WESTINGHOUSE PROPRIETARY CLASS 3

WCAP-16163-NP, REVISION 0 **JANUARY 2004**
(SUPPLEMENT 1-NP TO CENPD-397-NP, REV. 01)

IMPROVED FLOW MEASUREMENT ACCURACY USING CROSSFLOW ULTRASONIC FLOW MEASUREMENT TECHNOLOGY

Westinghouse

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EXECUTIVE SUMMARY

The purpose of this Supplement is to document a completed development activity by Westinghouse Electric Company LLC (Westinghouse) and the Advanced Measurement and Analysis Group, Inc. (AMAG) to further enhance the accuracy of the CROSSFLOW Ultrasonic Flow Measurement System. Specifically, an optional, slightly modified Mounting/Transducer Support Frame (M/TSF) has been developed so that the CROSSFLOW system has the capability to acquire multiple flow measurements from a single M/TSF location. This simple solution precludes the need to mount multiple standard CROSSFLOW meters in series on a feedwater pipe to obtain the same number of flow measurements. The accuracy improvement is achieved through the statistical combination of multiple flow measurements and not by a change in the previously approved CROSSFLOW system flow measurement accuracy of 0.5% or better.

Additionally, an appendix has been included in this supplement which provides more detailed background information regarding the conduct of in-situ calibration not explicitly discussed in prior documentation.

The CROSSFLOW ultrasonic flow measurement system technology and methodology was documented in CENPD-397-P-A, Rev. 01, "Improved Flow Measurement Accuracy Using CROSSFLOW Ultrasonic Flow Measurement Technology", (Reference 1) and was approved by the NRC on March 20, 2000 (Reference 2), for improved feedwater flow measurement accuracy for use in support of Appendix K power uprates.

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ACRONYMS

AMAG	Advanced Measurement and Analysis Group, Inc.
DPC	Data Processing Computer
L/D	Pipe Length/Pipe Diameter
M/TSF	Mounting/Transducer Support Frame
MUX	Multiplexer
NRC	Nuclear Regulatory Commission
SCU	Signal Conditioning Unit
SER	Safety Evaluation Report
SRSS	Square Root of the Sum of Squares
Westinghouse	Westinghouse Electric Company LLC

Improved Flow Measurement Accuracy
Using CROSSFLOW Ultrasonic Flow Measurement Technology

1.0 INTRODUCTION

This Supplement documents a completed development activity by Westinghouse Electric Company LLC (Westinghouse) and the Advanced Measurement and Analysis Group, Inc. (AMAG) to further enhance the accuracy of the CROSSFLOW Ultrasonic Flow Measurement System. Specifically, an optional, slightly modified Mounting/Transducer Support Frame (M/TSF) has been developed so that the CROSSFLOW system has the capability to acquire multiple flow measurements [ ]^{a,c} from the same M/TSF location. This simple solution precludes the need to mount multiple standard CROSSFLOW M/TSFs in series on a pipe in order to obtain the same number of flow measurements. This enhanced functionality is accomplished by using a M/TSF modified to accommodate multiple independent ultrasonic transducer sets instead of the single set on the standard M/TSF [ ]^{a,c} This modified M/TSF has been designated the 'X-Beam' design or configuration. The effective accuracy improvement is achieved through the statistical combination of multiple flow measurements and not by a change in the previously Nuclear Regulatory Commission (NRC) approved CROSSFLOW system flow measurement accuracy of 0.5% or better. Specifically, the overall accuracy of any parameter measurement can be improved by averaging a larger number of measurements of the parameter and then using the standard and widely accepted square root of the sum of squares (SRSS) statistical technique to combine the measurement uncertainties, taking into account dependent and independent uncertainties. There are no changes to the ultrasonic transducer design, other CROSSFLOW system hardware, software, the cross-correlation method of assessing time delay or the calculational procedures for determining the uncertainty of the individual flow measurement.

Additionally, in response to NRC inquiries regarding how in-situ calibration is accomplished, Appendix A, "CROSSFLOW Meter In-Situ Calibration", has been included in this supplement. Appendix A provides more detailed background information regarding the conduct of in-situ calibration not explicitly discussed in prior documentation.

