providing a start pulse (and appropriate magnetic biasing) which cleared the counter and initiated the stress pulse in the sensor. The output of the pick-up coil, which converted stress pulses to voltage pulses, was amplified and differentiated. Any pair of echos falling within the window produced a pair of logic timing pulses whose trailing edge corresponded to the zero-crossing of the differentiated signal, and hence to the position of the peak maximum. This pair was then used to start and stop the counter, thus the counts read by a microcomputer and divided by the clock frequency was the time interval between the two echos. The precision of the measurement was within 1 clock pulse tick, and the accuracy depended upon the stability and noise properties of the differentiator and the clock stability, resulting in an overall error per measurement of about 0.2 microseconds.

The use of a microcomputer has a number of advantages: (1) control of the measurement cycle allowing alternate torsional and extensional pulses with the appropriate magnetic biasing, (2) on-line calculation of the data using calibration tables and appropriate algorithms, and (3) graphic display of the level along with density and temperature profiles showing any sections where voids or high temperatures may be present. Figure 3 is an example of a computer-generated display showing level and density changes resulting from adding a brine solution to alcohol (density 0.8).

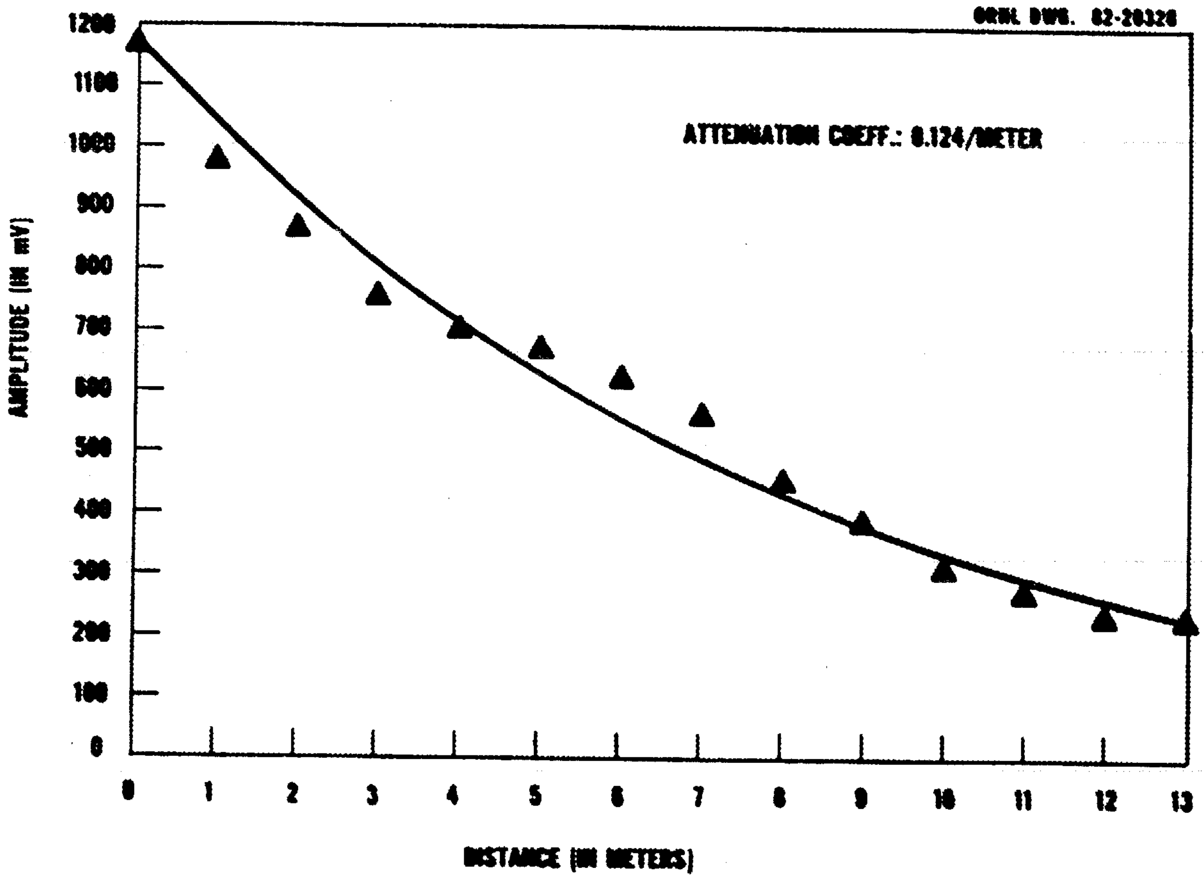

Fig. 1. Pulse attenuation vs length of a flat ribbon waveguide.

