Measurement Systems

Caldon® Ultrasonics Technology Center
1000 McClaren Woods Drive
Coraopolis, PA 15108
Tel 724-273-9300
Fax 724-273-9301
www.c-a-m.com

CAMERON

March 18, 2010

Document Control Desk
U. S. Nuclear Regulatory Commission
Washington, DC 20555

Subject: Documentation to Support review of Caldon® ER-157P Rev. 8

Dear Ms. Lenning:

Per your request please find attached Cameron's engineering report ER-764 Rev. 0. This engineering report is being submitted for information only.

- Caldon® Ultrasonics Engineering Report: ER-764 Rev. 0, "The Effect of the Distribution of the Uncertainty in Steam Moisture Content on the Total Uncertainty in Thermal Power"

If you have any questions or require additional information, please contact me at 724-273-9300.

Regards,

Ernie Hauser
Director of Sales

Enclosure

T007
NRR

Caldon® Ultrasonics

Engineering Report: ER-764 Rev. 0

The Effect of the Distribution of the Uncertainty in Steam Moisture Content on the Total Uncertainty in Thermal Power

Prepared by: Herb Estrada
Reviewed by: Ernie Hauser EMH

September 2009

Engineering Report: ER-764 Revision 0

The Effect of the Distribution of the Uncertainty in Steam Moisture Content on the Total Uncertainty in Thermal Power

Table of Contents

1.0 BACKGROUND

Revision 8 of ER-157[1] is the most recent revision of a topical report describing the characteristics and uncertainties associated with the use of LEFM Check and CheckPlus ultrasonic flow measurement systems for Measurement Uncertainty Recapture power uprates in nuclear power plants. Table A-1 of Appendix A of that report provides detailed breakdowns of the uncertainties for a typical Check system and for a typical CheckPlus system making a single total feedwater flow measurement in an (approximately) 3450 MWt plant. The largest power uncertainties in the breakdowns are those estimated for:

- The Profile Factor (calibration coefficient) — ± 0.4% power for a Check and ± 0.22% power for a CheckPlus, and
- Steam moisture — ± 0.21% power for cases where a licensee uses a 0.25% moisture content for his calorimetric computation and assumes a ± 0.25% uncertainty in this figure.

The uncertainties quoted are 95% confidence limits with normally distributed uncertainties.

ASME PTC 19.1 (1985)[2] states that uncertainties contributing to the overall thermal power uncertainty must be roughly comparable in magnitude, if the contributors are to be combined as the square root of the sum of the squares. This criterion is contained in footnote (1) of Table A-1. It is not obvious that the terms cited in the preceding paragraph meet this criterion; they are significantly larger than most of the entries in Table A-1. However, as noted in the discussion in footnote (1) of Table A-1, the contributors to the Profile Factor uncertainty are themselves in the same order as the other uncertainties of Table A-1 (excluding the uncertainty in steam moisture); hence the ASME requirement is met with regard to Profile Factor.

The discussion of the footnote begs the question: What impact do the uncertainty and the distribution of the uncertainty in moisture carryover have on the overall thermal power uncertainty? The analysis of this document addresses this question.

The moisture carryover assumed in the calorimetric calculation for the steam delivered to the power conversion system is of course the responsibility of the licensee. It is almost always based, directly or indirectly, on a test of the moisture separators and dryers of the steam supply system—often a one-time test performed at the manufacturer's test facility. Occasionally the figure used will be based on a chemical tracer test performed in-plant. Where the assumed moisture is based on a test or tests, it may plausibly be argued that its uncertainty is normally distributed because that uncertainty is made up of a number of small contributors. A licensee, however, may not have access to the data that would support the calculation of this uncertainty, particularly if the uncertainty is based on tests at the manufacturer's facility.