The CROSSFLOW system technology and methodology is documented in CENPD-397-P-A, Rev. 01, "Improved Flow Measurement Accuracy Using CROSSFLOW Ultrasonic Flow Measurement Technology", (Reference 1) and was approved by the NRC on March 20, 2000 (Reference 2), for improved feedwater flow measurement accuracy for use in support of Appendix K power uprates. By employing CROSSFLOW ultrasonic flow measurement technology a utility can, subject to NRC approval, increase the thermal output of a nuclear power plant by taking credit for the reduction in the uncertainty of the secondary heat balance measurement.

2.0 CROSSFLOW SYSTEM

The standard CROSSFLOW Ultrasonic Flow Measurement System consists of a Data Processing Computer (DPC), a Signal Conditioning Unit (SCU), a Multiplexer (MUX) and a M/TSF holding one set of four ultrasonic transducers as described in Reference 1. In practice, the effective feedwater flow measurement accuracy, obtained from a single CROSSFLOW meter can be improved by simply taking multiple flow measurements by, for example, mounting multiple standard CROSSFLOW meters in series on the same feedwater pipe. However, installation of multiple M/TSFs generates unnecessary additional hardware cost, expenditure of additional installation time and requires that additional pipe insulation to be removed. The simpler more efficient solution is to incorporate additional ultrasonic transducers on a single M/TSF, thereby, allowing multiple flow measurements to be taken from a single M/TSF location.

This section describes the change to the standard CROSSFLOW system M/TSF made to effect multiple flow measurements from a single M/TSF location.

Unless described herein, other elements of the CROSSFLOW Ultrasonic Flow Measurement System (i.e., hardware, software, procedures, etc.) remain as described in Reference 1 and approved in Reference 2. That is, their functionality and compliance with those documents is unaffected.

2.1 Modified M/TSF Design

Reference 1, Section 3.1.1.2 describes the standard saddle-type M/TSF design. The X-Beam M/TSF design simply accommodates multiple ultrasonic transducer sets on a single M/TSF. X-Beam M/TSF material is the same as that used in the standard saddle-type M/TSF. Except for accommodating additional ultrasonic transducer sets, the X-Beam M/TSF is functionally consistent with References 1 and 2. [ ]^{a,c} A M/TSF schematic diagram is provided in Figure 2-1 that shows both the standard and X-Beam designs. Note that the principal difference is the inclusion of additional ultrasonic transducer mounting surfaces/blocks. This modification represents [ ]^{a,c}

The ultrasonic transducers used in conjunction with the X-Beam design are the same as those described in Reference 1 for the standard M/TSF design. The MUX auctioneers the ultrasonic signal from the SCU to each set of send/receive ultrasonic transducers in turn to provide the necessary data to establish the multiple flow measurements. Since the SCU only [ ]^{a,c}, there is no possibility of signal interference between the ultrasonic transducer sets. This electronic operation is the same as multiplexing the signal to multiple standard CROSSFLOW meters (such as multiple meters in series on one feedwater line or a single meter on each of the feedwater lines). Thus, the CROSSFLOW X-Beam ultrasonic transducer array is functionally consistent with References 1 and 2.

2.2 X-Beam Flow Area Measurement

Reference 1, Section 5.4 describes how the pipe cross-section flow area is calculated by measuring the [ ]^{a,c}

[$]^{a,c}$ Reference 1, Figure 5-1 provides a diagram showing how these measurements are taken.

For the X-Beam design, [

$]^{a,c}$ This approach conforms to the method of measurement discussed in Reference 1 and, therefore, also continues to meet the requirements of the NRC SER (Reference 2).

3.0 IMPLEMENTATION OF CROSSFLOW X-BEAM FLOW MEASUREMENTS

The improvements in accuracy using the CROSSFLOW X-Beam design are achieved by performing multiple flow measurements using a single M/TSF and applying the same cross-correlation methodology described in CENPD-397-P-A, Rev. 1.

The average feedwater flow is defined as:

$$\left(\qquad\qquad \right)^{a,c}$$

Eq. 1

Referring to Reference 1 and substituting Equation 5-1 into Equation 1 above, yields the following expression (note that the density is common to each measurement):

$$\left(\qquad\qquad\qquad\qquad \right)^{a,c}$$

Eq. 2

where:

C_{fi} = The velocity profile correction factor as defined in Reference 1, Section 2.3
ρ = The density of the feedwater
A_i = The cross-sectional flow area of the pipe
L_i = Spacing between the upstream and downstream transducer stations
t_{delayi} = Time that it takes for the eddies within the flow to pass between the transducer stations

Equation 2 is then modified to reflect the fact that some parameters have both common (i.e., dependent) and independent components that can affect the accuracy of the measured parameter. For example, [

$]^{a,c}$

[

]^{a,c}

[ ]$^{a, c}$ Eq. 3

In order to determine the effective uncertainty of the average feedwater flow, the natural log of both sides of Equation 3 are taken.

