March 15, 2000

Document Control Desk
11555 Rockville Pike
U. S. Nuclear Regulatory Commission
Rockville, MD 20852

Attn: Mr. Stuart A. Richards, Project Director

Dear Mr. Richards:

I would like to express my appreciation to the NRC for providing Caldon with the opportunity to explain our concerns about the accuracy of ultrasonic cross correlation technology. I compliment you for the professional way in which you conducted the March 8 meeting.

We provided a great deal of information to the NRC to show that the errors inherent in the application of ultrasonic cross correlation flow measurement technology to feedwater flow in nuclear power plants cannot be bounded to a value as small as 0.5%. Caldon and the independent experts who attended the meeting tried to be thorough in addressing the specific points we believe represent the more significant contributors to uncertainty for this technology. While we may have succeeded in being thorough, I left the March 8 meeting concerned that we may have addressed too many details for others to assimilate, thereby making it difficult for them to quickly come to our conclusion. If this is the case, I invite the NRC to question us. We would be pleased to provide clarification or even additional information.

In addition, I have concluded that it would be worthwhile to provide the NRC with an analysis from a different perspective on the matter of measurement uncertainty. Consequently, I requested my people to prepare a new analysis that shows how uncertainty can be related to the number of flow meters employed in the measurement and to clarify the role played by the systematic and random components. We have occasionally used the approach of multiple flow measurements to reduce errors in applications of our external LEFM, particularly when customers have wanted Caldon to achieve a particular uncertainty value. This experience has taught us some lessons, including the one that more is not always better. This is because of the presence of systematic errors that are not reduced by multiple measurements.

The staff may recall that during the review of Caldon's Topical Report, the I&C Branch emphasized that the use of multiple measurements to reduce uncertainty can become a misleading exercise in mathematics and statistics. Caldon was cautioned not to assume

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that the calibration factor uncertainty for a given flow meter is random. Caldon provided explanation of our treatment of calibration factor uncertainties and verified that for a given flow meter, many of them are systematic. The staff recognized that the magnitude of these systematic uncertainties would be large if the actual velocity profile was not clearly defined. They reinforced this point in the Caldon SER by noting: "A key element in achieving the accuracy with an ultrasonic flow meter (including a multipath chordal meter) is an extremely accurate representation of the flow profile in a piping configuration that represents the plant specific installation."

The results of our new analysis are presented in the attachment to this letter. They are more instructive than I had expected them to be. They show that when using multiple flow meters of the ultrasonic cross correlation type on nuclear plant feedwater lines, the following conclusions can be reached:

- Uncertainties in feedwater flow measurement can be reduced by using multiple flow meters.

- Because of systematic uncertainties inherent in the concept, a bounding value of 0.5% cannot be achieved, no matter how many flow meters are used.

- Taking the systematic uncertainties into account, a practical bounding value for the over-all flow measurement uncertainty is not less than 1.2%.

All of the recent information we have provided to the NRC, including the attached analysis, comes out of our understanding of the basic physical principles involved in the ultrasonic cross correlation technique. These ideas are not derived from our knowledge of any particular product, such as the CROSSFLOW UFM. They are applicable to all types of ultrasonic cross correlation flow meters. The uncertainties for a specific product design can be expected to be even greater, depending on the trade-offs and other decisions made by the designer.

We are prepared to respond to questions the staff may raise.

Respectfully,

Calvin R. Hastings
President & CEO

CRH:jt

Attachments

cc: Mr. Brian W. Sheron
Mr. John S. Cushing

Attachment to
Caldon Letter
Dated March 15, 2000

Effect of Multiple Meter Measurements On Thermal Power Accuracy By Cross-Correlation Technology

Summary

This memorandum seeks to quantify the accuracy benefit of applying multiple cross correlation meters to feedwater flow measurement. By applying multiple meters, any random uncertainties can be reduced. However, systematic uncertainties are not reduced by multiple applications. For cross correlation meters, results indicate that systematic uncertainties are large enough to significantly limit the benefit of using multiple meters. For two meters, mass flow accuracy is estimated at 1.45%. For five meters, the accuracy is reduced to 1.2%. Theoretically, if an infinite number of meters were installed, the mass flow accuracy would only be improved to 1.1% by our analysis.

Background

The purpose of this memorandum is to determine how the advantage of multiple meter application might favorably impact the thermal power accuracy as measured by cross-correlation flow meters. The issue of whether uncertainty contributors are systematic or random is central to the degree of accuracy improvement.

Systematic and Random Uncertainties

Systematic uncertainties, sometimes referred to as biases, are here defined as those that are unchanging from one meter application to the next. A simple example of this definition is a batch of yardsticks that are manufactured consistently out of tolerance so that their length is 37 inches. No matter how many different yardsticks are used to measure the height of a 3 foot fence, the overall length error persists and is not improved as a percentage of reading. However, if yardsticks were manufactured with a randomly varying length of plus or minus one inch about the true 36 inches, then the resulting error can be reduced substantially by use of a large number of the yardsticks to measure the fence height many times.

The same principle is true for flow measurement instruments. There are random uncertainties that can be reduced by application of multiple meters, and there are systematic uncertainties that cannot be reduced by this technique. Uncertainties often have components of each type and must be broken into the systematic and random parts.

