A simple system for detecting and measuring gas voids in safety-related fluid systems

Over the past 20 years there have a number of instances where nuclear power plant operators have discovered gas voids—typically air but occasionally other gases such as undissolved hydrogen— in fluid systems whose function is important to reactor safety. These systems have included emergency core cooling systems, decay heat removal systems, and containment spray systems. A new gas void detection system addresses these issues.

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The amount of gas has, in some cases, been sufficient to call into question the operability of the systems; had they been needed. The automatic initiation of a system with a gas void present may lead to gas binding of its pumps, or destructive water hammer. The sources of the gas have been various and not readily controlled.

The need for licensees to manage gas accumulation has been formally identified in a NRC generic letter which points out a need for continuous monitoring, to detect and quantify gas voids in these systems, thereby to ensure their availability in accordance with design basis requirements. The letter further notes that periodic functional tests of the critical systems will not provide the required assurance of operability; if a periodic test finds a system's functionality questionable because of gas accumulation, the question of how long its operability has been compromised is unanswered.

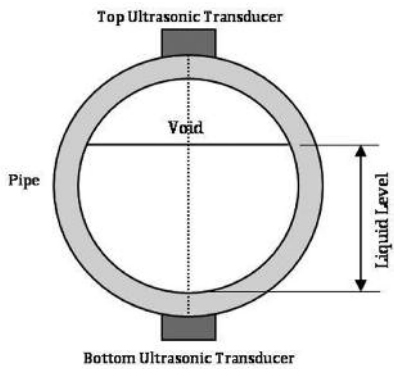

Figure 1: Arrangement, ultrasonic void detection and quantification

The Linewatch Gas Void Detection System addresses these issues. It provides the means to detect the onset of void formation in any one of multiple pipes in multiple systems on a continuous basis and, following void formation, the means to quantify the amount of these voids, again continuously.

Principles of operation

When a pulse of ultrasonic energy impinges on an interface between two media the amount of energy that makes its way into the receiving medium depends on the match between the acoustic impedances of the transmitting medium and the receiving medium—the greater the impedance mismatch the greater the fraction of sound energy that is reflected at the interface, instead of being transmitted into the second medium. The acoustic impedance depends on the compressibilities and densities of the adjoining media. Although there is a significant impedance mismatch between a pipe wall and liquid water, a substantial fraction (about 10%) of the ultrasonic energy transmitted into a pipe wall can nevertheless make its way into the water. But because the acoustic impedance mismatch between metal and gas is much greater, only a tiny fraction (about 1 part in 100,000) can make its way into gas. For this reason a tiny bubble of gas, collected in the top of a pipe will effectively prevent transmission of ultrasound from a transducer mounted on the top of a pipe from reaching a transducer on the bottom, and vice versa.

The Linewatch Gas Void Detection System utilizes this principle to detect the onset of void formation in pipes normally filled with water. Figure 1 diagrams the arrangement of the transducers for one void detection location.

Likewise, if a pulse of ultrasonic energy, traveling through a liquid, encounters a liquid-gas interface, the acoustic impedance mismatch between gas and liquid at the interface causes most of the energy in the pulse to reflect back into the liquid. Thus, after a void has been formed at the top of the pipe, a pulse of ultrasound transmitted from the transducer on the bottom will reflect off the interface and be received by the same transducer. The pulse's round trip transit time in the liquid is equal to the quotient of the distance the pulse has traveled—twice the height of the liquid in Figure 1—and the sound velocity in the liquid. Thus, if knowledge of the sound velocity can be gained by some means, the height of the liquid can be determined by a measurement of the transit time. The Linewatch void detection system measures the sound velocity of the liquid in the pipe when it is full and uses the principle described above to determine the height of liquid in a pipe after a void has formed.

