MPR
ASSOCIATES INC
ENGINEERS

MPR-1614
Revision 0
October 1995
NON - Proprietary

Feedwater Flow Measurement with LEFM Chordal Systems at Indian Point Unit 2

Configuration and Uncertainty Analysis

MPR ASSOCIATES INC ENGINEERS

Appendix B

Hydraulics Calculation

1. MPR Calculation No. 288-003-JAR-1, "Hydraulic Profile and Its Uncertainty," Rev. 0.

MPR

MPR Associates, Inc.
320 King Street
Alexandria, VA 22314

CALCULATION TITLE PAGE

Client Consolidated Edison Company	Page 1 of 14
Project Indian Point Unit 2 LEFM Uncertainty Analysis	Task No. 288-003
Title Hydraulic Profile and its Uncertainty	Calculation No. 288-003-JAR-1

Preparer/Date	Checker/Date	Reviewer/Date	Rev. No.
[signature] 7/19/95	[signature] ERIC B. MITCHELL 7/20/95	Herbert [signature] 7/20/95	ϕ

MPR

MPR Associates, Inc.
320 King Street
Alexandria, VA 22314

RECORD OF REVISIONS

Calculation No.	Prepared By	Checked By	Page 2
288-003-JAR-1	J Regan	[signature]	

Revision	Description
Ø	Original Issue

MPR

MPR Associates, Inc.
320 King Street
Alexandria, VA 22314

Calculation No.	Prepared By	Checked By	Page 3
288-003-JAR-1	[signature]	[signature]	

TABLE OF CONTENTS

1.0 PURPOSE

The Leading Edge Flow Meter (LEFM) calculates volumetric flow from fluid velocity measurements along acoustic paths in a measurement section or spool piece. The relationship between the velocity measured along the acoustic paths and the volumetric flow is determined by (a) the angle between the acoustic paths and the axial fluid velocity vectors which intersect them and (b) a profile factor which relates the axial velocities along the acoustic paths to the axial velocity averaged over the cross section of the spool piece. This calculation provides the basis for the profile factors to be used with the four four-path chordal flow meters installed at Indian Point Unit 2, and calculates the uncertainty bounds on the profile factor.

2.0 SUMMARY

A profile factor of [ ] should be used with each of the four four-path chordal flow meters at Indian Point Unit 2, and the uncertainty in this profile factor is [

]

3.0 APPROACH

The profile factor and its accuracy for a four-path chordal flow meter are dependent upon the ability of the meter to integrate from discrete velocities measured on each of four paths into the spatially averaged velocity across the spool piece section. This integration is affected by the inaccuracy of the four path Gaussian Quadrature integration method, and the fact that the velocity profile is not uniform across the section. The velocity profile is non-uniform on two counts. First, in long straight sections of pipe the velocity profile becomes rounded, blunt and symmetrical, characterized as "fully developed". In a fully developed profile, the velocity has a maximum at the fluid center and minimum at the pipe wall. Secondly, actual piping systems like the Indian Point feedwater system contain bends and other fittings which produce, in varying degrees, asymmetrical distortions that change the velocity gradients and introduce secondary non-axial flows.

To estimate the Indian Point Unit 2 four-path chordal profile factor and its uncertainty, this calculation takes the following approach:

(1) [

]

(2) [

]

(3) [

]

4.0 CALCULATION

4.1 Profile Factor and Uncertainty for Fully Developed Turbulent Flow

Reference 1 establishes a profile factor versus Reynolds' Number for measurement of fully developed flow using a four-path chordal flow meter. [

]

4.2 Indian Point Unit 2 Hydraulic Geometry Effects

The piping arrangement and flow meter orientation in the Indian Point Unit 2 feedwater piping are sketched in Figure 1 (Reference 2). Four flowmeters are located in straight, horizontal runs of piping downstream of a vertical run of piping, the distance varying from 7 to 19 diameters downstream of the vertical - to - horizontal elbow. The vertical run is 11 diameters in length in each of the four lines, and upstream of the vertical run is another horizontal with the feedwater control valves in the immediate vicinity. Thus, each LEFM meter lies downstream of two non-coplanar bends separated by a distance of 11 diameters. Based on the work of Murakami et al (Reference 3), it is likely that this upstream geometry will cause secondary flows in the piping at the LEFM locations.