Flow Profile Uncertainties

In the case of cross-correlation flowmeter technology, there are two fundamental characteristics that have been analyzed and have been found to contribute to systematic uncertainties. These are uncertainties in flow profile measurement and uncertainties related to acoustic scatter of the ultrasonic beams due to reflection and refraction at the pipe/fluid interfaces. Since these error sources are largely systematic, it is beneficial to determine ways to limit their magnitude. To this end, our analysis assumes that plant-specific calibration testing is performed for these applications. Remaining systematic uncertainties then are the portion of the calibration testing determined to be systematic, and uncertainties that exist because of differences between the plant and the calibration lab. These remaining uncertainties are then bounded as tightly as possible.

The need for calibration testing is great for two reasons. First, the cross-correlation method only measures the fluid velocity within the central 64% of the cross sectional area of the pipe. This limited coverage means that the variability of the calibration factor is great, as proven by research published in the literature. Secondly, there is no such thing as fully developed flow in a nuclear plant feedwater system. Fully developed flow requires between 30 and 100 diameters of piping downstream of any non-straight hydraulic feature. For example, significant differences have been shown to exist in axial and transverse velocity profile for 20-30 diameters downstream of a single bend. Those differences are greatest in the developing boundary layer, or outer annulus of the profile, which is not perceived by the cross-correlation meter due to lack of coverage in this area. This does not mean that the cross correlation meter is insensitive to these changes. Rather, the lack of information about the boundary layer makes the meter more sensitive to such changes.

Data which seem to show that the cross-correlation flow meter's correction factor does not change after about 15 diameters are misleading; the changing calibration factor may have been obscured by the poor repeatability of this meter. In addition, the large scale change in the factor over the first 15 diameters tends to render the 1-2% change over the next 15 diameters less perceptible.

Finally, flow profiles change over time in the plants due to changing wall roughness. Wall roughness effects on profile and the cross-correlation indication cannot be predicted for each specific case, but are large and are systematic from meter to meter because the wall roughness changes are driven by water chemistry which is common to all installation locations. Since successive applications of these meters will all be subject to the same poor profile coverage, velocity profile development is unidirectional, and wall roughness changes are likely to be common to most of the piping in the feedwater system, the majority of the profile related uncertainties are systematic.

Acoustic Uncertainties

A second fundamental characteristic of cross-correlation flowmeter technology is associated with the acoustic effects of the continuous wave cross-correlation employed. Ideally, one would like to have a single diametral beam from transmitter to receiver that interacts with turbulent eddies at the upstream and downstream stations, causing the correlation. However, because the acoustic beam actually refracts through and reflects off of pipe wall surfaces, it draws a pattern of superposition within the pipe diameter. This superposition results in beam focus in unintended areas of the flow profile. Since this characteristic also contributes to systematic uncertainties, its magnitude can also be diminished by calibration testing. However, the beam scattering is a function of both pipe diameter and of wavelength. Both of these factors typically change from calibration lab to the plant, and both changes are largely systematic among meters in the plant since the plant-to-lab difference between pipe diameters and between ultrasonic wavelengths will be common among plant-installed instruments.

Results

The systematic uncertainties related to the flow profile and acoustic characteristics which remain after calibration testing are significant. These systematic components limit the potential benefits of multiple meter application, as illustrated in Table 1. Table 1 lists estimated uncertainty contributions and total mass flow uncertainty for three cases of application of the cross correlation technology. These cases involve successively more meters applied to achieve greater accuracy. All three cases are based on instrumenting a plant with two feedwater lines, as this is most representative of the plant population. The first case is for one meter on each of the two feedwater lines. The second case adds a third meter on a common feedwater header. The third case includes two meters on each of the feedwater lines and a fifth meter on the header.

Table 1. Cross-Correlation Meter Accuracy Estimates: Benefit of Using Multiple Meters

Uncertainty Source	Case 1: Two Meters	Case 2: Three Meters	Case 3: Five Meters
Acoustics	1.0%	0.79%	0.68%
Flow Profile	1.0%	0.96%	0.96%
Dimensions	0.29%	0.24%	0.19%
Timing	0.33%	0.29%	0.18%
Total Mass Flow	**1.45%**	**1.3%**	**1.2%**

The uncertainties are grouped into four categories: acoustics and flow profile as discussed above, dimensions and timing. The values reported are the result of combining between 3 and 7 sources within each category. Random and systematic components have been separated and the random uncertainty components are reduced with use of additional meters. All values in the table are considered best case values, and values for some systematic uncertainties are based on plant data. These plants include Arizona Power & Light's Palo Verde and Florida Power & Light's St. Lucie.

The reduction in uncertainty for each category, progressing from left to right in the table, is the smallest for the flow profile category. This is because the flow profile uncertainties are almost entirely systematic. For example, the best-case uncertainties due to modeling effects and wall roughness discussed above are relatively large and highly systematic. These contributors also have random components which reduced with additional meters, but the remaining uncertainty is dominated by the systematic non-reducing portion.

Acoustic uncertainties are also large and contain significant systematic contributors. The dimensional and timing uncertainties tend to be more random, and show a greater benefit with multiple meter applications.

In total, the systematic uncertainties are large enough to significantly limit the benefit of adding meters in the plant. In fact, theoretically, if an infinite number of meters were installed, the mass flow accuracy would only be improved to 1.1% by our analysis.