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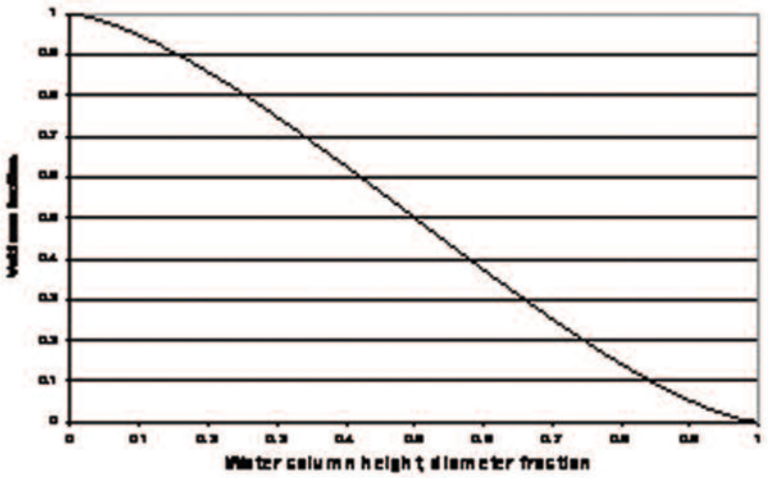

Figure 2: Void fraction with circular cross section vs. height of water column

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Given the height of liquid in a circular pipe, the void area fraction is readily quantified, using standard trigonometric identities. Figure 2 graphs the relationship. The area fraction occupied by a void, rather than the fact of its existence is of interest, since it is the volume of a void—the void area times the pipe length over which it may exist—that can threaten the operability of a downstream pump, or can generate an unacceptably large water hammer.

Detailed description

Linewatch is simply installed on the outside of existing piping and can be configured for 3 to 8 measurement points. Each measurement point consists of a rugged transducer mounting assembly and two ultrasonic transducers mounted vertically, as shown in Figure 3. When a void is detected, the system will provide an alert and commence measuring and indicating void area. The latter data may be used by plant engineers to determine system-wide gas accumulation and system operability.

The measurement points are connected to an electronic unit that independently monitors up to eight points, as shown in Figure 4. The electronic unit sends out the void/no-void and void area fraction data in digital format for computer display to the plant operators.

Performance

The onset of void formation can be measured by a Linewatch system before the void thickness reaches one wavelength of the ultrasound in the liquid—in the 0.03 to 0.05 inch range. As was noted above, after a void is formed, Linewatch determines the height of remaining liquid from the quotient of the round trip transit time in the liquid of a pulse transmitted from the transducer on the bottom, reflected off the liquid surface and received by that same transducer, and a stored sound velocity. To make this computation the system needs three parameters:

- The internal pipe diameter

Figure 3: A Linewatch measurement point

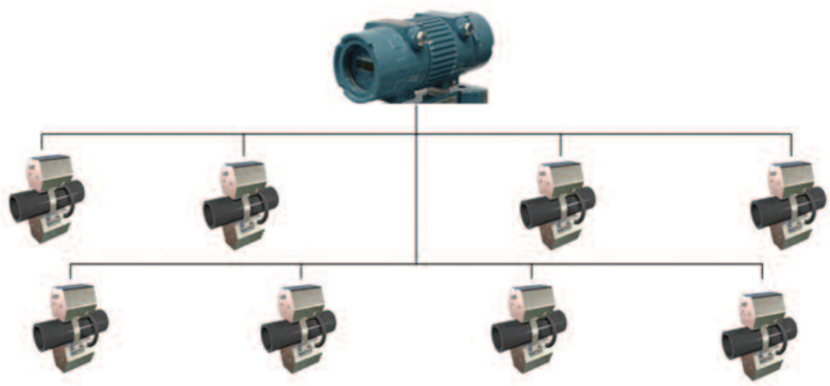

Figure 4: System configuration

- The non fluid delays associated with transmitting and receiving signals from the bottom transducer (so as to measure the net round trip transit time in the fluid),
- A sound velocity for the fluid remaining in the pipe after the formation of the void.

These parameters are determined as follows:

1. The internal pipe diameter is input by the user. The performance figures given below assume the user uses nominal internal diameter for the pipe schedule and diameter as quoted on the system isometric. The tolerance on internal diameter for commercial steel pipe is in the range 2 to 3%, depending on the diameter. The user may measure internal diameter for applications requiring greater accuracy in the void volume measurement. The performance figures following are based on a nominal ID uncertainty of 3%, which envelopes pipes of 4 inch diameter or more.

