ASEA BROWN BOVERI

CENPD-397-NP, REVISION 01

ABB COMBUSTION ENGINEERING NUCLEAR POWER

IMPROVED FLOW MEASUREMENT ACCURACY USING CROSSFLOW ULTRASONIC FLOW MEASUREMENT TECHNOLOGY

JANUARY 2000

Prepared by
ABB Combustion Engineering Nuclear Power, Inc.
2000 Day Hill Road
P.O. Box 500
Windsor, CT 06095-0500

Legal Notice

THIS REPORT WAS PREPARED AS AN ACCOUNT OF WORK PERFORMED BY ABB COMBUSTION ENGINEERING NUCLEAR POWER, INC. NEITHER ABB COMBUSTION ENGINEERING NUCLEAR POWER NOR ANY PERSON ACTING ON ITS BEHALF:

- MAKES ANY WARRANTY OR REPRESENTATION, EXPRESS OR IMPLIED INCLUDING THE WARRANTIES OF FITNESS FOR A PARTICULAR PURPOSE OR MERCHANTABILITY, WITH RESPECT TO THE ACCURACY, COMPLETENESS, OR USEFULNESS OF THE INFORMATION CONTAINED IN THIS REPORT, OR THAT THE USE OF ANY INFORMATION, APPARATUS, METHOD OR PROCESS DISCLOSED IN THIS REPORT MAY NOT INFRINGE PRIVATELY OWNED RIGHTS; OR
- ASSUMES ANY LIABILITIES WITH RESPECT TO THE USE OF, OR FOR DAMAGES RESULTING FROM THE USE OF, ANY INFORMATION, APPARATUS, METHOD OR PROCESS DISCLOSED IN THIS REPORT.

CENPD-397-NP, REV. 01

ABB COMBUSTION ENGINEERING NUCLEAR POWER

IMPROVED FLOW MEASUREMENT ACCURACY USING CROSSFLOW ULTRASONIC FLOW MEASUREMENT TECHNOLOGY

JANUARY 2000

Prepared by

ABB Combustion Engineering Nuclear Power, Inc.
2000 Day Hill Road
P.O. Box 500
Windsor, CT 06095-0500

ABSTRACT

The CROSSFLOW Ultrasonic Flow Measurement (UFM) System, developed by the Advance Measurement and Analysis Group (AMAG) of Mississauga, Ontario, is being marketed to nuclear power plants worldwide in conjunction with ABB Combustion Engineering Nuclear Power (ABB CENP) of Windsor, CT. The CROSSFLOW UFM System provides a means for plant operators to recover power, currently lost to electric output, by increasing feedwater flow measurement accuracy. CROSSFLOW consists of four (4) ultrasonic transducers mounted on a metal support frame that attaches, externally, to the feedwater piping (or any pipe in which the flow rate is to be measured). The ultrasonic transducers are connected to a Signal Conditioning Unit (SCU) and a Data Processing Computer (DPC). A Multiplexer (MUX) is also available for automatically sequencing measurements on multiple channels. There is one (1) upstream and one (1) downstream transducer station, each station consisting of one (1) transmitting and one (1) receiving transducer which send out the turbulence signatures to the DPC through the demodulating and filtering stages of the SCU. Signatures from the upstream and downstream transducer stations are compared, using the cross-correlation mathematical technique imbedded in proprietary CROSSFLOW software, to obtain a highly accurate feedwater flow rate measurement. A unique advantage of the CROSSFLOW UFM System is that it does not require any intrusion into plant piping and, consequently, cannot compromise pressure boundary integrity. Additionally, maintenance and/or system trouble shooting, if necessary, are also simplified by not requiring any repeated pipe boundary intrusion protocols. The entire CROSSFLOW system is external to the pipe in which flow is to be measured; penetrating pressure boundary piping is unnecessary.

CENPD-397-P provides information on the CROSSFLOW UFM System design, its underlying principles of ultrasonic measurement, experimental data validating system accuracy and an overview of installation, proprietary software and setup procedures. The combined effect of these elements is to provide an improvement in flow measurement accuracy over current flow measurement systems. This increased flow measurement accuracy can be translated into a like improvement in the accuracy of the core power level calculation, due to the use of a more accurate feedwater flow in the calorimetric (PWR terminology)/heat balance (BWR terminology) calculation. The measurement uncertainty reduction allows a Utility to:

1) Operate the plant at a higher power level without exceeding the 10 CFR 50, Appendix K mandated 102% power margin (attributed to instrument uncertainty).
2) To apply the reduced uncertainty to overall margin improvement.
3) Recovery of lost generating capacity due to feedwater venturi fouling while staying within the plant's licensed operating power level.
4) Possess an in-plant capability for periodically recalibrate the feedwater venturi flow coefficient to adjust for the adverse effect of fouling.

CENPD-397-P does not, however, address the pertinent information for justifying either a higher power level or margin improvement (Items 1 and 2 above). This justification must be provided on a plant specific basis depending upon the application to which individual licensees decide to apply CROSSFLOW's improved flow measurement accuracy. CROSSFLOW can be used in various applications as determined by the Utility. Of the various applications to which CROSSFLOW can be applied, only the justification of operation at a power level that would exceed the Utility's current licensed power level requires prior interaction with the Nuclear Regulatory Commission (NRC).

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

SECTION TITLE PAGE

TABLE OF CONTENTS

SECTION **TITLE** **PAGE**

TABLE OF CONTENTS

SECTION TITLE PAGE

LIST OF TABLES

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES

LIST OF ACRONYMS

AMAG	Advance Measurement and Analysis Group
ABB CENP	ABB Combustion Engineering Nuclear Power
ANSI	American National Standards Institute
ARL	Alden Research Laboratory
ASME	American Society of Mechanical Engineers
BNC	Bayonet N-Type Compact
BWR	Boiling Water Reactor
CFR	Code of Federal Regulations
CNC	Computerized Numerical Control
COAX	Coaxial Cabling
DPC	Data Processing Computer
ECCS	Emergency Core Cooling System
EIA	Environmental Information Association
FSAR	Final Safety Analysis Report
LMIE	Liquid Metal Induced Embrittlement
LSSS	Limiting Safety System Setting
M/TSF	Mounting/Transducer Support Frame
MUX	Multiplexer
NIST	National Institute of Standards and Technology
NRC	Nuclear Regulatory Commission
NSSS	Nuclear Steam Supply System
OH	Ontario Hydro
OL	Operating License
PWR	Pressurized Water Reactor
RCS	Reactor Coolant System
Re	Reynolds Number
RG	Regulatory Guide
RSSI	Received Signal Strength Indicator
SCU	Signal Conditioning Unit
SMIE	Solid Metal Induced Embrittlement
SRSS	Square Root Sum of the Square Method
UFSAR	Updated Final Safety Analysis Report
VPCF	Velocity Profile Correction Factor

IMPROVED FLOW MEASUREMENT ACCURACY USING CROSSFLOW ULTRASONIC FLOW MEASUREMENT TECHNOLOGY

1.0 INTRODUCTION

The CROSSFLOW Ultrasonic Flow Measurement (UFM) System is a joint venture of the Advanced Measurement and Analysis Group (AMAG) of Mississauga, Ontario and ABB Combustion Engineering Nuclear Power (ABB CENP) of Windsor, CT. Currently, the CROSSFLOW UFM System provides a means for nuclear power plant operators to recover lost electrical generation capacity resulting from venturi fouling. This lost power recovery is accomplished within a plant's current licensed power level and has become feasible because of CROSSFLOW's ability to perform a feedwater flow venturi recalibration to remove the adverse effects of fouling.

