PROGRESS ENERGY FLORIDA, INC.

CRYSTAL RIVER UNIT 3

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ATTACHMENT

MEASUREMENT UNCERTAINTY RECAPTURE

Cameron Engineering Report ER-608, Revision 2
LEFM CheckPlus Meter Factor Calculation and Accuracy Assessment for Crystal River Unit 3 Nuclear Power Station

NON-PROPRIETARY

CAMERON

Measurement Systems

Caldon® Ultrasonics

ER-608NP
REVISION 2
DECEMBER 2007

Engineering Report-ER-608NP Rev 2

LEFM✓ + Meter Factor Calculation and Accuracy Assessment for Crystal River Unit 3 Nuclear Power Station (Alden Reports No. 2007-133/C1229)

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APPENDICES

Appendix A – [ ]

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a,b,
c,e

ER-608NP Rev 2, LEFM✓+ Meter Factor Calculation and Accuracy Assessment for Crystal River Unit 3 Nuclear Power Station

1.0 INTRODUCTION

1.1 Scope

This report documents calibration of the Crystal River Unit 3 LEFM✓+ flow elements (Serial Number 17932 - Loop A and 17933 – Loop B). This report includes:

- LEFM✓+ meter factors (e.g., calibration coefficients) as measured [ ] a,b,c,e
- Meter factor uncertainty
- Description of the calibration facility and the hydraulic mode
- Description of the tests conducted
- Acoustic delays determined for the LEFM✓+ flow element

1.2 LEFM✓+ Background

The LEFM✓+ meter measures the fluid velocity projected onto an acoustic path between pairs of ultrasonic transducers. The velocity is calculated from the transit times of pulses of ultrasonic energy traveling in both the upstream and downstream directions between the two transducers and from the distance separating the transducers. The LEFM✓+ is an eight path chordal ultrasonic meter in which there are two crossing paths on each of four chords, essentially creating two four path meters. The meter measures volumetric flow by numerically integrating the fluid-velocity chord length product along the chords, where each velocity chord length product is determined from the transit times along the respective acoustic paths.

For typical nuclear power plant applications, such as the Crystal River Unit 3 installation, it is Cameron's practice to perform a calibration test in order to determine the meter calibration constant, or meter factor. The meter factor provides a small correction to the numerical integration to account for the specifics of the fluid velocity profile as well as any dimensional measurement errors. The calibration test was performed at Alden Research Laboratories (Alden), an independent hydraulic laboratory.

Alden can provide flow rates up to ~4500 m^3/hr (~20,000 gpm). [ ] In order to determine the meter factor, the LEFM✓+ flow rates are compared with reference flow rates, provided by the laboratory. a,b,c,e

During the calibration, reference flow rates are determined by Alden using the weigh tank fill times, fluid temperature and barometric pressure measurements. All elements of the lab measurements—weigh tank scale, time measurements, thermometers and pressure gages—are traceable to NIST standards. The Crystal River Unit 3 calibration test procedures were [ ], which provided overall guidance for the test setup and test scope. a,b,c,e

[1] [ ] a,b,c,e

1.3 Report Summary

a. The Crystal River Unit 3 LEFM✓+ spool piece meter factors and uncertainties when calibrated [ ] are as follows (see Section 4): a,b, c,e

Serial Number	17932 Loop A	17933 Loop B	System
Meter Factor	[ ]	[ ]	
SRSS Uncertainty (2 standard deviations)	[ ]	[ ]	[ ]

a,b, c,e

Table 1: Calibration Summary

[ ] a,b, c,e

b. The LEFM✓+ electronics worked within specifications, with the signal to noise ratios [ ] The uncertainty attributable to the electronics and signal to noise ratio are included in the overall meter factor uncertainty quoted above. a,b, c,e

c. The following table documents the [ ] during the calibration. (These [ ].) a,b, c,e

Path Name	S/N 17932 Loop A [ ]	S/N 17933 Loop B [ ]
Path 1	[ ]	[ ]
Path 2	[ ]	[ ]
Path 3	[ ]	[ ]
Path 4	[ ]	[ ]
Path 5	[ ]	[ ]
Path 6	[ ]	[ ]
Path 7	[ ]	[ ]
Path 8	[ ]	[ ]

a,b, c,e

Table 2: [ ]

2.0 CALIBRATION TESTS

The objectives for the calibration tests were to:

- Determine the meter factor [ ]
- Determine the sensitivity of the meter factor [ ]
- Determine the LEFM✓+ [ ] used in the calibration.

a,b, c,e

2.1 Meter Setup

2.1.1 LEFM✓+ Setup

The LEFM✓+ meter was installed in accordance with portions of Cameron Engineering Field Procedure [ ]. Specifically, the portions of [ ] accomplished:

- Confirmed satisfactory signal quality,
- [ ]
- Confirmed the [ ]

a,b, c,e

The signal quality tests include the reviewing of received signals and the [ ] A special serial hookup to a PC laptop computer was used during testing to obtain data automatically from the test LEFM✓+ electronics during calibration tests.