The hydraulic geometry upstream of the four LEFMs at Indian Point 2 can also be related closely to the geometry employed during hydraulic tests performed in 1978 by Westinghouse and documented in Reference 4. Specifically, Westinghouse performed tests using chordal LEFM meters in straight pipe and downstream of closely coupled non-coplanar bends to

[

]

4.3 In-Situ Path Velocity Data

Figure 1 shows the orientation and numbering of the LEFM paths for each of the four meters at Indian Point Unit 2. Individual path velocities recorded during commissioning each of the LEFM meters at Indian Point Unit 2 (Reference 5) are summarized in Table 1 below, for which the following nomenclature applies:

[ ]

Calculation No.	Prepared By	Checked By	Page
288-003-JAR-1			7

Profile Development

The data in Table 1 can be evaluated for degree of profile development, and for profile asymmetry due to secondary flow. Profile development will be assessed first. For a fully developed profile which exists in straight pipe distant from upstream hydraulic disturbances, typical ratios of short and long path velocities to the mean velocity of the cross-section are shown in Table 2, based on Reference 6.

[ ]

[ ]

[

]

Profile Asymmetry and Secondary Flows

Profile asymmetry is assessed by comparing one short path to another, and one long path to the other for each meter. A fully symmetric profile would show equal short paths and equal long paths. [

]

Figure 2 illustrates the effect of swirl on LEFM path velocities. Clockwise swirl would decrease the apparent velocities measured by paths 1 and 2 on the left side of the pipe, and increase the apparent velocities measured by paths 3 and 4 on the right side. [ ]

magnitude about 5 to 8% at the location of the short paths and 2-3% at the long paths. For Meter 21, closest to the upstream bends, the data suggest a counter-clockwise swirl looking upstream of magnitude 9% at the short and 4% at the long paths, indicating slightly more intense swirl as expected. The opposite - hand sense of swirl in Meter 21 with respect to the other meters is plausible considering its proximity to the upstream bends, and the likelihood that the profile entering those bends is distorted by the upstream control valve. The varying distance between control valves and bends, and between bends and the LEFM for the other meters could explain the clockwise sense of the swirl for the other meters.

Swirl sense does not affect the accuracy of the LEFM measurement, as long as the swirl is centered in the pipe. Regardless of the sense of the swirl, Figure 2 illustrates that the LEFM short paths and long paths will be effected equally if the swirl is axisymmetric. The effect on total flow is nil because the secondary velocity distortions cancel one another path-to-path. However, swirling flow may affect the flow measurement if it is not axisymmetric, or if its intensity is sufficient to penetrate the transducer wells where flow would otherwise be zero. The results of the Westinghouse testing (Ref. 4) discussed above may be indicative of such an effect.

If the flow is not swirling, but is distorted axially, LEFM in situ data presented in Table 1 would suggest that the flow through Meter 21 is higher to the left side of the pipe while the flow through Meters 22-24 is higher to the right side. In this case, the profile would be interpreted as having 10 to 18% higher flow along one short path versus the other. This would compare to the Westinghouse test data, interpreted in the same way, as having about 22% higher flow along one short path versus the other. This close relationship of path velocity data would support using the Westinghouse test results, again indicating the Indian Point profile factors should be corrected to account for a bias of between 0 and 0.3 percent.