[ ]$^{a, c}$ Eq. 4

Differentiating both sides of this equation provides an expression that describes how the average feedwater flow changes, when any parameter is changed.

[ ]$^{a, c}$ Eq. 5

The 95% confidence interval for the average of the multiple flow measurements can now be calculated by taking the square root of the sum of the squares (SRSS) of the weighting coefficients and their respective confidence intervals.

[ ]$^{a, c}$ Eq. 6

Although not necessary, Equation 6 can be further simplified by assuming that [
]^{a,c} The equation can then be rewritten as:

[ ] a, c Eq. 7

where:

[ ] a. c

3.1 Sample Uncertainty Assessment

Using Equation 7, it is possible to estimate the effective overall uncertainty for the average of each flow measurement. When performing this analysis, it was assumed that the uncertainties for each of the measurements was equal to the uncertainties that are presented in Reference 1, Table 5-1, which has been reproduced here in Table 2-1 for convenience along with some corresponding plant specific data.

Substituting the values for the typical CROSSFLOW uncertainties into Equation 7 and assuming that the independent uncertainties are the same for each meter, provides the corresponding effective overall uncertainty for the average of the CROSSFLOW flow measurements.

[ ] a, c

A similar calculation can be performed using plant specific data, an example of which is provided in Table 2-1.

[ ]$^{a, c}$

Hence, it can be seen from these two calculations that by averaging the output of the meters together, the effective [ ]^{a,c}

4.0 IMPLEMENTATION

Reference 1, Section 5.6.1 outlines the requirements for determining the velocity profile correction factor (C_f). These same requirements apply to the X-Beam design. [ ]$^{a, c}$ This approach allows the X-Beam design to meet the installation requirements of Reference 1, as approved by the SER (Reference 2). See Appendix A for a discussion of in-situ calibration.

5.0 CONCLUSIONS

In conclusion, the above information describes the optional CROSSFLOW X-Beam M/TSF design and how it achieves a higher level of effective flow measurement accuracy simply by enhancing the previously approved CROSSFLOW meter standard M/TSF to include the capability for multiple flow measurements. Moreover, the enhancement of effective flow measurement accuracy is based on proven technologies and well established statistical methodologies that have been previously reviewed and approved by the NRC. That is, the accuracy improvement is achieved through the statistical combination of multiple flow measurements and not by a change in the previously NRC-approved CROSSFLOW system flow measurement accuracy of 0.5% or better.

Further, except for the change to the M/TSF, other elements of the CROSSFLOW Ultrasonic Flow Measurement System (i.e., hardware, software, procedures, etc.) remain as described in Reference 1 and approved in Reference 2. That is, their functionality and compliance with those documents is unaffected.

6.0 REFERENCES

1. CENPD-397-P-A, Revision 1, "Improved Flow Measurement Accuracy Using CROSSFLOW Ultrasonic Flow Measurement Technology", May 2000
2. Transmittal Letter to Ian Rickard (ABB-CE) from Stuart Richards (NRC), "Acceptance for Referencing of CENPD-397-P, Revision-01-P, 'Improved Flow Measurement Accuracy Using CROSSFLOW Ultrasonic Flow Measurement Technology' (TAC No. MA6452)", March 20, 2000

Table 2-1

Comparison of CROSSFLOW Uncertainty Elements

Uncertainty Component	Typical CROSSFLOW Uncertainties			Plant Specific Uncertainties		
	Single CROSSFLOW Meter	X-Beam Uncertainty Allocation		Single CROSSFLOW Meter	X-Beam Uncertainty Allocation	
	Reference 1 Table 5-1 Values	Common Portion	Independent Portion	Plant Specific Data	Common Portion	Independent Portion

a, c

Figure 2-1

Comparison of CROSSFLOW Standard M/TSF and X-Beam M/TSF

a, c

Appendix A

CROSSFLOW Meter In-Situ Calibration

Introduction

The Nuclear Regulatory Commission (NRC) Safety Evaluation Report (SER), Section 3.4, "CROSSFLOW UFM Field Implementation", acknowledges the use of in-situ calibration wherein it notes that:

> "...if the piping configuration is such that the velocity profile is not fully developed at the desired location for permanent installation of the UFM, a second UFM can be installed at a location where the velocity profile is fully developed and the second meter can be used to calibrate the permanent meter on-line at the desired location."