2.2 [ ] Model

[

] The pipe inside diameter matches the nominal pipe inside diameter to be used at the Crystal River Unit 3 installation. [ ]

a,b, c,e

[

]

[2] See Alden report for drawings of each configuration.

a,b,
c,e

Figure 1: [

]

a,b,
c,e

Figure 2: Loop B – [

]

a,b,
c,e

Figure 3: Loop B – [

]

a,b,
c,e

Figure 4: Loop A – [ ]

Figure 5: Loop B – [ ]

2.3 Calibration Data

References 1 and 2 outline [

a,b, c,e

]

The tests and calibration numbers are listed in Tables 3 and 4. [

]

Each model test consisted of typically 20 to 25[ ] weigh tank runs over a range of different flow rates. The maximum flow rate in the model tests was approximately [ ]

Test No.		Notes
A-1	CAM 16J	[ ]
A-2	CAM 16K	[ ]

Table 3: Test Summary – S/N 17932 – Loop A

Test No.		Notes
B-3 (ALD-1097 Rev 1)	CAM16B	[ ]
B-7 (ALD-1097 Rev 1)	CAM 16G	[ ]
B-8 (ALD-1097 Rev 1)	CAM 16H	[ ]
B-2 (ALD-1097 Rev 2)	CAM 17B	[ ]
B-6 (ALD-1097 Rev 2)	CAM 17F	[ ]
B-7 (ALD-1097 Rev 2)	CAM 17G	[ ]

[[3] For parametric tests, the lowest flow was omitted, total of 20 runs. For model tests, 25 runs are performed. The exception is calibration CAM17G. For this test there was a failure in the Alden pumps and only 15 tests could be performed.]

Table 4: Test Summary – S/N 17933 – Loop B

2.3.1 Test Collection Procedure

Weigh tank testing at a specific flow rate begins by setting the proper flow in the flow loop, using a remotely operated butterfly valve located downstream of the model.

[a,b, c,e

]

The test procedure at any given flow rate was as follows:

- Set the flow rate and allow flow to stabilize
- Alden personnel operate weigh tank run by moving the diverter valve.
- [a,b, c,e

  ]

3.0 LEFM✓+ METER FACTOR CALCULATION

3.1 Meter Factor Definition

The purpose of the calibration tests is to determine the meter factor. The meter factor accounts for (typically small) biases in the numerical integration due to the hydraulics, dimension measurements and acoustics of the application. The LEFM✓+ software multiplies the result of the multi-path numerical integration by the product of the meter factor to obtain the flow rate. For the Alden tests, the meter factor was set at 1.000.

The LEFM✓+ meter factor is calculated by the following equation:

$$MF = \frac{Q_{Alden}}{Q_{LEFMCheckPlus}}$$

Where:

$Q_{LEFM✓+}$ = Volumetric flow rate from LEFM✓+ (with meter factor set to 1.000)

Q_{Alden} = Volumetric flow rate based on Alden weigh tank

3.2 Test Results

[a,b, c,e

]

- Alden certified flow rate for each run.
- [
-]

Tables 5 and 6 below, summarize the data (including velocity profile data). Figures 6 and 7 plot the meter factor data for all the model test cases (including error bars).

As seen in Table 6, [

]

a,b, c,e

Calibration	MF Average	Number Points	FR[4]	Absolute Swirl Rate[5]
CAM 16J	[ ]	[ ]	[ ]	[ ]
CAM 16K	[ ]	[ ]	[ ]	[ ]

Table 5: S/N 17932 (Loop A) [

]

Calibration	MF Average	Number Points	FR	Absolute Swirl Rate
CAM16B	[ ]	[ ]	[ ]	[ ]
CAM 16G	[ ]	[ ]	[ ]	[ ]
CAM 16H	[ ]	[ ]	[ ]	[ ]
CAM 17B	[ ]	[ ]	[ ]	[ ]
CAM 17F	[ ]	[ ]	[ ]	[ ]
CAM 17G	[ ]	[ ]	[ ]	[ ]

Table 6: S/N 17933 (Loop B) [

]

[

]

a,b,
c,e

Figure 6: S/N 17932 (Loop A) – [ ]

a,b,
c,e

Figure 7: S/N 17933 (Loop B) – [ ]

3.3 [

]

a,b,
c,e

Figure 8: Velocity Profile (CAM16K) – [ ]

a,b,
c,e

Figure 9: Velocity Profile (CAM17B) – [ ]

3.3.1 [

]

[6] For more information on the LEFM✓+ meter, refer to Cameron Engineering Report - 157, "Supplement to Caldon Topical Report ER-80P: Basis for Power Uprates with an LEFM Check or an LEFM CheckPlus", dated October 2001, Revision 5.