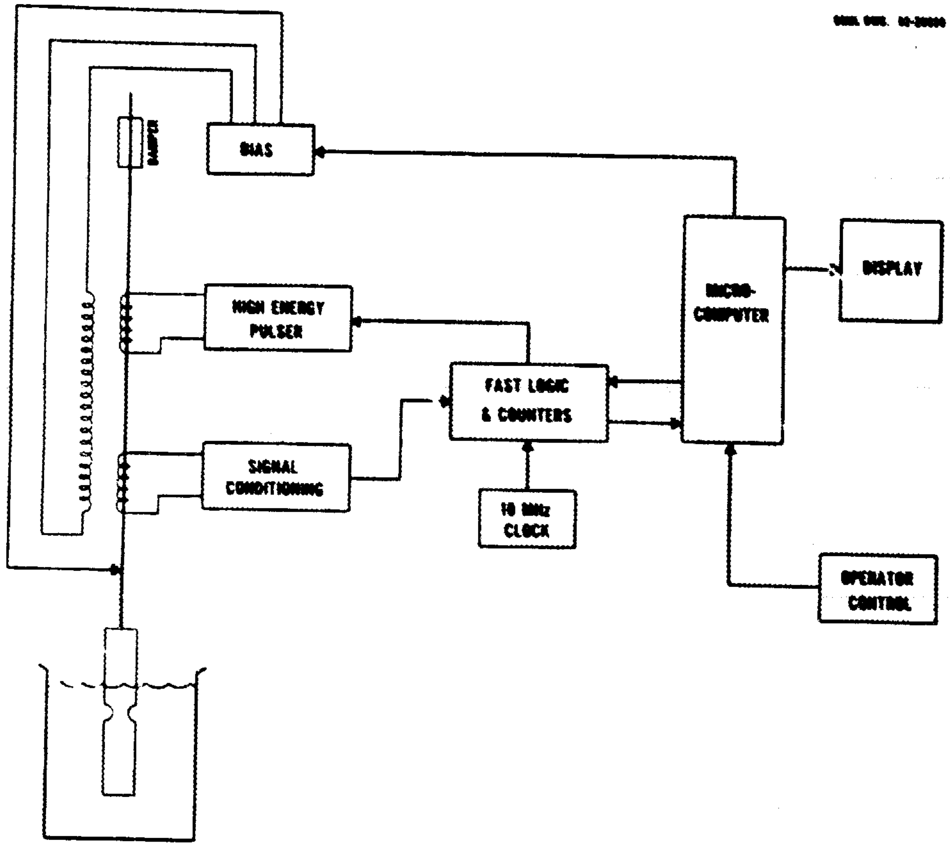

Fig. 2. Block diagram of experimental level test.