The analyses in ER-157 for the cases where significant moisture is assumed to be present in the steam use a maximum moisture content equal to a typical steam supplier's guarantee for some early water reactor designs and an uncertainty of plus or minus that guarantee (an uncertainty also typical of thermal power uncertainty analyses for early water reactors). ER-157 also presents an alternative analysis wherein zero moisture is assumed in delivered steam. Some modern

[1] Cameron Caldon Engineering Report ER-157P, Revision 8, dated May 2008, "Supplement to ER-80P...."
[2] ASME PTC 19.1 (1985), ASME Power Test Code, Part 1 Measurement Uncertainty. The methodology of this reference is the basis for the uncertainty calculations of ER-157.

separators and dryers deliver steam having a moisture content in the 0.05% range. For these systems licensees often assume zero steam moisture content in their calorimetric power calculation. In such cases, it is not necessary to assume any uncertainty for the moisture. If moisture *is* present, the calculated power will be greater than the actual power and therefore conservative.

A licensee should be able to justify both the moisture assumed in his calorimetric power calculation and the uncertainty that he uses in the calculation of overall thermal power uncertainty. If he has knowledge of the uncertainties in the measurement of the moisture content and/or they are of the same order of magnitude as the other calorimetric uncertainties, i.e. ~ 0.1%, he may be able to justify the combination of the moisture uncertainty with the other thermal power uncertainties as the root sum squares. On the other hand if he cannot characterize the moisture uncertainty as normally distributed and it is significant relative to other uncertainty contributors, i.e. 0.21% or more, it may more conservatively be assumed that the moisture is uniformly distributed (as in a roulette wheel) within the uncertainty band.

The uniform distribution can be qualitatively justified for the 0.25% moisture content, ± 0.25% moisture uncertainty case analyzed in ER-157. The steam cannot be dryer than 0% moisture, and is unlikely, over the long term to be wetter than 0.5% (since moisture content at this level will cause observable erosion damage in the initial stages of the high pressure turbine). Accordingly, the analysis below will examine the difference, in overall power uncertainty, between a moisture uncertainty normally distributed and having a defined two standard deviation band and a moisture uncertainty uniformly distributed over the same band.

2.0 ANAYLSIS

For each moisture content uncertainty band, the analysis is based on a series of 10,000 sample Monte Carlo calculations of total power uncertainty. For each calculation, the uncertainty in the thermal power due to the measurement of all variables *excluding moisture* was taken as normally distributed with two standard deviations of 0.3357%, the aggregate uncertainty of all contributors excluding moisture for the LEFM CheckPlus system of ER-157. For each sample, a normally distributed random number was generated. The random number distribution was scaled to have a standard deviation of 1.000; hence the random numbers range from roughly – 3.8 to + 3.8—a sample of 30,000 should encompass ± 4 standard deviations. For each sample, the error contribution, E_{bal} for all contributors except moisture, is the product of the normally distributed random number and *one* standard deviation of these contributors. That is,

E_{bal} = the normally distributed random number $N_N \times 0.3357/2$

$$E_{bal} = N_N \times 0.165785$$

For each sample, the contribution of the uncertainty in moisture content was calculated by multiplying a second, *uniformly distributed* random number N_U times the magnitude of the uncertainty band assigned to the moisture, B (for a moisture uncertainty band of ± 0.21%, B = 0.21). The uniformly distributed random number was determined using the Excel random number generating function, RAND(), which generates a random number between 0 and 1. N_U was computed as follows:

$$N_U = 2 \times (0.5 - \text{RAND}()).$$

To find the uncertainty due to moisture, E_{moist} the assigned magnitude of the band B was multiplied by N_U which, it will be noted, can vary between +1 and –1. That is

$$E_{moist} = N_U \times B$$

For each sample the total uncertainty in thermal power, E_{total} was found by algebraically summing the uncertainties for the moisture and the balance of the power calculation contributors:

$$E_{total} = E_{moist} + E_{bal}$$

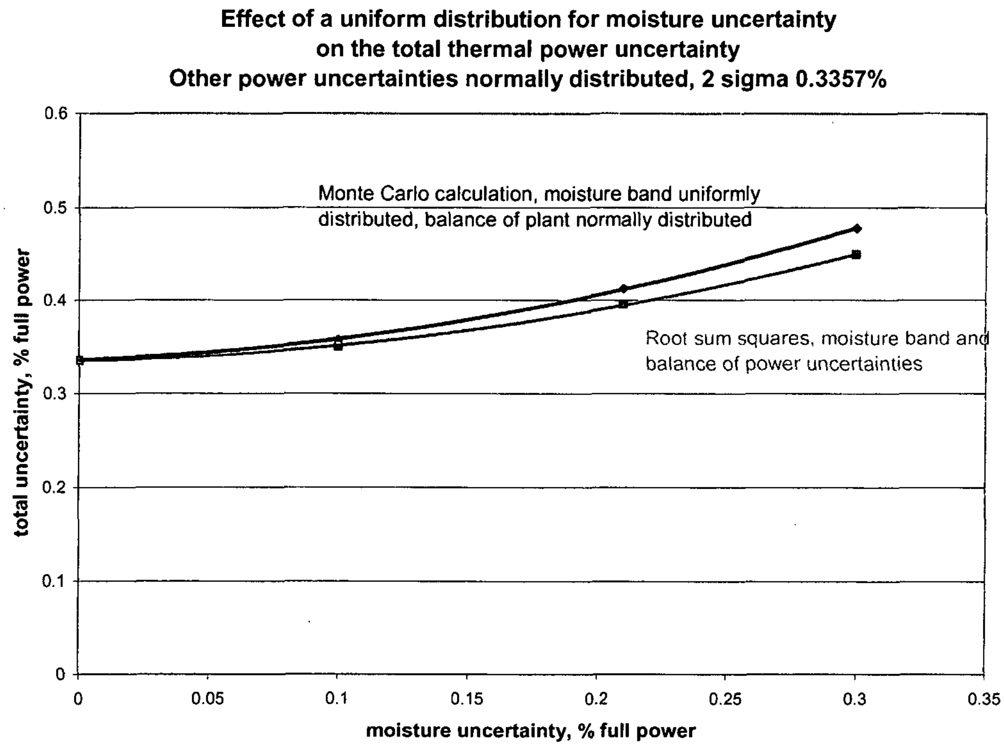
3.0 RESULTS

Figure 1 below plots the results of the analyses for uncertainties due to moisture content ranging from ± 0% power to ± 0.3% power ,The latter figure is considered a practical upper limit for a tolerable moisture content—a power uncertainty of ± 0.3% translates to a moisture content uncertainty of ± 0.36% which implies a nominal steam moisture content of 0.36%. The figure plots two standard deviations of the distribution of 10,000 samples of the total power uncertainty for moisture uncertainty bands of 0% power, 0.1% power, 0.21% power and 0.3% power. It should be noted that, for the larger moisture contents, a ± 95% confidence limit is achieved by a band slightly smaller than the curve in the figure. For example, for a uniform moisture uncertainty distribution of ±0.3% power, 95% of the errors are bounded by a ± 0.47% band (versus the ± 0.48% band determined by the two standard deviation calculation and shown in the figure). Both numbers are larger than the uncertainty band characterizing normally distributed moisture uncertainties. This uncertainty, which is calculated by combining the two uncertainties as the root sum squares, is also shown in the figure (it is the magenta curve labeled as the root sum square). For a ± 0.3% moisture uncertainty band, the curve for normally distributed moisture uncertainty is about 0.03% below the two standard deviation curve for the uniform distribution.

For the ± 0.21% power uncertainty assumed in the (typical) ER-157 analysis, Figure 1 indicates that total power uncertainty for the uniform moisture uncertainty distribution is between 0.01% and 0.02% greater than it is for a normal moisture uncertainty distribution.

From this analysis it is concluded that licensees assuming large uncertainties in steam moisture content should have an engineering basis for the distribution of those uncertainties or, alternatively, should ensure that their calculations provide margin sufficient to cover the differences shown in Figure 1.

Figure 1


Effect of a uniform distribution for moisture uncertainty
on the total thermal power uncertainty
Other power uncertainties normally distributed, 2 sigma 0.3357%
total uncertainty, % full power
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
moisture uncertainty, % full power
Monte Carlo calculation, moisture band uniformly distributed, balance of plant normally distributed
Root sum squares, moisture band and balance of power uncertainties