[

]

3.3.1.1 [

a,b,
c,e

]

Figure 10: [ ]

[

]

3.3.2 [

a,b,
c,e

.]

[8] See Reference 7.

a,b,
c,e

Figure 11: Summary of [ ]

3.4 Relationship [ ]

In 2002, Cameron published an analysis of velocity profiles observed in the field. In this analysis, an analytical relationship between the LEFM✓+ meter factor (MF) and the observed flatness ratio (FR) was computed. This relationship is based on integration of velocity profiles that were constructed using a power law representation. The power law velocity profile is described as follows:

$$u = (1-r)^{1/n}$$

Where:

u	=	Velocity at any point in the pipe normalized with respect to the maximum velocity
r	=	Distance from the center of the pipe as a fraction of the pipe radius
n	=	Exponent term that changes the shape of the profile as a function of Reynolds number and pipe roughness.

[ ]

a,b,
c,e

The analysis calculated profiles with values of n of between 4 and 20. This range of n covers a very wide range of Reynolds Numbers, as it has been shown that $n = 6$ to $n = 14$ covers a Reynolds number range of 4,000 to 3,200,000[9]. The analysis has shown that MF for a 4 path Gaussian integration will have a linear relationship with FR. According to Reference 16, the relationship between MF and FR should be approximately as shown in Figure 12.