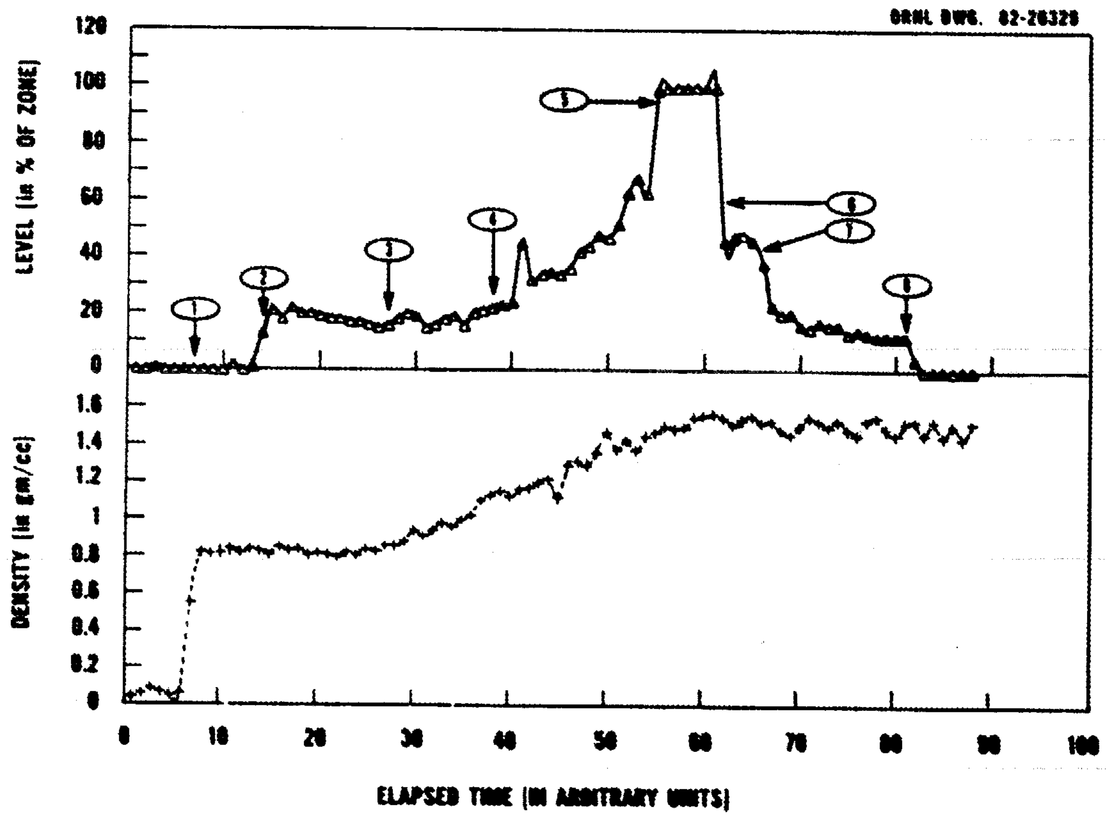

Fig. 3. Level and density indications while adding brine to alcohol.

4. EVALUATION OF A NEW TECHNIQUE FOR MAINTAINING THE TORSIONAL SIGNAL

Previously, a severe environmental restriction to the generation of torsional signals has been the loss of permanent magnetic bias in the magnetostrictive materials at elevated temperatures. The azimuthal-magnetic field used to generate the torsional waves disappears completely from Remendur between 250 to 300°C. Earlier solutions to this problem involved thermal isolation of the transducer by transmitting the stress pulses through a bulkhead, cooling the transducer section with water coils, or placing sufficient distance between transducer and heat source. There are drawbacks to all of these methods, however, because of the loss of signal through any isolating bulkheads or the additional complications due to the presence of cooling coils.

The method adopted by Arave[3] for the in-vessel LOFT density probe was to use "mode conversion," that is, to mechanically convert extensional stress pulses to torsional pulses. This method requires a bulkier transducer section and having to deal with an excessive number and intensity of possibly-interfering extensional echos from the several transition regions where the wave guide makes a right angle bend for purposes of the mode conversion.

A second solution, which we employed, is to actively apply a torsional-magnetic bias as mentioned above. The azimuthal-magnetic field was established by an axial electric current through magnetostrictive material. Examples of applying several values of such currents on the torsional amplitude are shown in Fig. 4 over a range from 66 to 370°C. Here it is seen that amplitude of the torsional signal is directly proportional to the applied axial current, and that strong, usable signals are obtained even up to 370°C.

5. DEMONSTRATIONS OF DENSITY AND LEVEL MEASUREMENT

The configuration of the apparatus for a level/density demonstration is shown in Fig. 5. The probe and liquid are in the center of the photograph, the electronics above left, and the computer display to the left. In this demonstration, the computer generated a start pulse to initiate the measurement cycle. The start pulse turned on the torsional bias supply and gated the pulser on. Blanking was also provided by the computer so that echos not of interest were ignored. The correct echos, corresponding to the section of the probe under consideration, were selected to start and stop a scaler which counted stable clock pulses at a 10 MHz rate. Upon the stop signal, the counts were then read by the computer and averaged. Averaging over 200 cycles of about 10 ms duration resulted in a time resolution of 10 ns which is adequate for a temperature resolution of 1°C and 0.1% density and level determination (relative to the length of the section of the probe under consideration).

