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Author(s): Daniel Vnuk

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# Acoustic Techniques for Localizing Holdup\*

Daniel Vnuk  
Los Alamos National Laboratory  
Los Alamos, New Mexico USA

## Abstract

Material that does not come out of a process as product or waste is called *holdup*. When this is fissile material, its location and quantity must be determined to improve safeguards and security as well as safety at the facility. The most common method for detecting and measuring holdup is with radiation based techniques. When using them, one must consider equipment geometry, geometry of holdup, and effects of background radiation when converting the radiation measurement into a fissile material quantity. We are developing complementary techniques that use tiny acoustic transducers, which are unaffected by background radiation, to improve holdup measurements by aiding in determining the above conversion factors for holdup measurements. Thus far, we have applied three techniques, Acoustic Interferometry, Pulse Echo, and Bending Wave Propagation, of which the latter appears most effective. This paper will describe each of these techniques and show how they may ultimately reduce costs and personnel radiation exposure while increasing confidence in and accuracy of holdup measurements.

## I. Advantages of Acoustic Techniques

### A. Non-Radiation-Based Measurement

When using traditional gamma or neutron detectors to locate holdup, one generally operates in background radiation fields. To accurately determine the amount and location of holdup material in a section of pipe, one must properly subtract this background radiation from the total detected radiation. Where background radiation is large compared to the holdup signal, such measurements can be time consuming and difficult, which increases the cost and radiation exposure to the operator.

Acoustic techniques are completely unaffected by background radiation because the transducers are only sensitive to vibration. If a small amount of holdup is

present, background radiation can significantly complicate the task of detecting and quantifying the holdup using conventional radiation detectors alone (Fig. 1).

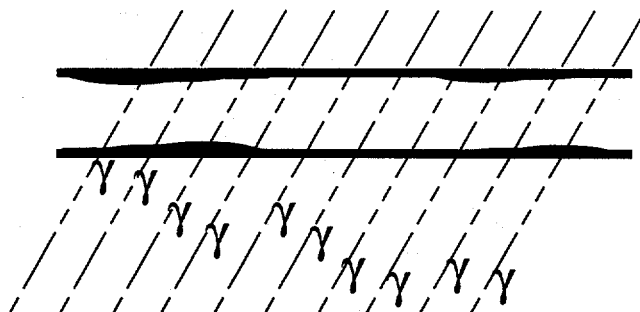


Fig. 1. Thin layer of holdup with large background field.

Also, if the holdup is not uniformly distributed it can be difficult to determine where to place a gamma detector to get an accurate reading (Fig. 2).

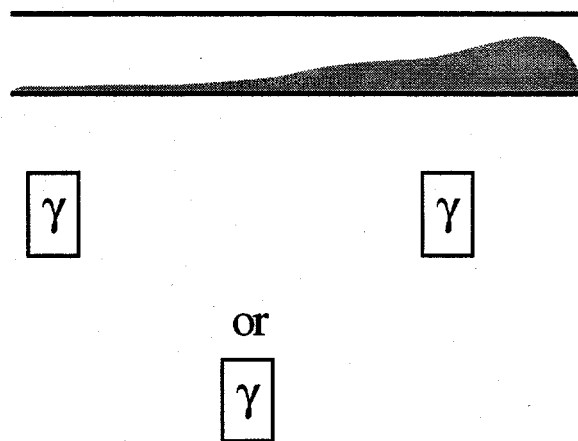


Fig. 2. Holdup thickness varying along the length of a pipe.

In these cases, acoustic techniques can improve the accuracy of holdup measurements while reducing the time and radiation exposure of personnel.

### **B. Reduce Error by Allowing Mapping of Holdup Geometry**

Another advantage of acoustic techniques is that they allow the careful mapping of the geometry of holdup. Unless the mechanism for holdup accumulation is well understood, it can be difficult to assess whether the material is at the top, bottom, or evenly distributed about the perimeter of a pipe. Measurement biases resulting from such uncertainty can increase the error of radiation-based measurements because the operator may make an incorrect assumption about the location of the holdup within the pipe. Acoustic techniques would allow an operator to map out the edges of the holdup material, thus increasing the accuracy of the assumptions used to convert the radiation-based measurements to estimates of the mass of fissile material.

### **C. Mitigate Equipment Geometry Constraints**

Acoustic methods may also facilitate holdup measurements in very tight areas. Shielding around gamma detectors can be large and difficult to maneuver into tight spots. Also, when large numbers of pipes are close together it is very difficult to accurately convert a holdup measurement to fissile material mass if holdup is in a single pipe in the array. The sensors that we use for acoustic testing can be extremely small and can easily test single pipes in a large array, so the distance from the material to the radiation detector can be accurately estimated.