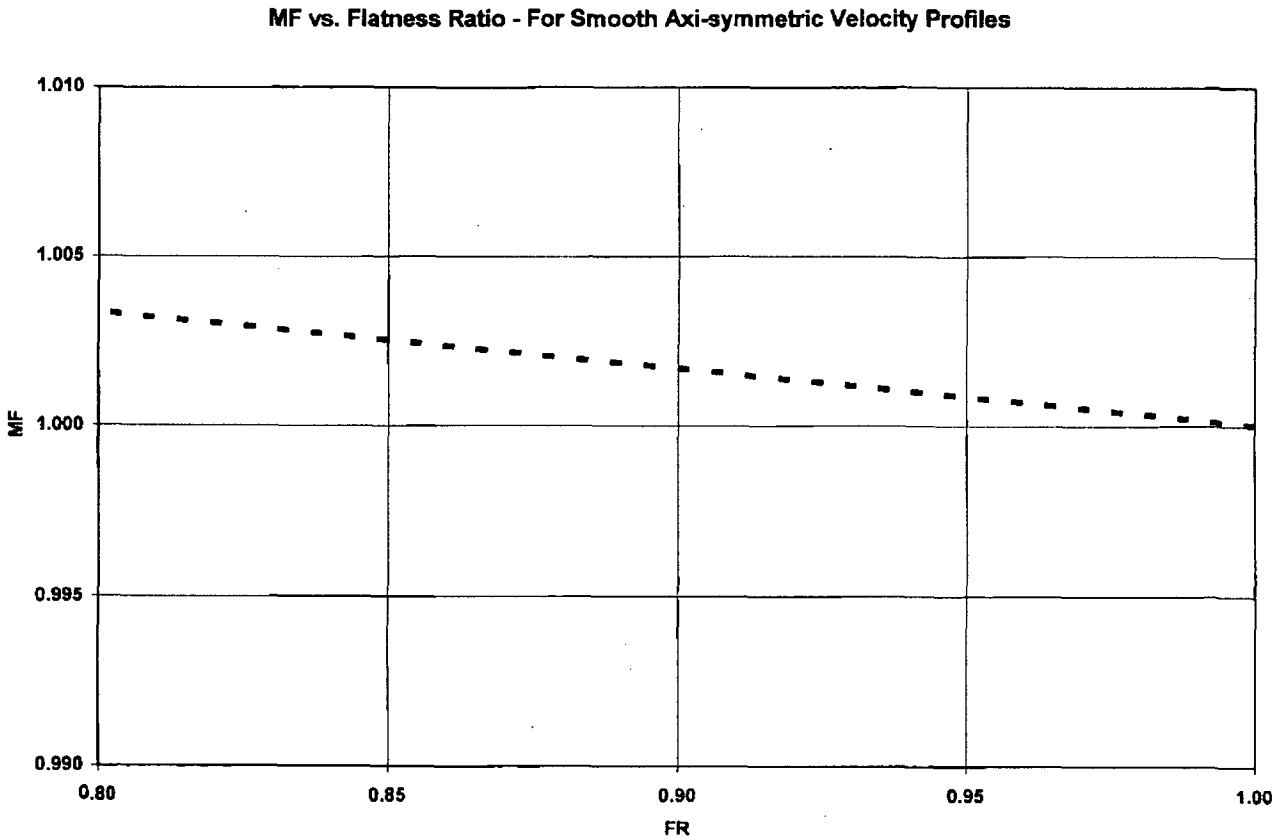

Figure 12: MF vs. FR for a 4 path Gaussian Integration of the Velocity Profile

[ ] It can be seen that the calibration MF has a nearly identical relationship with respect to FR as that predicted in Reference 16. [ ] a,b,c,e

[9] See Reference 16.
[10] All cases without the tube bundle upstream are shown.

a,b,
c,e

Figure 13: MF vs. FR for [ ]

[

]

4.0 METER FACTOR ACCURACTY ASSESSMENT

This section documents the methodology for calculating the uncertainty or accuracy of the LEFM✓+ meter profile factor. This report was produced using a process and quality assurance consistent with the requirements of 10CFR50 Appendix B, Cameron's Topical Report ER-80P, ER-160P, ER-157P, ASME PTC 19.1 and ISA-RP67.04.02-2000. The approach to determination of the set points is to combine the random and bias terms by the means of the RSS approach given that all the terms are independent, zero-centered and normally distributed.

First the sensitivity of the calculated flow to each independent variable or input is determined. Once the sensitivities to the independent variables have been calculated, then the independent variables' uncertainties are calculated and multiplied with their sensitivity coefficient, such as calibration facility, timing errors, etc. The 95% confidence level uncertainty bounds are calculated for each element.

The evaluation of the sensitivity coefficients is performed by determining the independent variables in the mass flow (and volumetric flow) calculation. For example, if volume flow is a function of independent variables $X_1, X_2, ..., X_n$, as follows:

$$Q = f(X1, X2, ..., Xn).$$

The uncertainty effect of specific independent variable on the flow measurement is calculated by partial differentiation of the above equation. Expressing the result as a per unit sensitivity:

$$\frac{dQ}{Q} = \left[\frac{X_1 \partial Q}{Q \partial X_1}\right]\left(\frac{\Delta X_1}{X_1}\right) + \left[\frac{X_2 \partial Q}{Q \partial X_2}\right]\left(\frac{\Delta X_2}{X_2}\right) + ... + \left[\frac{X_n \partial Q}{Q \partial X_n}\right]\left(\frac{\Delta X_n}{X_n}\right).$$

Where the terms in the brackets are the sensitivity coefficients for $X_1, X_2, ..., X_n$. The magnitudes and signs of each uncertainty for a given flow measurement are then bounded by 95% confidence intervals. The ASME PTC 19.1 demonstrates that by combining the independent uncertainty contributions as the root sum square, the overall uncertainty in volumetric flow is bounded by a 95% confidence level. Specifically,

$$\frac{dQ}{Q} = \sqrt{\left[\left(\frac{X_1 \partial Q}{Q \partial X_1}\right)\left(\frac{\Delta X_1}{X_1}\right)\right]^2 + \left[\left(\frac{X_2 \partial Q}{Q \partial X_2}\right)\left(\frac{\Delta X_2}{X_2}\right)\right]^2 + ... \left[\left(\frac{X_n \partial Q}{Q \partial X_n}\right)\left(\frac{\Delta X_n}{X_n}\right)\right]^2}.$$

The allocation of uncertainties for meter factor for the LEFM✓+ meter (consistent with the Cameron Topical report) is shown in Table 7 below. Using the data in Tables and using a root mean square summation technique indicated for combining independent uncertainties of relatively the same magnitude, the total uncertainty due to MF is computed.

	S/N 17932 Loop A	S/N 17933 Loop B	System
Facility Uncertainty	[ ]	[ ]	[ ]
Measurement Uncertainty	[ ]	[ ]	[ ]
Extrapolation	[ ]	[ ]	[ ]
Observation and Modeling	[ ]	[ ]	[ ]
Data Scatter	[ ]	[ ]	[ ]
RMS Total	[ ]	[ ]	[ ]

a,b, c,e

Table 7: Uncertainty Summary for Meter Factor

4.1 Facility Uncertainty

A facility uncertainty of [ ] has been budgeted and this figure appears in the table above.

a,b, c,e

4.2 Measurement Uncertainty

[ ] calculates the uncertainties in the volumetric flow measurement (excluding meter factor) of the LEFM✓+ used for this test. The results are summarized below in Table 8. [

]

Summary	Random	Systematic	Combined
[			
RMS Subtotal			]

Table 8: [

]

[11] See Reference 14.