CROSSFLOW has been in operation in Canada since 1987 and at this writing has been used in tests or installed for continuous monitoring at over 40 commercial nuclear power reactors in the United States, Canada, South America and Europe over the last ten (10) years. Some utilities have reported a recovery of electrical generating capacity of ~20 MWe or more that would have otherwise been lost due to venturi fouling. Consequently, CROSSFLOW offers utilities a significant operational cost benefit.

Comparisons have been made with plant flow instrumentation, which demonstrate stable CROSSFLOW system performance and accuracy. Further confidence in CROSSFLOW's accuracy has been gained through comparisons with recently calibrated plant instrumentation and chemical tracers. In each case, these independent measurements have actually demonstrated a repeatable accuracy of [ ].

1.1 GENERAL DESCRIPTION

CROSSFLOW consists of four (4) ultrasonic transducers mounted on a metal support frame that attaches, externally, to the feedwater piping (or any pipe in which the flow rate is to be measured). The ultrasonic transducers are connected to a Signal Conditioning Unit (SCU) and a Data Processing Computer (DPC). A Multiplexer (MUX) is also available for automatically sequencing measurements on multiple channels. There is one (1) upstream and one (1) downstream transducer station, each station consisting of one (1) transmitting and one (1) receiving transducer which send out the turbulence signatures to the DPC through the demodulating and filtering stages of the SCU. Signatures from the upstream and downstream transducer stations are compared, using the cross-correlation mathematical technique imbedded in proprietary CROSSFLOW software, to obtain a highly accurate feedwater flow rate measurement. A unique advantage of the CROSSFLOW UFM System is that it does not require any intrusion into plant piping and, consequently, cannot compromise pressure boundary integrity. Additionally, maintenance and/or system trouble shooting, if necessary, are also simplified by not requiring any repeated pipe boundary intrusion protocols. The entire CROSSFLOW system is external to the pipe in which flow is to be measured; penetrating pressure boundary piping is unnecessary.

CENPD-397-P provides information on the CROSSFLOW UFM System design, its underlying principles of ultrasonic measurement, experimental data validating system accuracy and an overview of installation, proprietary software and setup procedures. All modes of CROSSFLOW application take advantage of the increased flow measurement accuracy achieved. The combined effect of these elements is to provide an improvement in flow measurement accuracy over current flow measurement systems (e.g., a venturi). This increased flow measurement accuracy can be translated into a like improvement in the accuracy of the core thermal power level calculation, due to the use of a more accurate feedwater flow in the calorimetric (PWR terminology)/heat balance (BWR terminology) calculation. The measurement uncertainty reduction allows a Utility to:

1) Use of the increased accuracy to support a license amendment justifying operation at a higher power level ([ ]) by requesting a like reduction in the 10 CFR 50, Appendix K mandated 2% instrument uncertainty margin applied to power level.
2) Apply the reduced uncertainty to overall margin improvement.
3) Recover lost generating capacity due to feedwater venturi fouling while staying within the plant's licensed operating power level.
4) Possess an in-plant capability for periodically re-calibrating the feedwater venturi to adjust for the effect of fouling; thereby, allowing recovery of lost generating capacity while staying within a facility's licensed power level.

To take advantage of operation at a higher power level, based on relief from certain aspects of 10 CFR 50, Appendix K[1], Nuclear Regulatory Commission (NRC) interaction in the form of review and approval of a license amendment would be necessary. It is to this application (Item 1 above) that CENPD-397-P is focused. In this regard, CENPD-397-P does not provide the pertinent plant specific information justifying operation at a higher power level. Rather, that justification must be provided by the Utility, on a plant specific basis, depending upon the application to which the Utility decides to utilize the CROSSFLOW UFM System. Instead, CENPD-397-P only addresses, and seeks NRC acceptance of, the increased flow measurement accuracy achieved using the CROSSFLOW UFM System and which are generically applicable to any Utility.

1.2 COMPARISON OF CROSS-CORRELATION AND TRANSIT TIME TECHNOLOGIES

Referring to Figure 1-1, the basic difference between the cross-correlation and transit time technologies, is the way that each of these meters measures the velocity of the fluid within the pipe. The transit time technology injects an ultrasonic signal diagonally through the fluid and then measures the difference in the time that it takes the signal to travel upstream versus downstream. It can then be shown that the difference in these times is proportional to the velocity of the fluid in the pipe.

---

[1] An exemption to 10 CFR 50, Appendix K will only be necessary until the NRC completes the rulemaking process which is geared toward recognizing the substantial improvement in instrumentation measurement technology and, therefore, the consequential justification for decreasing the currently mandated 2% instrument uncertainty factor applied to power level.

The fluid flowing within the pipe causes the difference in the upstream and downstream times. When injecting a signal downstream and diagonally across the pipe, the velocity vector of the fluid in the plane of the ultrasonic signal adds to the acoustical velocity of the fluid. Consequently, the velocity of the ultrasonic signal going downstream is slightly faster than the acoustical velocity of the fluid. When the process is reversed and the ultrasonic signal is injected upstream and diagonally across the pipe, the velocity vector of the fluid in the plane of the ultrasonic signal now subtracts from the acoustical velocity. This results in an ultrasonic velocity that is slightly less than the acoustical velocity of the fluid. The difference in these times is on the order of a few microseconds.

The two equations that describe the time for the ultrasonic signal to travel upstream and downstream can be written as:

$$t_u = L_t/[a - V\cos(\alpha)] \qquad \text{Eq. 1-1}$$

$$t_d = L_t/[a + V\cos(\alpha)] \qquad \text{Eq. 1-2}$$

where: t_u is the time that it takes for the ultrasonic signal to travel upstream through the fluid. If the transducers are mounted on the outside of the pipe, the measured time delays must be corrected for the time that it takes the ultrasonic signal to travel through the walls of the pipe.
t_d is the time that it takes for the ultrasonic signal to travel downstream. This signal must also be corrected for transport time through the pipe walls, if the transducers are mounted on the outside of the pipe.
L_t is the diagonal distance that the ultrasonic signal must travel through the fluid when using the transit time technology.
A is the acoustical velocity of the ultrasonic signal in the fluid
V is the velocity of the fluid in the pipe
α is the angle that the diagonal signal makes with the axis of the pipe

Equations 1-1 and 1-2 can be combined to obtain an expression for the velocity of the fluid in the pipe as a function of these parameters:

$$V = a^2(t_u - t_d)/2L\cos(\alpha) \qquad \text{Eq. 1-3}$$

The cross-correlation meter measures the velocity of the fluid by determining the time that it takes for a unique pattern of eddies to pass between two sets of transducers. When using this meter to measure the velocity, an ultrasonic beam is injected perpendicular to the axis of the pipe rather than diagonally as is required for the transit time meter. As the ultrasonic signal passes through the fluid, the eddies within the fluid modulate the ultrasonic signal, creating a phase shift, which is unique to the eddies passing through the ultrasonic beam at that moment in time. These same eddies then pass through a second ultrasonic beam that is located a known distance downstream of the first beam. Once again these eddies modulate the second ultrasonic beam in the same manner as they did the first beam. The only difference between the two modulated signals is the difference in the time that it took for the eddies to pass between the two ultrasonic beams.