In response to NRC inquires regarding how in-situ calibration is accomplished, Appendix A has been included to provide more detailed background information regarding the conduct of in-situ calibration not explicitly provided in CENPD-397-P-A, Rev. 01[1].

In-situ calibration effectively utilizes one CROSSFLOW ultrasonic flow meter to calibrate a second CROSSFLOW meter which is to be located in the piping system where the flow is not fully developed. An in-situ calibration is accomplished in one of two ways:

1. [

   ]^{a,c}

2. [

   ]^{a,c}

Figure A-1 provides a schematic diagram depicting these two in-situ calibration options. In general, in-situ calibration is used instead of developing a scale model of the piping configuration and then using a laboratory calibration approach as discussed in CENPD-397-P-A, Rev. 01, Section 5.6.1.

Discussion

The advantage of an in-situ calibration is that the meter can be calibrated under actual operating conditions (i.e., flow, temperature and pressure), which eliminates the need to model the piping configuration and calibrate the meter in a hydraulics laboratory. Furthermore, the in-situ calibration also removes uncertainty that would result from

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[1] CENPD-397-P-A, Rev. 01, "Improved Flow Measurement Accuracy Using Crossflow Ultrasonic Flow Measurement Technology", May 2000

having to extrapolate the laboratory calibration for undeveloped flow to a higher Reynolds number. When performing an in-situ calibration, installation of both the meter that is to be calibrated and the calibrating meter are conducted in accordance with the CROSSFLOW Topical Report, CENPD-397-P-A, Rev. 01.

<u>Option 1: [</u>]^{a,c}

For the [ ]^{a,c}, the calibration coefficient is defined by Equation A-1, starting with the flow equation for the CROSSFLOW meter as defined in CENPD-397-P-A,, Section 5.0, Equation 5-1.

$$\left(\qquad\qquad \right)^{a,c} \qquad \text{Eq. A-1}$$

where: [

]^{a,c}

Several simplifying assumptions can be made. For calibrations where there are no changes in feedwater temperature between the [

]^{a,c} The resulting calibration coefficient is shown in Equation A-2.

$$\left(\qquad \right)^{a,c} \qquad \text{Eq. A-2}$$

Substituting the calibration coefficient into the flow equation [

]^{a,c}

$$\left(\qquad\qquad\qquad\qquad \right)^{a,c} \qquad \text{Eq. A-3}$$

From Equation A-3, it can be seen that the flow equation now includes [

]^{a,c}

The uncertainty of the flow equation (i.e., Eq. A-3) can now be derived using the procedures as outlined in CENPD-397-P-A, Section 5.0.

[ ]a, c Eq. A-4

where: [ ]a, c

Option 2: [ ]a, c

When the calibration is performed using [ ]a, c The calibration coefficient is then calculated using Equation A-2. However, when the calibration coefficient is factored into the flow equation, [ ]a,c

[ ]a, c. This is shown in Equation A-5, [ ]a, c

[ ]a, c Eq. A-5

The corresponding uncertainty for an in-situ calibration, where the calibration is performed [ ]^{a,c} is defined by Equation A-6.

$$\left\{ \qquad \right\} \quad \text{Eq. A-6}$$

From Equation A-6, it can be seen that [

]^{a,c}

Conclusion

In conclusion, this Appendix presents the methodology for performing an in-situ calibration of a CROSSFLOW meter. Because this calibration can be performed at full power, under actual plant operating conditions, it represents the most desirable method of calibration. Furthermore, as documented in this Appendix, the equations and methods of implementation are all consistent with the procedures set forth in CENPD-397-P-A, Rev. 01 and the acknowledgement of the use of in-situ calibration already contained in the NRC SER.

Figure A-1

Option 1: [ ]$^{a, c}$

a, c

Option 2: [ ]$^{a, c}$

a, c