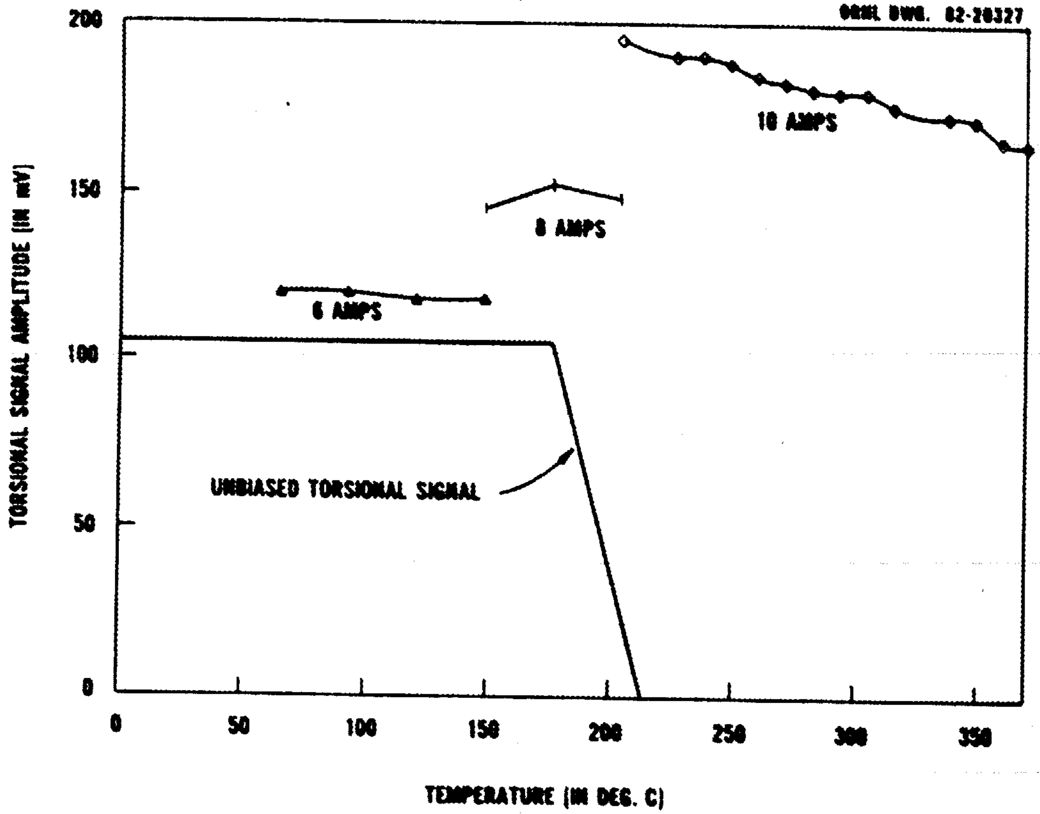

Fig. 4. Temperature effects on torsional signal amplitude as a function of bias current.