Both modulated beams are demodulated, by removing the high frequency carrier signal, leaving two wave forms that are unique signatures of the eddies passing through the beams. The cross-correlation process mathematically calculates the difference in the time that it took for the eddies to pass between the two beams by mathematically shifting the downstream signature backwards in time to a point where there is maximum correlation between the two demodulated signals. Knowing this time, which is referred to as the delay time and the physical distance between the two ultrasonic beams, allows one to calculate the velocity of the fluid by dividing the distance by the delay time. The magnitude of the delay time is on the order of 50 milliseconds. The equation for the fluid velocity, when using the cross-correlation technology becomes:

$$V = L_{c-c}/\tau \qquad \text{Eq. 1-4}$$

where: V is the velocity of the fluid
L_{c-c} is the physical distance between the two ultrasonic beams
τ is the time that it takes for the eddies to pass between the two ultrasonic beams

1.3 REASON FOR SELECTING THE CROSS-CORRELATION TECHNOLOGY

The cross-correlation technology offers several distinct advantages over conventional venturis for feedwater flow measurements that are to be used for secondary heat balance calculations. Since the system mounts on the outside of the feedwater pipe, it is not subject to the build-up of corrosion products as is common with venturis. Because the venturi throat sensing port is exposed to the flow, corrosion products can form upstream of the port altering the boundary layer, which in turn reduces the differential pressure being monitored by the differential pressure transmitter.

The differential pressure can also be affected when the sensing tube that goes from the throat of the venturi to the outside of the feedwater pipe has also been known to crack. When this occurs, the fluid from the stagnate pressure region between the venturi and the surface of the pipe flows into the sensing tube, lowering the differential pressure.

The upstream sensing port can also be affected by erosion of the carbon steel piping around the sensing port boss. When this occurs, the port sees a lower dynamic rather than a static pressure. When this occurs, the differential pressure is reduced, giving a non-conservative lower flow readings.

Each of these mechanical problems is avoided with the cross-correlation meter, since it does not rely on a differential pressure to measure flow. Moreover, the cross-correlation meter would actually act to correct these problems, thus preventing either an underpower or overpower conditions because of one of these failures.

In addition to avoiding the mechanical problems noted above, the cross-correlation meter is much less sensitive to electronic drift. A conventional venturi uses both a differential transmitter and analogue to digital converters that introduce error in to the flow measurement. Moreover, unlike venturis, electronic checks can me activated on-line to confirm that both the electronics and transducers are operating as designed.

1.4 CROSSFLOW INSTALLATION AND OPERATING FEATURES

The CROSSFLOW UFM System offers features that are beneficial during both system installation and operation. Although CROSSFLOW does not replace the plant venturis, it offers significant advantages over the venturis in its ability to precisely measure feedwater flow. The uncertainties associated with venturi accuracy such as fouling, instrumentation drift and calibration are essentially eliminated for the CROSSFLOW UFM System. Therefore, the uncertainty of the flow measurement can be reduced from well over 1%, in many cases, to [ ] or less, depending on the specific plant installation.

Some of CROSSFLOW's more significant features are summarized below.

1.4.1 EXTERNALLY MOUNTED

The CROSSFLOW UFM System externally attached Mounting/Transducer Support Frame (M/TSF) offers significant flexibility in both the timing and ease of installation. Since the M/TSF is mounted externally on the surface of the pipe, it is not necessary to cut into the pressure boundary to install a spool piece. This one feature precludes the necessity of scheduling the installation during a plant outage. Rather, installation and commissioning can be performed while the plant is on-line (only installations in a high radiation area would preclude an on-line installation). This has the additional advantage of allowing work to be done when plant staff is less likely to be distracted by other pressing needs due to typically tight outage schedules.

1.4.2 INSTALLATION LOCATION FLEXIBILITY

Another unique feature of the CROSSFLOW UFM System that has become apparent is the ability to calibrate the meter where the velocity profile may not be fully developed. For example, it is possible to encounter a piping configuration where the upstream flow conditions prevent the flow from being fully developed at the desired installation location. However, flow conditions may be fully developed at a location further upstream or downstream of the desired installation point. Because of the ease with which the CROSSFLOW meter can be installed, it is possible to install a second meter at one of these locations and calibrate the permanent meter on-line; at the desired installation location. This has a distinct advantage, in that the meter is calibrated at full power under actual operating conditions, thus eliminating the need to perform model tests.

1.4.3 VELOCITY PROFILE CORRECTION FACTOR ALGORITHM

Perhaps the most important feature of the CROSSFLOW UFM System is the algorithm used to calculate the Velocity Profile Correction Factor (VPCF). The theoretical bases for this equation which, for fully developed flow, is only a function of Reynolds Number is discussed in Section 2.0 of this report. Section 4.0 discusses how the algorithm was verified at a national hydraulics laboratory. It is shown through multiple weigh tank and limited in-plant tests, where the accuracy of the in-plant instrumentation had recently been verified, that this simple algorithm accurately predicts the changes in the VPCF for Reynolds Numbers ranging from below $<1\times10^6$ to $\sim25\times10^6$. Furthermore, it is shown that the equations that form the bases for this algorithm can be traced to classical hydraulics that have withstood the test of time through many years of laboratory and field verifications.

1.4.4 STATISTICALLY ROBUST FLOW MEASUREMENTS

Another feature of the CROSSFLOW UFM System that contributes to its accuracy and repeatability is the statistically robust nature in which it achieves the flow measurements. Unlike other algorithms that rely on a time-of-flight principle of one or more ultrasonic beams, the CROSSFLOW meter tracks thousands of eddies within the fluid, with each eddy imparting it own distinct time to the determination of the velocity of the fluid. With this large amount of data and the ability to conduct these measurements in millisecond rather than nanoseconds, the reliability and repeatability of the meter is greatly improved.

1.4.5 TRANSDUCER ORIENTATION

Repeatability is also enhanced by the simple perpendicular orientation of the ultrasonic transducers to the flow stream. Because of the perpendicular orientation, errors due path length and path angle, which must be dealt with when using the transit time technology, are eliminated along with their associated uncertainties when using cross-correlation technology

1.5 CROSSFLOW UFM SYSTEM ACCURACY

Based on the above features (and others discussed later), the CROSSFLOW UFM System is able to achieve an accuracy of [ ] or better with a 95% confidence interval. When credit is taken for this feedwater flow measurement accuracy in a plant's thermal power calculation, it can easily be shown that the uncertainty of the calculation falls well below [ ] with a 95% confidence interval. Thus, a utility is presented with the opportunity to take advantage of a power uprate to increase the electrical output of their plant, yet still remain bounded by the existing Appendix K ECCS analyses.