### **D. Survey Large Areas Quickly**

In facilities with large amounts of piping, holdup measurements can be extremely time consuming using conventional detectors. Acoustic techniques offer the potential for the operator to simply scan a hand-held device along a length of pipe and quickly determine areas where holdup may exist. After pinpointing areas of concern using acoustic techniques, radiation detectors can be brought in to quantify the holdup. This combined method could result in a significant reduction in the time spent on holdup measurements.

## **II. Techniques**

### **A. Acoustic Interferometry**

Acoustic interferometry obtains a spectrum by establishing standing waves in a thickness of material over an appropriate frequency range. The technique is employed by using a dual-element piezoelectric transducer and a digital synthesizer and analyzer with analysis and display software. A measurement is obtained by placing the transducer in contact with the material and scanning a range of frequencies where standing waves are likely to occur. The appropriate frequency range is estimated from a knowledge of the speed of sound and the thickness of the material being tested. This measurement result is compared to identical measurements performed where it is known that no holdup exists.

Acoustic interferometry could be useful in detecting edges of holdup in process pipes because the presence of material at the internal boundary would affect the resonance frequency of the standing waves as well as the amplitude. In addition, holdup thickness can be calculated from the distance between successive resonant peaks if the speed of sound in the holdup material is known.

### **B. Pulse Echo**

Another technique that we have investigated for detecting holdup is pulse echo. In normal pulse echo operation, an acoustic pulse is excited in a metal plate and reflections from the opposite wall of the plate are detected. Using an oscilloscope one can measure the time it takes for the pulse to make the round trip. With knowledge of the speed of sound in the metal, the thickness can be determined from a simple calculation. When holdup material is present, a first reflection should be detected from the opposite wall of the material but some energy from the pulse should be transmitted to the holdup thus causing another reflection from the inside surface of the holdup layer. Careful screening for these secondary reflections may allow for the detection of holdup. If the speed of sound in the holdup is known, one could then determine its thickness from a calculation based on the time of flight for the pulse.

### C. Bending Wave Propagation

Sound can propagate through a metal plate in the form of flexural or bending waves. The speed of bending waves depends on the thickness  $t$  and the frequency  $f$  as follows:

$$V = \sqrt{1.8 C_L t f} \quad (1)$$

In Eq. 1,  $C_L$  is the speed of a longitudinal wave in the material.

When the metal plate is coated with a dense substance (holdup), the bending waves slow down. Therefore, if one measures the propagation of bending waves between two transducers in a region where no holdup exists and then in a region where holdup is present, one detects an increase in propagation time between the transducers. Detecting this change in the propagation time of bending waves is the basis for this application.

The technique is employed by using a pair of closely spaced transducers (Fig. 3). One transducer excites a burst of bending waves in the shell of the material being tested while the other transducer detects the burst. The propagation time of the burst is determined from a phase measurement between the sent and received signals. A burst is used rather than a constant wave to eliminate reflections from edges and corners of the equipment or piping under testing. Only direct

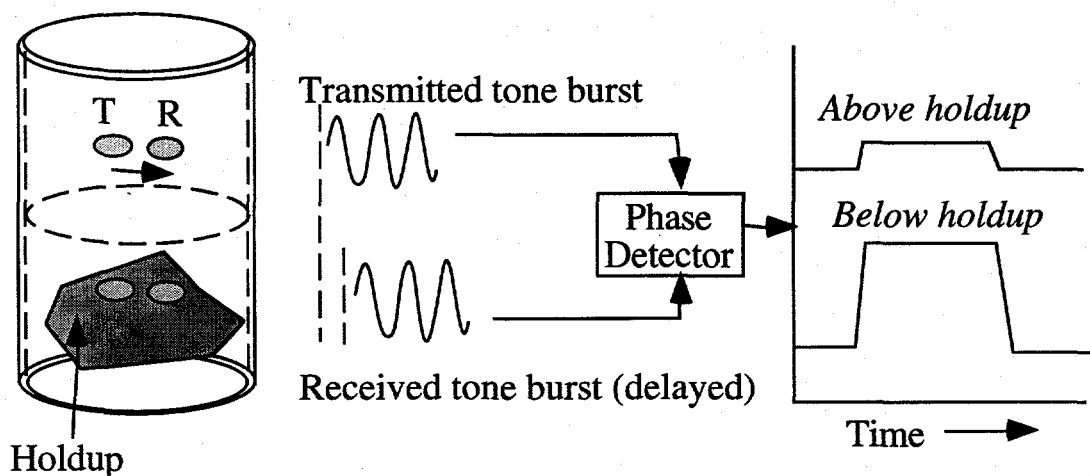
transmission between the transducers is monitored this way.<sup>1</sup>