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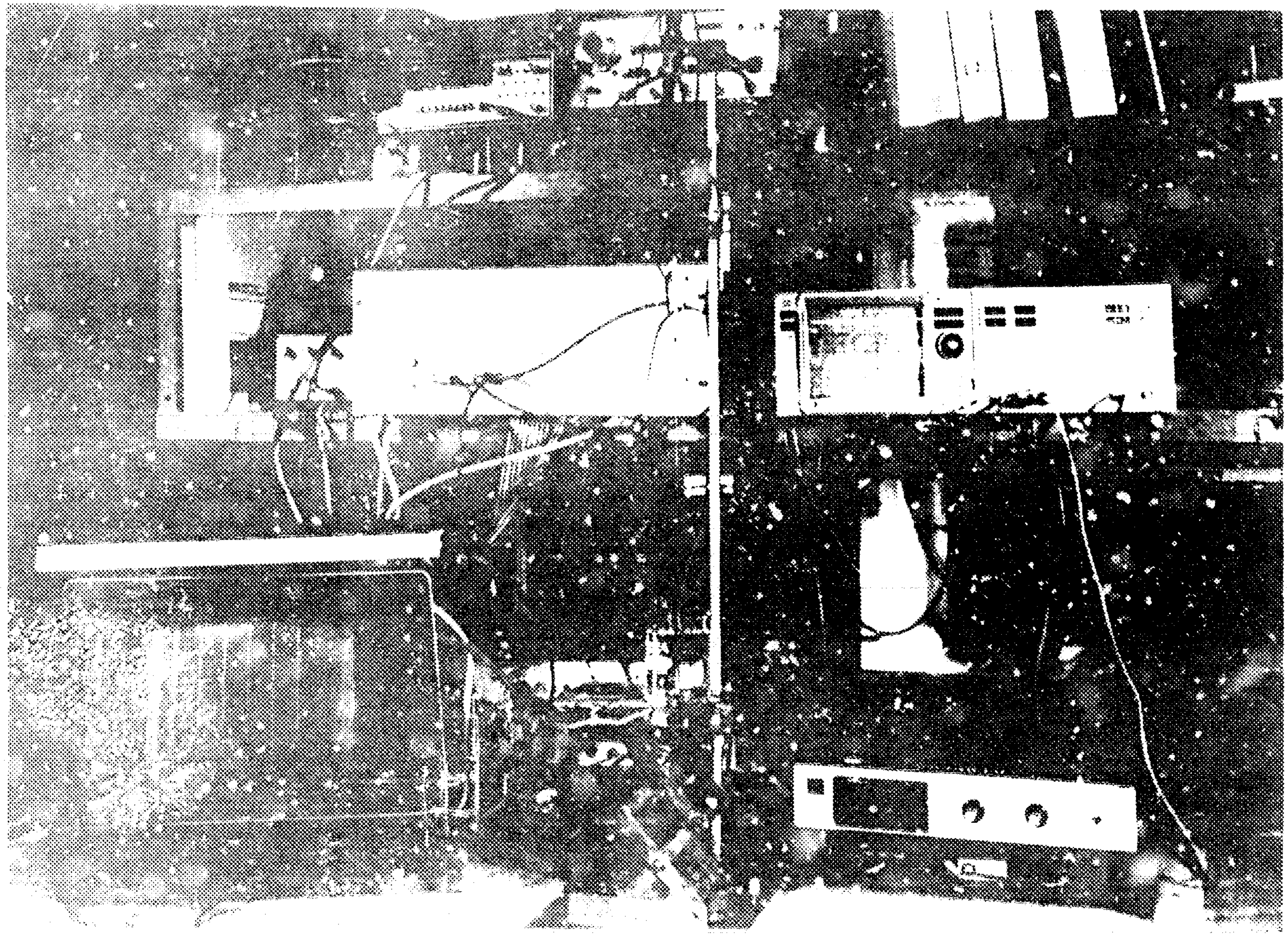

... and density.

Figure 3 shows the results of slowly adding a brine solution (density of about 1.5) to the bottom of a container to alcohol (density of about 0.8). The change in the level and densities of resulting mixtures was measured with a two-section probe. The keyed points on the plot show where: (1) all of the lower section of the probe was immersed in the alcohol; (2) a portion of the upper section was immersed; (3) initial introduction of brine by pouring it down a tube leading to the bottom of the vessel so that the less dense alcohol tended to "float" on top; (4) brine reached the upper section — here the level information was no longer valid since it was based on an assumed density for alcohol, however, the sudden and sharp change in "level" indicated that the denser medium was forcing out the lighter alcohol; (5) alcohol completely overflowed (the level remained constant thereafter); (6) probe withdrawn exposing upper section; (7) upper section drained of brine; (8) upper section cleaned of salt residue.

6. CONCLUSION

In conclusion, we have successfully demonstrated several major milestones on the way to a functional ultrasonic sensor for light water reactor instrumentation. In particular, we have overcome the problem of temperature on the torsional signals and shown that transmission of useful stress pulses over long distances is feasible. Transducer sections and waveguides of 3-mm and 6-mm diameter were successfully tested, and will lead to the construction of sturdier probes for the tests specified in the 1983 milestones. Adequate reflections were obtained from multiple-sectioned probes (notches) and through curved sections of 3-mm flat and round waveguides down to 30-cm radius of curvature. Thus profiling of density and temperature down to, and below, 30-cm resolution becomes feasible; and installation in awkward spaces, which would require bending the waveguide, should be possible.

A simple demonstration of level measurements and density changes was undertaken graphically, using the instrument system which included the level transducer with the torsional and extensional bias controlled by a microcomputer, high-speed electronics for precise time measurements, and on-line display of the resulting data shown graphically.

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