1.6 REASON FOR TOPICAL REPORT

The purpose of CENPD-397-P is to provide a source for a CROSSFLOW UFM System description and justification of improved measurement accuracy, suitable for reference (i.e., the generic elements) by Utilities employing the CROSSFLOW UFM System to pursue operation at a higher power level; based on the improved flow measurement accuracy achieved. In so doing, the resources of the Utility, AMAG, ABB CENP and the NRC are conserved by providing a one time review and approval for the generically applicable elements of the CROSSFLOW UFM System. Each Utility should, therefore, only have to provide the plant specific implementation information and safety analysis considerations on their docket via a 10 CFR 50.90 license amendment; along with an exemption request to 10 CFR 50, Appendix K and a reference to the NRC approved version (i.e., "-A") of CENPD-397-P.

1.6.1 TOPICAL REPORT ORGANIZATION

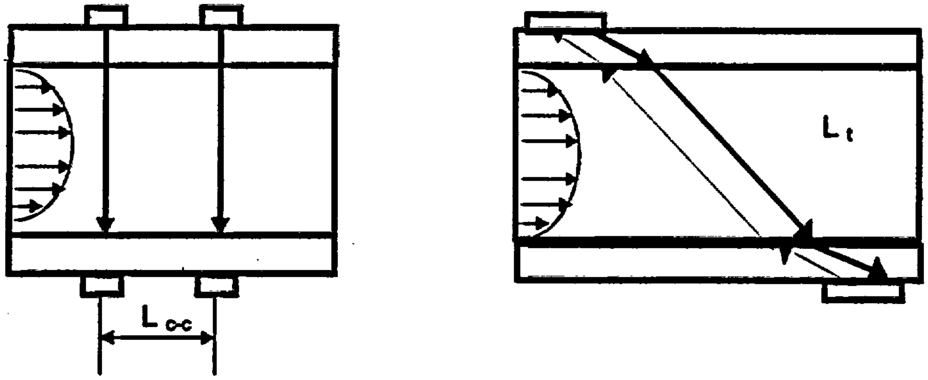
The information contained in CENPD-397-P is presented in a manner that takes the reader through the following report sections:

1. Introduction
2. Theory of CROSSFLOW Ultrasonic Flow Measurement
3. CROSSFLOW System Description
    - Hardware
    - Software
4. CROSSFLOW Calibration and Validation
5. Determination of Feedwater Flow and Flow Uncertainty
6. CROSSFLOW Materials Considerations
7. CROSSFLOW Reliability
8. CROSSFLOW Field Implementation

References are provided at the end of each section, as appropriate.

FIGURE 1-1

COMPARISON OF CROSS-CORRELATION AND TRANSIT TIME TECHNOLOGIES



Cross-Correlation Meter

Transit Time Meter

2.0 THEORY OF CROSSFLOW ULTRASONIC FLOW MEASUREMENT

Starting from first principles, this section develops the equations that are used by the CROSSFLOW meter to measure flow in a pipe.

2.1 THE FLOW EQUATION

Flow in a pipe is defined by the equation:

$$W = \rho A V_a \qquad \text{Eq. 2-1}$$

where: W is the mass flowrate
ρ is the density of the fluid
A is the cross-sectional flow area
V_a is the average velocity of the fluid in the pipe

A cross-correlation meter measures the time that it takes for eddies within the fluid to pass between two ultrasonic beams that are perpendicular to the axis of the pipe (and, therefore, the flowstream). Knowing the physical distance between these two beams, the velocity of eddies can be calculated and hence, the velocity of the fluid that contains them.

$$V_m = L/\tau \qquad \text{Eq. 2-2}$$

where: V_m is the velocity of the eddies in the fluid that are tracked by the cross-correlation meter
L is physical distance between the two ultrasonic beams
τ is the time that it takes for the eddies to pass between the two beams

This velocity, V_m, is not the average velocity, V_a, of the fluid. Hence, the measured velocity V_m must be multiplied by a velocity profile correction factor, C_0, to obtain the average velocity of the fluid in the pipe.

$$V_a = C_0 V_m = C_0 (L/\tau) \qquad \text{Eq. 2-3}$$

Substituting Equation 2-3 into Equation 2-1 gives the flow equation for the cross-correlation meter.

$$W = C_0 \rho A L / \tau \qquad \text{Eq. 2-4}$$

2.2 CROSS-CORRELATION TECHNIQUE

A cross-correlation meter measures τ, the time that it takes for eddies to pass between two ultrasonic beams that are directed through the flowing fluid perpendicular to the axis of the pipe.

2.2.1 EFFECT OF TURBULENCE ON AN ULTRASONIC SIGNAL

[

]

2.2.2 MATHEMATICAL FORMULATION OF CROSS-CORRELATION

Cross-correlation is a mathematical process for determining the displacement in time between similar curves. In the case of CROSSFLOW, this is the time for the eddies to pass between the two sets of transducers.

In general, the cross-correlation of two functions is defined according to the following equation:

$$R_{AB}(y) = \int_{-\infty}^{\infty} A(x)B(x+y)dx \qquad \text{Eq. 2-5}$$

If the two functions represent time-dependent properties A(t) and B(t+τ) at time t and t+τ, respectively, then the cross-correlation function will also be time-dependent and can be written as:

$$R_{AB}(\tau) = \frac{1}{T}\int_{0}^{T} A(t)B(t+\tau)dt \qquad \text{Eq. 2-6}$$

[

]

Equation 2-6 is the cross-correlation function, which measures the degree of correlation between the two functions, A(t) and B(t) provided that each of the signals are random with a mean value equal to zero. Hence, if A(t) and B(t) are not correlated, the product of any two points on the curves A(t) and B(t) at some time t have an equal probability of being either positive or negative. Thus, the average of all these products, $R_{AB}(\tau)$, over the time interval T would be approximately equal to zero indicating no correlation.

However, if signals A(t) and B(t) are correlated, when A(t) is positive, B(t) is also positive and the product of A(t) B(t) is positive. Furthermore, if A(t) is negative, B(t) would also be negative and the product A(t) B(t) would again be positive. Thus, the function, $R_{AB}(\tau)$, over the time interval T would be positive indicating a correlation exists between the two signals.