To account for the profile development and asymmetry observed in the Indian Point in-situ data, the profile factor for the Indian Point meters is corrected slightly, by reducing the straight pipe factor of Section 4.1 by 0.2 percent. This correction is less than the 0.3 percent observed in the Westinghouse testing due to the reduced severity of the hydraulic conditions at Indian Point as compared to the test. This results in a profile factor of

$$1.001 - 0.002 = 0.999$$

for the four Indian Point Meters. This corrected profile is applied to all four meters due to the similarity in their profiles.

The uncertainty in profile factor due to profile development and secondary flows is taken as 0.2 percent, [ ]

4.4 Other Sources of Uncertainty

There is additional uncertainty in the LEFM profile factor due to lack of knowledge regarding pipe relative roughness. The relative roughness of the piping through which the feedwater flows affects the development of the hydraulic profile, as shown in Table 2. However, due to the close proximity of the LEFM's at Indian Point to the upstream hydraulic disturbance, the roughness effect is considered to be nil in this case. Any small roughness effect is already accounted in the profile development uncertainty discussed above.

Finally, hydraulic testing is performed in the Reynolds Number range of $Re = 2 \times 10^6$. There is a small additional uncertainty in extrapolating from typical ARL conditions of $2 - 3 \times 10^6$ to $Re = 3 \times 10^7$, [ ] based on Reference 1.

4.5 Combination of Errors

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

[ ]

5.0 REFERENCES

1. MPR Calculation Number 15708HE1A, "Determination of the Profile Factor and Its Uncertainty for a 4 Path LEFM in Long Straight Pipe," Rev. 0, H. Estrada, 12/18/82.

2. UE&C Drawing No. 9321-F-2061, Rev. 20, "Yard Area - West of Containment Building Boiler Feed Piping Plan - Sheet No. 1; For Consolidated Edison Co., Indian Point Generating Station Unit 2".

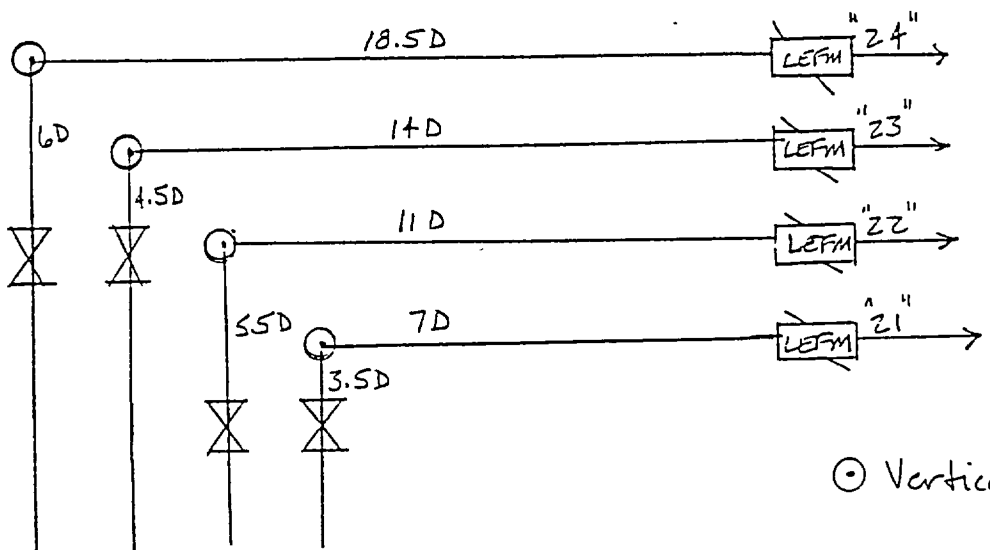
3. Murakami, M., Shimizu, Y., and Shiragumi, H., "Studies on Fluid Flow in Three Dimensional Bend Conduits," Japan Society of Mechanical Engineers (JSME) Bulletin V. 12, No. 54, Dec. 1969, pp 1369-1379.