2. After its installation, when the affected pipe is full, the void detection system performs a series of 1-way (pitch-catch) and round trip (pulse-echo) transit time measurements from which it determines the non-fluid delays. These delays are insensitive to ambient and fluid temperatures, so that, after a void forms, the delays measured when the pipe was full may be used to determine the net round trip transit time in the remaining liquid. After a void forms, the accuracy of the liquid height measurement is a function of the accuracy of the total time measurement as well as the accuracy of the non-fluid delays computed from the transit times when the pipe was full. The performance figures quoted below are based on an uncertainty of 100 nanoseconds for each time measurement, whether before void formation, for the computation of non-fluid delays, or after, for the measurement of liquid height. The time measurement uncertainty is affected primarily by the accuracy of the time measurement clock and the received signal quality. The allowance is considered conservative.

3. The same series of 1-way and round trip transmissions that determine non-fluid delay when the pipe is full are used to determine the sound velocity of the liquid in the pipe. The uncertainties due to these time measurements are captured in (2) above. However, changes in liquid temperature can cause changes in sound velocity, and may occur before or after a void begins to form. When the pipe is full, the 1-way and round trip transmissions are performed continuously; consequently the value of sound velocity stored in the system memory is constantly refreshed and current for the then-prevailing liquid temperature. However, all transmissions except the round trip (pulse echo) transmission from the bottom transducer are discontinued when a void is formed (because of the void, the transmissions would not be received if the system attempted to continue them). Thus changes in temperature after a void has been formed may cause the retained value of sound velocity to become stale. The vulnerable segments of the monitored systems may be insulated or not—practice varies from plant to plant. In any case the stagnant liquid in them tends to reach a temperature in equilibrium with the surroundings. The performance described below assumes an ambient temperature change, after a void has formed, from 100 °F to 130 °F (considered a reasonable bound for the rooms in which the monitored systems are installed).

Figure 5 shows the uncertainty in void area fraction based on the assumptions listed above, as a function of the water level that defines the void. The figure applies to line sizes from 4 inches up. It will be seen that the potential errors are below 6%, an amount that would allow the setting of practical limits on void formation. Errors are substantially smaller—less than 2% if the allowable void fraction is 0.2 or less.

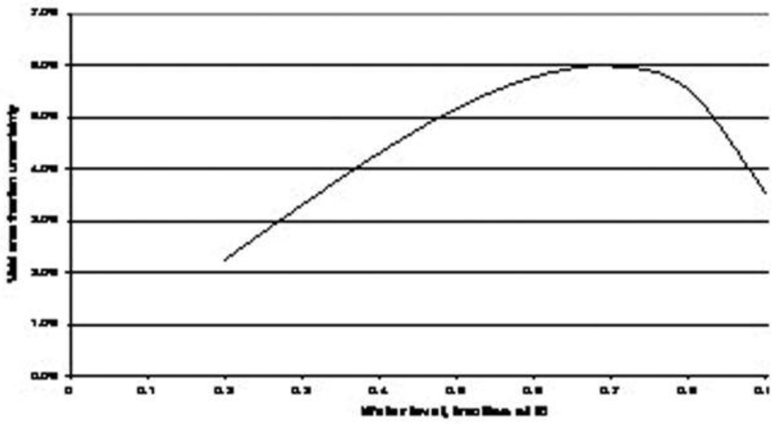

Figure 5: Void area fraction uncertainty

Conclusion

The Linewatch Void Detection System continuously monitors static emergency systems for gas voids and reliably detects the onset of void formation. The system quantifies the size of a void if one is detected. It replaces periodic surveillance, saving man-hours and allowing the dedication of operators to more immediate tasks. It can also be installed in locations inaccessible except during refueling outages. The system thus ensures 100% system operability, a condition impossible to achieve by periodic surveillance.

References available on request.