Now, if signals A(t) and B(t) are correlated but displaced in time by τ, the function, $R_{AB}(\tau)$, will reach a maximum value when B(t) is shifted by the time that it takes for the eddies to traverse the distance, L between the two ultrasonic beams. Knowing this time, τ, which produces a maximum value for the function $R_{AB}(\tau)$ and the distance between the beams, one can then calculate the velocity of the eddies and, hence, the velocity of the fluid, V_m at the location in the velocity profile, where a correlation exists between the signals.

$$V_m = L/\tau \qquad \text{Eq. 2-7}$$

2.2.3 NUMERICAL TECHNIQUE

[

Eq. 2-8

Eq. 2-9

]

[

]

2.2.4 FLOW TRAVEL TIME DETERMINATION

[

Eq. 2-10

]

2.3 VELOCITY PROFILE CORRECTION FACTOR FOR A SMOOTH PIPE

The velocity profile correction factor (VPCF), C_0, is defined as the ratio of the average velocity of the fluid in the pipe, V_a, divided by the velocity of the fluid measured by the cross-correlation meter, V_m.

$$C_0 = V_a / V_m \quad \text{Eq. 2-11}$$

[

Eq. 2-12

Eq. 2-13

]

[

Eq. 2-14

Eq. 2-15

Eq. 2-16

] Eq. 2-17

This equation is plotted in Figure 2-2 as a function of Reynolds Number using Equations 2-14 and 2-13. Experimental data, which was obtained from laboratory tests and plants where the venturi readings were known to be correct have also been entered on the same plot. In order to plot the experimental data points on Figure 2-2, the VPCF, C_o, was calculated for each data point using the following equation:

$$C_o = \frac{Q_{measured}}{Q_{CROSSFLOW}} \quad \text{Eq. 2-18}$$

where: $Q_{measured}$ is the volumetric flow measured by the weigh tank or plant venturi
$Q_{CROSSFLOW}$ is the corresponding volumetric flow measured by the meter without the velocity profile correction factor. $Q_{CROSSFLOW}$ is defined as:

$$Q_{CROSSFLOW} = A\,L / \tau \quad \text{Eq. 2-19}$$

where: A is the flow area
L is the spacing between the ultrasonic beam
τ is the time that it takes for the eddies to pass between the ultrasonic beams

The close agreement between Equation 2-17 and the experimental data over a wide range of Reynolds Numbers provides confidence that the bases for the theoretical equation is well founded.

2.4 REFERENCES

2-1 H. Schlichting, "Boundary-Layer Theory", McGraw-Hill Book Company, 6th Edition

2-2 Proceedings of The 9th International Conference on Flow Measurement, FLOMECO'98. Edited by Jerker Delsing, June 15-17, 1998, Lund, Sweden

FIGURE 2-1

SCHEMATIC OF CROSSFLOW MEASUREMENT ARRANGEMENT

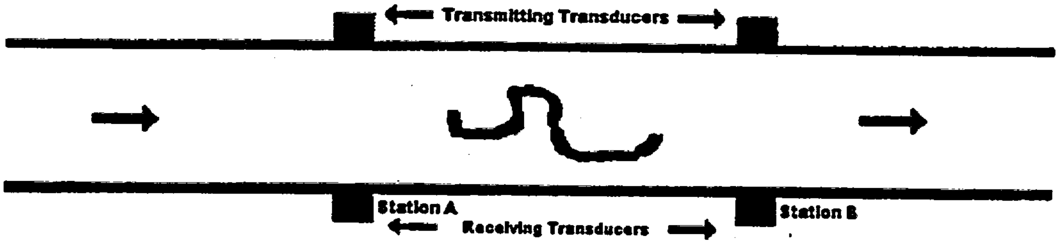


FIGURE 2-2

VALIDATION OF THE THEORETICAL FUNCTION

3.0 CROSSFLOW SYSTEM DESCRIPTION

CROSSFLOW consists of the following principal components:

1. Mounting/Transducer Support Frame (M/TSF); which is externally attached to the pipe in which the flow is to be measured
2. Four (4) Ultrasonic Transducers; two transmitters & two receivers
3. Signal Conditioning Unit (SCU)
4. Multiplexer (MUX) (optional)
5. Coaxial Cabling (COAX)
6. Data Processing Computer (DPC)
7. CROSSFLOW Software

There two (2) ultrasonic transducer (UT) stations; one (1) upstream and one (1) downstream that are generally denoted as A and B in CENPD-397-P, respectively. Each station consists of a transmitting and receiving transducer pair, mounted on a support frame, which send and receive the acoustic signals, across the pipe diameter. The SCU generates the high frequency voltage that is fed to the transmitting transducers and receives the carrier wave signal that is generated by the receiving transducers. It then extracts the turbulence modulations from the carrier wave and passes them to the DPC and its resident CROSSFLOW software. The software determines the pipe flow rate using built-in signal processing algorithms. The following sections discuss each of these CROSSFLOW components. In the CROSSFLOW software description, the online and off-line diagnostics and system functional verification are addressed.

3.1 CROSSFLOW HARDWARE

Figure 3-1 is a schematic of the current CROSSFLOW system hardware components. The following subsections describe these hardware components.

3.1.1 MOUNTING/TRANSDUCER SUPPORT FRAME

There are two (2) Mounting/Transducer Support Frame (M/TSF) designs. The old frame design is a box-type structure made of aluminum bar stock (see Figure 3-2). This early frame design is no longer offered. The current frame design, and the one used at almost all plants today, is a saddle-type structure made of carbon steel bar stock (see Figure 3-3). This frame design is now standard for all CROSSFLOW systems. Each of these M/TSF designs accommodates four (4) transducers; one (1) transmitting and one (1) receiving at each of two (2) transducer mounting stations as described above.

3.1.1.1 Box-Type Support Frame Design

The box-type M/TSF design, shown in Figure 3-2, is field assembled for the pipe on which it is to be mounted. The frame sub-components (i.e., the aluminum bar stock) are bolted together in order to make up the completed frame assembly. The four (4) [ ] bodied transducers screw directly into their respective locations on the M/TSF. The transducers interface with the pipe surface via an elastomeric couplant. The M/TSF was made from anodized aluminum and its four connecting bars maintain the spacing between the transducers. [

]

3.1.1.2 Saddle-Type Support Frame Design

The saddle-type M/TSF design, shown in Figure 3-3, is shop fabricated for the pipe on which it is to be mounted. The frame sub-components (i.e., the carbon steel bar stock) are welded together in order to make up each half of the complete frame assembly. These are then precision machined to the finished dimensions. The two halves of the frame assembly are bolted together to complete the mounting assembly. Four (4) [ ] bodied transducers bolt into a mounting fixture that is an integral part of the frame assembly. The transducers interface with the pipe through a [ ] over the ultrasonic crystal.

3.1.2 ULTRASONIC TRANSDUCER

Like the M/TSF, the ultrasonic transducers have evolved from their early design to the current design. As with the M/TSF, the evolving designs were primarily driven by improvements to installation, reliability, longevity and maintenance flexibility rather than by a technological need for a transducer flow measurement performance improvement. Today there are just two transducer designs in use; specifically, generations 3 and 4 listed below. One of these transducer designs is used with the aluminum box-type M/TSF, the other with the carbon steel saddle-type M/TSF. For the sake of comprehensiveness, the complete transducer design evolution is described below.

Four (4) generations of CROSSFLOW transducers can be identified:

1. Original Ontario Hydro Transducer - This transducer is included only for completeness, it has not been used on any CROSSFLOW systems.
2. Original CROSSFLOW Transducer - Used in combination with aluminum M/TSFs
3. No-twist Transducer - Used in combination with aluminum M/TSFs.
4. Permanent Transducer - Used in combination with saddle-type M/TSFs.

A brief description of each of these transducer designs follows.