4. Westinghouse Document No. OEM 78-40, "Results of February and July 1978 LEFM Hydraulic Tests at Alden Labs", February 7,1979.

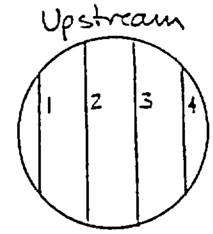
5. Caldon Procedure No. EFP56, "Installation and Commissioning of LEFM 8300," Completed 7/8/95 for Indian Point Unit 2 Installation by S. Johnson (Caldon) and M. Roberts (MPR).

6. MPR Calculation Number 108-054-LAS-03, Rev.0, "Average Chordal Velocities for Universal Fluid Velocity Model."

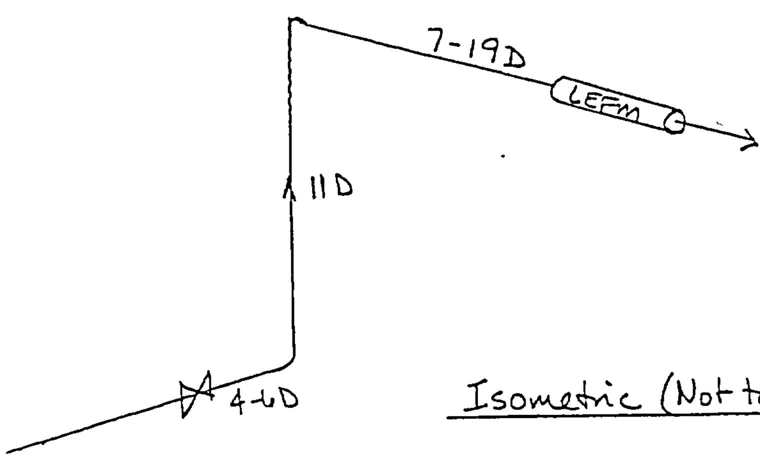
7. Abernathy et al, "ASME Measurement Uncertainty," ASME Journal of Fluids Engineering, Vol. 107, p. 161-164, June 1985.



Plan (Not to Scale)



LEFM Path Orientation (Typical)



Isometric (Not to Scale)

Figure 1. LEFM Locations In Indian Point Unit 2 Feedwater System. (Reference 2)