## II. Results

Each technique was tested under identical conditions in the laboratory and in an operating plutonium facility. In the laboratory we tested several 3.1-mm-thick stainless steel plates containing various forms of simulated holdup such as wax, salt, solder, and grease. We also tested a 55-gal. drum, similar to the drums used in special nuclear material storage, with a patch of grease on the inner surface. In the operating facility we tested two different 6-in. horizontal pencil tanks used to store radioactive material from experiments.

### A. Acoustic Interferometry

In an idealized situation, acoustic interferometry provides positive results. We observed decreases in resonance amplitude of up to 100 mV when the transducer was moved from a clean area to an area where simulated holdup was present on the stainless steel plates. In the operating facility the signal was quite variable from one location to the next making the tests inconclusive. Although the field tests were inconclusive, the laboratory tests demonstrate the potential for acoustic interferometry as a method for detecting holdup.



**T: Transmitter transducer**  
**R: Receiver transducer**

Fig. 3. Bending Wave Technique.

One main drawback to this technique lies in the dependence on consistent acoustic coupling between the transducer and test surface. In many cases, poor acoustic coupling results in a false positive by reducing the amplitude of the detected standing wave. For this reason, acoustic interferometry is less than ideal because our goal is to develop a sensor that can be slid easily along the surface of a pipe or container and determine the location of holdup.

## B. Pulse Echo

As predicted, our results showed the reflections associated with the thickness of the stainless steel plates and pencil tanks, but no reflections were found that we could attribute to the holdup. The cause of failure for this technique appears to be that 1) the internal surface of the holdup is extremely uneven and 2) transmission of acoustic energy into the holdup material may be too low to detect. Uneven surfaces cause the pulse to be randomly dispersed and thus very little energy makes it back to the transducer. Perhaps with a more powerful, gated amplifier this technique may be effective. However, pulse echo is currently unsuccessful at detecting holdup.

## C. Bending Wave Propagation

Bending wave propagation was the most successful of the three techniques tested. In the laboratory tests on the 55-gal. drum we observed significant phase shifts when the pair of transducers was slid from a clear region to a region with simulated holdup. Tests on the stainless steel plates also provided positive results, however the phase shifts were much smaller. The decrease in phase shifts can be attributed to the difference in thickness between the drum and the plates.

In the tests on the horizontal pencil tanks in the plutonium facility, we observed some small phase shifts when the pair of transducers was moved from the top to the bottom of the tanks. The actual phase measurements are recorded in Table 1.

**Table 1. Results from Field Tests on Horizontal Pencil Tanks**

Rotation Angle (degrees from top of tank)	Phase (degrees)
0	0
60	0
120	0
180	94

We attempted to confirm the presence of holdup at the bottom of the tank using an available survey meter. The radiation detector registered a uniform 3 mRem/hour over the entire surface of the tank. Thus, either the acoustic measurement resulted in a false positive or the amount of holdup in the tank was too small for the survey meter to distinguish it from the radiation background. Based on the geometry of the tank and the resulting difficulty in completely flushing the system free of material, we assume the latter case is true. We had hoped to extend these measurements to other areas with known holdup amounts for quantitative comparison. However, the facility had no locations where such measurements could be made at the time of our visit.

In any case, we have demonstrated clear success for this technique in the laboratory and we believe that it may be useful in making holdup measurements in operational settings. One of the main reasons for the success of this technique is that comparisons are based on a phase measurement instead of amplitude which makes it unnecessary to have consistent coupling. This allows the transducers to be slid along the test surface without seriously degrading the measurement.

## IV. Conclusions

Acoustic methods for detecting holdup have the advantage of being unaffected by background radiation, they allow accurate mapping of holdup edges, and have geometry capable of assaying small areas. These advantages combine to reduce the cost of holdup measurements while significantly aiding in keeping personnel radiation exposure as low as reasonably achievable. We are confident that acoustic techniques can provide a useful and cost-saving method for detecting holdup material. In particular, the bending wave application appears to provide the most flexibility in these acoustic measurements and provides the best results for detecting discontinuities in holdup accumulation.

## Reference

1. Dipen Sinha and Chad Olinger, "Acoustic Techniques for Nuclear Facility Design Verification and Process Monitoring," Report for the IAEA on POTAS project #A189, August 1995.

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