3.1.2.1 [ ]

[

]

[

]

3.1.2.2 [ ]

[

]

3.1.2.3 [ ]

[

]

[

]

3.1.2.4 [ ]

[

]

[

]

3.1.3 INFLUENCE OF TRANSDUCER DESIGN ON CROSSFLOW PERFORMANCE

This section discusses the potential influence of variations in the transducer design evolution on CROSSFLOW performance.

3.1.3.1 Transducer Frequency

[

]

3.1.3.2 Transducer Diameter and Acoustic Field

[

]

[

]

3.1.3.3 Acoustic Couplant

[

]

[

]

3.1.3.4 Mounting/Transducer Support Frame (M/TSF)

[

]

5. Transducer alignment is important in achieving two well-defined ultrasonic beams inside the pipe. Since both transducer holes on each side of the saddle-type

M/TSF are bored in one run on a computerized numerical control (CNC) machine tool and no further adjustments are made during installation, this frame delivers exceptional transducer alignment as manufactured. Although the box-type M/TSF is assembled during installation at the site, proper alignment is still assured since all M/TSF components are CNC machined.

3.1.3.5 Installation Location

[

.]

3.1.4 SIGNAL CONDITIONING UNIT

[

]

3.1.4.1 Transmitter Circuit

[

]

[

]

3.1.4.2 Receiver Circuit

[

]

[

]

3.1.4.3 Digital Bus

[

]

3.1.4.4 Test Signal Modulator Circuit

[

]

3.1.5 CABLES

The are two (2) principal types of cable used for signal interconnection in the CROSSFLOW system. The ultrasonic transmission signal cables and data communication/control cables.

The standard cables used for ultrasonic transmission system are coaxial cables (COAX). These cables are high bandwidth, low loss, with good electromagnetic interference (EMI) shielding which are suitable for transmitting the ultrasonic signal of the CROSSFLOW system. These standard coaxial cables, which are used for permanent installations, satisfy IEEE 383, or equivalent, flame test requirements. Optionally, custom-made fiberglass coaxial cable for use in high temperature applications is also available.

The data communication and control cables for signal and data interfacing between various electronic components in the CROSSFLOW system are standard data transmission cables. These cables allow high data throughput and low interference for data transmission.

Additionally, the cables used in the CROSSFLOW system not only optimize the signal transmission but also ensure that the delay in the cable is negligible. [

]

3.1.6 DATA PROCESSING COMPUTER

[

]

3.2 CROSSFLOW SOFTWARE

The CROSSFLOW software and the DPC make up the central processing unit of the CROSSFLOW system. It is used to control the SCU and the MUX, perform digital signal processing on the demodulated signals and derive the delay time for use in the flow calculation.

3.2.1 SOFTWARE FUNCTIONALITY

The CROSSFLOW software is used in conjunction with the system hardware to measure pipe flow. Its major functions include:

1. Provision of a user to CROSSFLOW system interface
2. Communication and control of the CROSSFLOW SCU and MUX
3. Digital Signal Processing
4. Flow Calculation
5. Report Generation

The CROSSFLOW software design specification is written around two architectural models. The first model, called the CROSSFLOW Software External Function Model, defines the structure of the software system functions and the relationship among those functions. This model gives insight into how system users interface with the software. The second model, called the CROSSFLOW Software Internal Design Model, defines how the software design is organized internally. These models are discussed in the following sections.

3.2.2 EXTERNAL FUNCTION MODEL

[

]

3.2.2.1 Top Level Panel

[

]

3.2.2.2 Options Screen

[ ]

3.2.2.3 RSSI Scan

[ ]

3.2.2.4 Channel Configuration

[ ]

3.2.2.5 Hardware Setup Screen

[ ]

3.2.2.6 [ ] and Discriminator Criteria Configuration Screen

[.]

3.2.2.7 Measurement Initialization Screen

[ ]

3.2.2.8 Measurement Screen

[

]

3.2.3 INTERNAL DESIGN MODEL

The CROSSFLOW Software Internal Design Model shows the major system components that make up the software system. These components, or modules, are grouped by function and include the following:

- [
-
-
-
-
-
-
-
-
-]

The CROSSFLOW Software Internal Design Model is depicted schematically in Figure 3-6 and its principal elements are discussed in the subsections below.

3.2.3.1 General System Property Management

[

]

3.2.3.2 Global Data Buffer Management

[

]

3.2.3.3 System Security

[ ]

3.2.3.4 SCU and MUX Control System

[

]

3.2.3.5 Data Acquisition System

[

]

3.2.3.6 Digital Signal Processing

[

]

3.2.3.7 System Parameter Processing and Flow Calculation

[ ]

3.2.3.8 File I/O and Data Storage

[

]

3.2.3.9 Data Display and Export

[ ]

[

]

3.2.3.10 Error Handling System

[

]

3.2.4 CROSSFLOW SOFTWARE FUNCTIONAL REQUIREMENTS SPECIFICATION

The Functional Requirements Specification discusses the required CROSSFLOW software functions. The topics discussed include:

1. File System and Data Structure
2. SCU/MUX Interface
3. Data Acquisition System
4. Frequency Modes
5. Data Filtration Criteria
6. DSP and Flow Calculation

3.2.4.1 CROSSFLOW Software File System and Data Structure

This section discusses the file types that the CROSSFLOW software utilizes, specifically, data files naming convention, automatic file name creation, and file data structure.

[

]

3.2.4.2 Signal Conditioning Unit (SCU) and Multiplexer (MUX) Interface

[

]

3.2.4.3 Data Acquisition

[

]

3.2.4.4 Frequency Modes

[

]

3.2.4.5 Data Filtration Criteria

[

]

[

]

3.2.4.6 Digital Signal Processing and Flow Calculation

[

]

3.2.5 SOFTWARE VERIFICATION AND VALIDATION

CROSSFLOW software is under configuration control and, verification and validation (V&V) is performed in accordance with the ABB CENP, Quality Procedures Manual, QPM 101, Section QP 3.13 – Computer Software (Reference 3-4). Following this procedure, the software is evaluated to determine its adequacy for its intended use, V&V activities are identified and documentation needed to be placed under configuration control defined.

Prior to release of a CROSSFLOW software version revision, the V&V of the software is performed in accordance with ABB CENP implementing procedure, MISC-PENG-TOP-007, Revision 00, 08-26-1997, "Procedure for the Verification and Validation of the AMAG CROSSFLOW Meter Software" (Reference 3-5). This procedure utilizes software verification tests performed in accordance with AMAG procedure, AMAG-I-004, Revision 03, "Software Verification and Validation Instruction" (Reference 3-6).

3.2.5.1 Verification and Validation Method - Time Delay and Flow Rate Calculation

[

]

[

]

3.3 CROSSFLOW SYSTEM OPERATION VERIFICATION AND DIAGNOSTICS

From the initial development and application of the CROSSFLOW UFM System, accuracy and reliability have continuously improved. It is a priority to ensure that system uncertainty is always within the design bounds during normal operation. A number of verification and diagnostic techniques and tools have been developed to ensure accuracy claims for the CROSSFLOW system. The following subsections discuss these features.