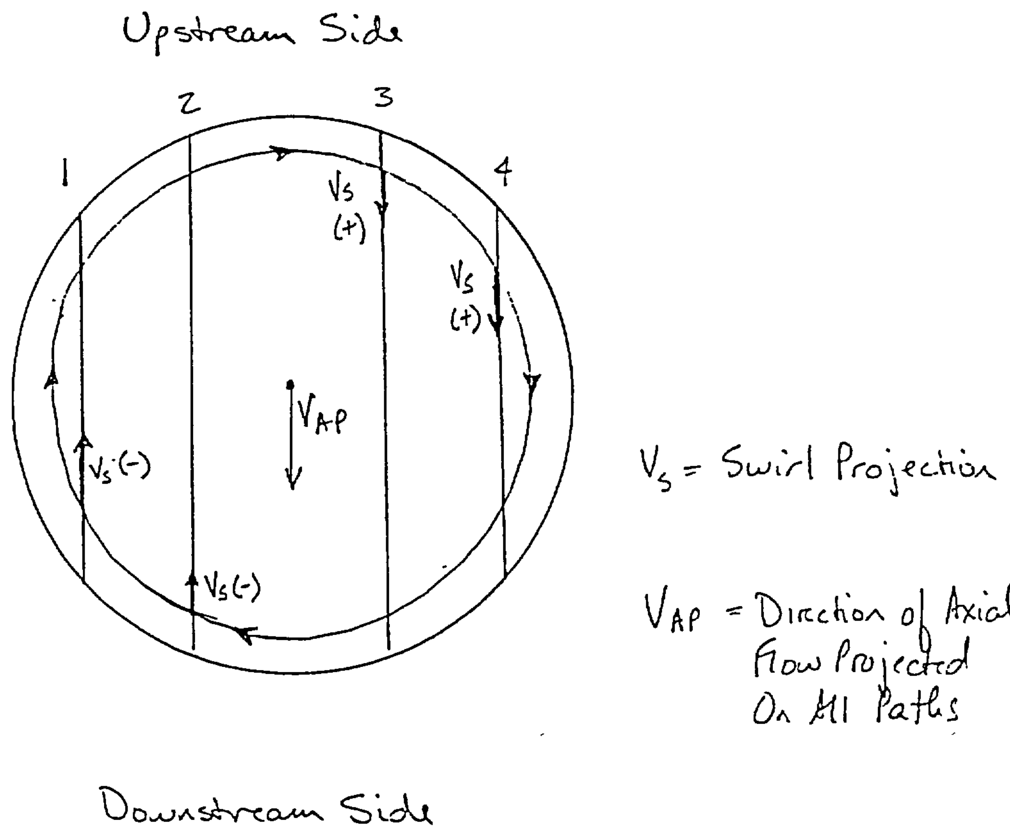


Figure 2. Effect of Axisymmetric Swirl on LEFM Path Velocities

Question 13:

In the first paragraph of Section 3.5, ENO stated that the LEFM Check System was originally installed in 1980 and the upgrade to the electronic unit, which meets the requirements of the approved Topical Report ER-80P, was installed in October 2002. The second paragraph of this section states that the Caldon LEFM Check System was installed in the fall of 2002. Please explain how the LEFM hardware (spool piece, etc) installation requirements of ER-80P was met in 1980 while ER-80P was approved in 1999. Also, please identify and explain if there was any failure of the LEFM system or its component since its original installation at IP2.

Response 13:

The LEFM flow elements were installed in 1980 by Westinghouse. A complete refurbishment was accomplished in 1995. The refurbishment included the replacement of transducers and reconditioning of transducer housings. The LEFM Electronic Unit was also upgraded in 1995 to the then current generation electronic platform.

In 2002, the electronic unit was again upgraded to the LEFM Check System Electronic Unit that meets all of the requirements of the approved Topical Report ER-80P. At the time of the upgrade in 2002, the system was recommissioned to verify that all of the requirements of ER-80P were met. [

] Uncertainties for all dimensions are bounded in the uncertainty analysis per the practices established and approved in ER-80P, and used at Comanche Peak.

The system has been used and maintained throughout its installed history. During that period, transducers have been replaced as a normal maintenance item. Most of this history is included in Section 7 of ER-80P.

Question 14:

In Section 3.6, ENO stated that uncertainty calculations have been performed and determined a mass flow accuracy of better than 0.5 percent of rated flow for IP2. Please submit this calculation for staff review. Additionally, the instrument uncertainty of feedwater flow used in WCAP-15904-P is much lower (proprietary) than the calculated value determined to be better than 0.5 percent of rated flow. It is noted that the instrument uncertainty of feedwater flow used in power calorimetric uncertainty calculation for IP3 (WCAP-15824) was much higher (proprietary) than the calculated value (proprietary) provided in the ENO letter to the NRC, dated November 20, 2002. It is not clear why IP3 power calorimetric calculations used much higher than the calculated value of the LEFM measurement uncertainty while a similar calculation for IP2 used much lower than the calculated 0.5 percent, which makes it non-conservative. Please explain.

Response 14:

Enclosed is Caldon,Inc. Engineering Report: ER-290 Revision 2, Bounding Uncertainty Analysis for Thermal Power Determination at Indian Point Unit 2 Nuclear Power Station using the LEFM check System, (proprietary), which is the calculation that determined a mass flow accuracy of better than 0.5 percent of rated flow for IP2.