[

]

4.3 LEFM✓+ Extrapolation to Plant Conditions

At the plant, it is possible that the hydraulic conditions will not equal those tested at Alden for the calibration. If plant conditions are at higher Reynolds numbers (which is the case) or have a lower wall roughness, [ ] Alternatively, [ ] is addressed by the Gaussian integration, Cameron includes an uncertainty term for any numerical integration errors.

The numerical calculation of meter factor for fully developed flow profiles (profiles empirically determined by hydraulic researchers) was illustrated in Section 3.4. [ ]

[ ].

a,b, c,e

4.4 [ ] Uncertainty

[ ]

Test No.	Chordal LEFM✓+
CAM16B	[ ]
CAM 16G	[ ]
CAM 16H	[ ]
CAM 17B	[ ]
CAM 17F	[ ]
CAM 17G	[ ]
Spread (+/-)	[ ]

Table 9: [ ]

[ ]

4.5 LEFM✓+ [ ] Uncertainty

The meter factor used at Crystal River [

]

Test No.	MF	Number of Points	[ ] Uncertainty
CAM 16J	[ ]	[ ]	[ ]
CAM 16K	[ ]	[ ]	[ ]
Average	[	[ ] Uncertainty	[ ]

Table 10: Loop A LEFM✓+ [Data Scatter] Uncertainty

a,b,c,e

Test No.	MF	Number of Points	[ ] Uncertainty
CAM16B	[ ]	[ ]	0.0005
CAM 16G	[ ]	[ ]	0.0002
CAM 16H	[ ]	[ ]	0.0002
CAM 17B	[ ]	[ ]	0.0001
CAM 17F	[ ]	[ ]	0.0002
CAM 17G	[ ]	[ ]	0.0003
Average	[ ]	[ ] Uncertainty	[ ]

Table 11: Loop B LEFM✓+ [ ] Uncertainty

5.0 REFERENCES

1. [ ]
2. [ ]
3. [ ]
4. [ ]

a,b, c,e

5. Moody, L. F., "Friction Factors for Pipe Flow," ASME Transactions, V. 66, 1944, pp. 671-694
6. National Bureau of Standards and Technology, "Experimental Statistics Handbook 1991"
7. Murakami, M., Shimizu, Y., and Shiragami, H., "Studies on Fluid Flow in Three-Dimensional Bend Conduits," Japan Society of Mechanical Engineering (JSME), Bulletin V. 12, No. 54, Dec. 1969, pp. 1369-1379.
8. Cameron Topical Report ER-80P Rev 1, "Improving Thermal Power Accuracy and Plant Safety While Increasing Operating Power Level Using the LEFM Check System", March 1997.
9. ER-551, [ ] a,b, c,e
10. ISA-RP67.04.02-2000, Methodologies for the Determination of Setpoints for Nuclear Safety-Related Instrumentation
11. ASME PTC 19.1-1985, Measurement Uncertainty
12. Cameron Engineering Report ER-160P Rev 1, "Supplement to Topical Report ER 80P: Basis for a Power Uprate with the LEFM System", May 2000
13. Cameron Engineering Report ER-157P Rev. 5, "Supplement to Caldon Topical Report ER-80P: Basis for Power Uprates with an LEFM Check or an LEFM CheckPlus", October 2001
14. [ ] a,b, c,e
15. Cameron Engineering Report ER 262 Rev 1, "Effects of Velocity Profile Changes Measured In-Plant on LEFM Feedwater Flow Measurement Systems", January 2002
16. 2006 South East Asia Flow Workshop Paper, "The Relative Merits of Ultrasonic Meters Employing Between Two and Eight Paths", Gregor Brown, Don Augenstein, Terry Cousins, Herb Estrada

[14] As executed test plan for Crystal River.
[15] As executed test plan for Crystal River for Loop B only

Appendix A – Calibration Data

This Appendix contains the raw data for each test. The data includes the Alden calibration period flow, the LEFM✓ + average flow during the calibration, and the computed meter factor at each flow.

a,b,
c,e

]

Appendix A is proprietary in its entirety.

Appendix B - LEFM✓ + Meter Uncertainty

Tab 1 – [ ] a,b,c,e
Tab 2 – [ ]
Tab 3 – [ ]

Appendix B is proprietary in its entirety.