Verification is normally carried out at pre-determined periodic intervals. Diagnostics are performed if a system failure occurs. Some of the verification techniques are used during the system's initial installation as a baseline for any subsequent troubleshooting.

[

]

The following subsections discuss each of these techniques.

3.3.1 [ ]

[

]

[

]

3.3.2 [ ]

[

]

3.3.3 [ ]

[

]

3.3.4 [ ]

[

]

[

]

3.3.5 [ ]

[

]

3.3.6 [ ]

[

]

3.4 CROSSFLOW COMPONENT CLASSIFICATION

[

]

3.4.1 CROSSFLOW APPLICATION

[

]

3.4.2 CROSSFLOW HARDWARE SAFETY SIGNIFICANCE

[

]

[

]

3.4.3 CROSSFLOW SOFTWARE SAFETY SIGNIFICANCE

[

]

3.4.4 CROSSFLOW CALIBRATION AND PLANT SPECIFIC UNCERTAINTY ANALYSIS ACTIVITIES

[

]

3.5 REFERENCES

3-1 Metals Handbook, Vol. 11, Failure Analysis and Prevention, American Society for Metals, 1986

3-2 Materials Characterization 28:279-289 (1992)

[

]

Table 3-1

Typical CROSSFLOW SCU Filter Settings

[ ]

FIGURE 3-1

CROSSFLOW SYSTEM PRINCIPAL HARDWARE COMPONENTS

FIGURE 3-2

Box-Type Mounting/Transducer Support Frame

FIGURE 3-3

SADDLE-TYPE MOUNTING/TRANSDUCER SUPPORT FRAME

FIGURE 3-4

SIGNAL CONDITIONING UNIT PRINCIPLE COMPONENTS

FIGURE 3-5

CROSSFLOW SOFTWARE EXTERNAL FUNCTION MODEL

FIGURE 3-6

CROSSFLOW SOFTWARE INTERNAL DESIGN MODEL DIAGRAM

FIGURE 3-7

RANDOM FREQUENCY RANGES CONFIGURATION

FIGURE 3-8

SETUP FOR THE NIST TRACEABLE TIME DELAY TEST

4.0 CROSSFLOW CALIBRATION AND VALIDATION

The CROSSFLOW UFM System was calibrated at the Alden Research Laboratory (ARL) for Reynolds Numbers (Re) ranging from 0.8×10^6 - 7×10^6.

The objective of the calibration was to determine an expression for the Velocity Profile Correction Factor (VPCF) using the form of the equation established in the previous theory discussion (see Section 2.2). This approach provides a traceable calibration to the National Institute of Standards and Technology (NIST) with a verifiable uncertainty for the VPCF.

This section describes the method of calibration, the results and the uncertainty of VPCF. A discussion is also presented regarding the extension of the VPCF to higher Reynolds Numbers. That is, to conditions representative of those encountered in nuclear power plant feedwater systems ($\sim 30 \times 10^6$).

4.1 CROSSFLOW CALIBRATION

[

Eq. 4-1

Eq. 4-2

Eq. 4-3

Eq. 4-4

] Eq. 4-5

[

Eq. 4-6

Eq. 4-7

]

Figure 4-1 shows the close correlation between the theoretical Equation 2-17 for the velocity profile correction factor and Equation 4-7, the correction factor based on the [ ]. Although Equation 4-7 is based on Reynolds Numbers of less than $7\text{x}10^6$, it can be seen that when this curve is extrapolated to much higher Reynolds Numbers, it is still tracks the theoretical curve quite closely.

4.2 PROFILE VALIDATION AT HIGHER REYNOLDS NUMBERS

The calibrated VPCF was developed using weigh tank data from the ARL. Due to the nature of these cold water tests, it was not possible to reproduce the operating conditions and the Reynolds Numbers that are normally present in nuclear power plant feedwater systems. Hence, a limited amount of data has been collected from several plants where the accuracy of the in-plant flow instrumentation was independently confirmed through weigh tank tests at ARL. This data, which ranges up to a Reynolds Number of $25\text{x}10^6$, was used to calculate a VPCF much like what was done for the ARL tests. These data points have been included in Figure 4-2 for comparison with the calibrated VPCF curve. In addition to the two (2) data points from operating plants, data has also been included from Ontario Hydro's specially constructed high temperature test loop plus other verification tests from the Everest Hydraulic Laboratory in Chatou France and NIST. Thus, a spectrum of independent data is provided covering both the expected operating and the calibrated range for the CROSSFLOW cross-correlation meter.

Two additional data points, "plant data 2" have also been included in Figure 4-2. This data was obtained from a plant, where CROSSFLOW meters were installed on two smaller feedwater pipes that were feeding into a common header with a third CROSSFLOW meter. Equation 4-6 was used for all three measurements, but it was possible to use correction factors from Equation 4-6 as standards that were just above or below the "OH High

Temp" data to compare with CROSSFLOW readings that were significantly higher than the "OH High Temp" data.

4.3 CONCLUSIONS

An accurate curve has been developed for the VPCF that is only a function of Reynolds Number. This curve assumes that the velocity profile is fully developed and that pipe wall friction is small. The use of plastic piping for the calibration provides a limiting condition that assures that the velocity measured by the CROSSFLOW cross-correlation meter will be equal to or greater than the actual velocity of the fluid. This in turn assures that the mass flow and, hence, the thermal power will be equal to or greater than the actual output of the reactor; a conservative condition.

Moreover, the high Reynolds Number tests confirmed that the calibration curve, which was developed at low Reynolds Numbers, is also applicable at higher values which includes those conditions that would be encountered in operating nuclear power plant feedwater systems.

4.4 REFERENCES

4-1 [

]

TABLE 4-1

DATA TAKEN AT ALDEN RESEARCH LABORATORY

[

]

TABLE 4-2

COMPARISON OF PREDICTED AND MEASURED VELOCITY PROFILE CORRECTION FACTOR

FIGURE 4-1

COMPARISON OF THEORETICAL CURVE VERSUS CALIBRATION CURVE USING ALDEN DATA

FIGURE 4-2

VERIFICATION OF THE ALDEN CALIBRATION CURVE AT HIGHER REYNOLDS NUMBER

5.0 DETERMINATION OF FEEDWATER FLOW AND FLOW UNCERTAINTY

The methodology for determining the CROSSFLOW input parameters, feedwater flow and associated feedwater flow measurement uncertainty is presented below.