The value of Instrument uncertainty for Feedwater Flow used in IP2 WCAP-15904-P is [ ]. This value is the value calculated by Caldon in ER-290 as Mass Flow Uncertainty. The instrument uncertainty factor for Feedwater Flow used in IP3 WCAP-15824 is [ ]. The calculated value (proprietary) provided in the ENO letter IPN-02-091 to the NRC, dated November 20, 2002 represents an aggregate Profile Factor uncertainty of [ ]. This aggregate Profile Factor uncertainty represents a portion of the total Feedwater Flow uncertainty. The equivalent Profile Factor uncertainty for IP2 is [ ].

The IP3 uncertainty factor for Feedwater Flow [ ], is the Total Mass Flow Uncertainty plus an additional factor for Feedwater Enthalpy Uncertainty. The Feedwater Flow Uncertainty for IP2 in WCAP-15904-P of [ ] is a complete Mass Flow Uncertainty but does not include the additional factor for Feedwater Enthalpy Uncertainty. The equivalent Total Mass Flow Uncertainty plus Feedwater Enthalpy Uncertainty for IP2 is [ ] as calculated by Caldon in ER-290.

IP2 WCAP-15904-P is being revised to include the enthalpy effects and utilize the value of [ ]. There will be no change to the results and conclusions for WCAP-15904-P. The requested 0.6% power calorimetric uncertainty remains bounding and applicable.

The equivalent Total Mass Flow Uncertainty plus Feedwater Enthalpy Uncertainty for IP2 [ ] is smaller than the IP3 value [047%] primarily due to the fact that two of the IP2 LEFM spool pieces were tested at Alden Labs (See response to RAI 16).

Question 16:

In Section 3.7, ENO stated that loops 21 and 22 LEFM Check Systems were calibrated at Alden Research Laboratory while loops 23 and 24 calibration coefficients are based upon ARL testing of a population of 7 flow elements with similar inside diameters and dimensions. It is assumed that the ARL calibration of loops 21 and 22 LEFM was performed on the plant-specific piping configuration. Please confirm. Staff review of the ARL report of loops 21 and 22 LEFM calibration and loops 23 and 24 LEFM measurement uncertainty calculations, similar to the one submitted in your letter to the NRC dated November 20, 2002, for IP3, is needed to complete our evaluation of the proposed power uprate of IP2.

Response 16:

The flow elements installed at IP2 in loops 21 and 22 were tested at ARL in a straight pipe configuration, not a plant-specific piping configuration. Calibration correction factors (profile factor and uncertainty) have been applied to the straight pipe test results to reflect the as-installed piping geometry. A description of the ARL straight-pipe testing and results for these flow elements are documented in ARL Report No. 106-79/C91 (proprietary). A description of the correction factor methodology and results applied for these flow elements is documented in MPR Associates, Inc Report MPR-1614 (proprietary). Both of these reports are being provided with this submittal for NRC review.

The calibration correction factors for the flow elements installed in loops 23 and 24 are based on straight-pipe testing of a population of seven flow elements at ARL, which is the same test population used to establish the correction factors for the flow elements installed at IP3. The testing for six of the seven flow elements is described in Appendix F of Caldon's NRC-approved Topical Report ER-80P. The testing, performed in the 1970's and 1980's under a Westinghouse program, demonstrated that the profile factor for the four-path LEFM system is not very sensitive to varying piping geometry. Specifically, ER-80P demonstrates that in nearly all fluid system configurations, the profile factor is within 0.1% to [ ] of what it is in straight pipe. Exceptions to this statement are associated with off-center swirling conditions, occurring downstream of closely-coupled non-planar bends. The piping bends upstream of the flow elements at IP2 are not closely-coupled, and therefore the profile factors for these elements are bounded by the [ ] straight pipe profile factor. Testing of the seventh reference flow element, performed in 1997 under a Caldon program, supported this conclusion. The correction factor methodology and results for the flow elements installed in loops 23 and 24 are also included in MPR-1614.