5.1 GENERAL EQUATION FOR CALCULATION OF FEEDWATER FLOW

[

Eq. 5-1

]

5.2 ERROR ANALYSIS

[

]

Eq. 5-2

[

]

5.3 STATISTICAL EVALUATION

[

Eq. 5-3

Eq. 5-4

]

[

]

5.4 INSIDE PIPE DIAMETER

5.4.1 INSIDE PIPE DIAMETER MEAN

[

]

[

Eq. 5-5

Eq. 5-6

Eq. 5-7

] Eq. 5-8

[

]

5.4.2 INSIDE PIPE DIAMETER 95% CONFIDENCE INTERVAL

[

Eq. 5-9

Eq. 5-10

Eq. 5-11

]

[

Eq. 5-12

Eq. 5-13

Eq. 5-14

]

[

] Eq. 5-15

5.5 TRANSDUCER SPACING

5.5.1 MEAN TRANSDUCER SPACING

[

Eq. 5-16

]

[

]

5.5.2 TRANSDUCER SPACING 95% CONFIDENCE INTERVAL

[

Eq. 5-17

Eq. 5-18

]

[

]

5.6 VELOCITY PROFILE CORRECTION

5.6.1 VELOCITY PROFILE CORRECTION FACTOR

[

Eq. 5-19

Eq. 5-19a

Eq. 5-19b

Eq. 5-19c

Eq. 5-20

]

[

Eq. 5-21

Eq.5-22

Eq. 5-23

] Eq. 5-24

[

]

5.6.2 VELOCITY PROFILE CORRECTION FACTOR CONFIDENCE INTERVAL

[

]

5.7 FEEDWATER FLOW DENSITY 95% CONFIDENCE INTERVAL

[

Eq. 5-25

Eq. 5-26

]

[Eq. 5-27

Eq. 5-28

]

5.8 95% CONFIDENCE INTERVAL FOR THE TIME DELAY

[

] Eq. 5-29

5.9 FEEDWATER FLOW

5.9.1 FEEDWATER FLOW DETERMINATION

[

] Eq. 5-30

5.9.2 FEEDWATER FLOW 95% CONFIDENCE INTERVAL

[

Eq. 5-31

Eq. 5-32

Eq. 5-33

Eq. 5-34

]

[

]

5.10 UNCERTAINTY SUMMARY

[

]

5.11 REFERENCES

5-1 USNRC Regulatory Guide 1.105, Revision 2, "Instrument Setpoints for Safety-Related Systems."

5-2 ANSI/ISA-S67.04, Part I-1994, "Setpoints for Nuclear Safety-Related Instrumentation."

5-3 ANSI/ISA-RP67.04, Part II-1994, "Recommended Practice For Methodologies For The Determination of Setpoints for Nuclear Safety-Related Instrumentation."

5-4 Statistical Methods for Business and Economics, R.C. Pfaffenberger and J.H. Patterson, Publisher - Richard D. Irwin, Inc.

5-5 Practical Stress Analysis in Engineering Design, Alexander Blake, 1982, Publisher Marcel Dekker Inc.

5-6 ASME B&PV Code Section II Table 1A, "Section I; Section III, Class 2 and 3; And Section VIII, Division 1 Maximum Allowable Stress Values *S* For Ferrous Materials.

5-7 ASME B&PV Code Section II Part D, Properties.

5-8 Crane Technical Paper No. 410, "Flow Of Fluids Through Valves, Fittings, And Pipe," Twenty-Fifth Printing – 1991).

5-9 Marks' Standard Handbook For Mechanical Engineers, Ninth Edition.

5-10 NIST/ASME Steam Properties, Version 2.11, in accordance with "Computer Program Release Notice CA-FE-1021" and "Implementation Report For NIST/ASME Steam Properties Version 2.11," W.B. Terney, VV-FE-0444, Revision 00, June 11, 1998.

TABLE 5-1

TYPICAL CROSSFLOW UNCERTAINTY

95% CONFIDENCE INTERVAL

PARAMETER

FIGURE 5-1

SAMPLE FEEDWATER PIPE REFERENCE LOCATIONS AND POSITIONS

FIGURE 5-2

TRANSDUCER SPACING MEASUREMENTS

6.0 CROSSFLOW MATERIALS CONSIDERATIONS

CROSSFLOW has several components that contact the feedwater piping system on which it is mounted. As discussed in Section 3.0 there are design variations because of the evolution of the CROSSFLOW UFM System, which present differences in materials usage; [

]

6.1 METALLURGICAL CONSIDERATIONS OF TRANSDUCER/PIPE INTERFACE

[

]

6.1.1 [ ]

[

]

[

]

6.2 FEEDWATER PIPE MATERIAL

[

]

[

]

6.3 REFERENCES

6-1 Materials Characterization 28:279-289 (1992)

6-2 Metals Handbook, Vol. 11, Failure Analysis and Prevention, American Society for Metals, 1986

7.0 CROSSFLOW RELIABILITY

[

]

7.1 POTENTIAL FOR NON-CONSERVATIVE PREDICTION OF FLOW RATE

[

]

7.1.1 [ ]

[

]

[

]

7.1.2 [ ]

[

]

7.1.3 [ ]

[

]

[

]

8.0 CROSSFLOW FIELD IMPLEMENTATION

CROSSFLOW is simple to install and operate. This section discusses the principal steps taken during installation of the CROSSFLOW system to assure proper performance with the high degree of accuracy discussed in Section 5.0. In addition to the physical installation, initial system setup is also discussed. The discussion that follows is simply an overview. An actual CROSSFLOW installation and setup is governed by detailed step-by-step procedures (reference 8-1) that require the documentation of key installation/setup steps and important parameter values.

8.1 HARDWARE INSTALLATION - GENERAL

A trained ABB CENP or AMAG representative performs the initial installation of both the CROSSFLOW hardware and software. [

]

The initial step performed by the installation team is a pre-installation survey. This survey identifies the installation location, the pipe outside diameter, the pipe material and its method of fabrication (i.e. rolled plate, forged, extruded, etc.). From this information the transducer mounting hardware is custom fabricated to the specific pipe on which it will be mounted. [

]

[

]

8.1.1 DETERMINATION OF PIPE GEOMETRY INFORMATION

[

]

8.1.1.1 Pipe Outside Diameter Determination

[

]

8.1.1.2 Pipe Wall Thickness Determination

[

]

[

]

8.1.2 MOUNTING/TRANSDUCER SUPPORT FRAME (M/TSF) INSTALLATION

[

]

8.1.3 ULTRASONIC TRANSDUCER INSTALLATION

[

]

[

]

8.1.4 SOFTWARE INSTALLATION

[

]

8.2 CROSSFLOW SYSTEM / PLANT COMPUTER INTERFACE

[

]

8.3 MAINTENANCE

The CROSSFLOW SCU and MUX are electronic hardware assemblies that contain no moving parts requiring periodic scheduled maintenance or replacement. Except for the commercial power supplies used, there are no user adjustable components. Periodic checks of the functionality of the electronics is recommended and discussed in the following subsections.

8.3.1 SIGNAL CONDITION UNIT (SCU)

Maintenance of the SCU involves the user performing some basic functionality checks using the CROSSFLOW internal Test Signal at regular intervals to gather historical data on the SCU performance [

]

8.3.2 MULTIPLEXER (MUX)

As with the SCU, maintenance of the MUX involves the user performing some basic functionality checks. Using CROSSFLOW software in the Hardware Setup Screen Mode (see Section 3.0 for further discussion of this feature) and exercising the various functions available therefrom, the operator can perform a systematic checkout of both the SCU and the MUX.

[ ]

8.4 REFERENCES

8-1 Standard Procedure for Ultrasonic Measurement of Feedwater Flow, MISC-PENG-TOP-003

PROPRIETARY INFORMATION

ABB COMBUSTION ENGINEERING NUCLEAR POWER, INC.