CALDON

Technical Paper

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All measurement systems are subject to errors, arising from the individual elements of the system. For example, a flow nozzle-based flow measurement might employ a nozzle, a differential pressure transmitter with associated plumbing, a temperature element and transmitter, a pressure transmitter, and analog and digital signal processing hardware to provide a flow indication. Each of these elements is subject to errors arising from a spectrum of causes. The errors may be in the nature of fixed biases—for example, a bias in a nozzle discharge coefficient owing to the presence of swirl in the flow stream or a calibration error in a differential pressure transmitter owing to errors in the standards used for its calibration. Or the errors may be slowly or rapidly varying in time—for example, drift in analog transmitters and observational errors due to turbulence. Whether the errors are biases or randomly varying, tests or calculations may be performed to bound them for each element of a measurement system.

It is appropriate to ask how the errors of individual elements—biases and time varying random errors—should be combined. In the treatment of uncertainties in LEFM flow measurements, it has been Caldon's practice to follow the guidance of ASME standard for heat balance testing[a] , with respect to estimating and combining potential errors from various sources in the measurement system. This standard was developed primarily for use in performing warranty tests to establish the efficiency of turbomachinery and heat transfer equipment in fossil steam power plants; such tests must measure many of the same variables needed for a nuclear plant heat balance, and must do so with high precision. The ASME put a great deal of effort into this standard, including analytical and computer studies to establish appropriate procedures for combining bias and randomly varying error contributions of the elements of the measurement system.

Essentially, the ASME procedure starts with the algorithm for the measurement system and uses partial differentiation to establish a sensitivity coefficient relating overall error to the error in an element, for each element of the system. If one element has several error contributors, the numerical contributions are combined in one of two ways:

(1) by the root-sum-square if the individual contributors are not correlated with each other (i.e., not due to a common cause), or

(2) algebraically, if they are (errors in this class are referred to as systematic).

The error contributions for each element are then multiplied by the sensitivity coefficient for that element; systematic contributors are maintained segregated from uncorrelated errors. The errors, weighted by the sensitivity coefficients, are then combined, by the root-sum-square for uncorrelated errors, and algebraically for systematically related errors. The total measurement error is then calculated by combining the aggregate systematic and uncorrelated errors by the root sum square. In this process no distinction is made between errors of the fixed bias type and errors of the random, time varying type. The efficacy of this procedure was demonstrated by the ASME using computer simulations of multi-element measurement systems. Both fixed biases and randomly varying errors were input, with values for a specific source in a given run chosen using a Monte Carlo technique. A spectrum of error distribution shapes were assumed. In summary, it was found that there is a 95% probability that the total measurement error will lie within a band computed according to the procedure outlined above, if 95% probability bands were used for the individual error elements (95% probability bands are conventionally used for ASME heat balance testing and are also used for calorimetric calculations in most nuclear power plants).

With a few exceptions, most of the errors in an LEFM measurement are fixed biases as opposed to errors which vary randomly in time. Although the biases are fixed, one does not have any foreknowledge of their actual values or sign in a specific application; instead he is able only to make calculations or measurements that will, with 95% probability, bound the range of values that a bias from a particular source might take on for the conditions of the measurement. Consequently, these biases are treated in accordance with the ASME standard; they are combined by the root-sum-square if they are uncorrelated, and algebraically if they are systematic.

From the description of the principles of operation of LEFM time-of-flight ultrasonic flow measurements in Appendix A, it will be noted that the uncertainties in LEFM measurements can be grouped for analysis in four categories:

1) Hydraulic Uncertainties—the uncertainties associated with measuring, in a test facility, the profile factor for a specific installation and applying this factor to a measurement system in the plant

2) Acoustic Uncertainties—for externally mounted time-of-flight measurements, the uncertainties associated with establishing the angle of the acoustic path relative to the axis of the pipe. This category of uncertainty is typically small to negligible in chordal systems, for the reason s described in Appendix A.

3) Geometric Uncertainties— the potential biases associated with imperfect knowledge of the dimensions of the measurement system—for external systems, the pipe wall thickness, for internal systems, the path angle, length and placement distances, and, for both systems, the internal pipe diameter.

4) Time Measurement Uncertainties—the potential biases and randomly varying errors associated with measuring the times of flight of the acoustic pulses, including the measurement or calculation of non fluid delays. These errors have primarily to do with detecting the transmission of electrical energy to the transmitting transducer, with detecting the receipt of electrical energy by the receiving transducer, and with measuring the time interval between these events. The same elements affect the measurement of non fluid delays in configurations where these delays can be

[a] ANSI/ASME PTC 19.1-1985, *Measurement Uncertainty (Instruments and Apparatus)*

measured in place. In configurations where they cannot (e.g., an externally mounted diagonal path), the uncertainties are determined by how well the dimensions and transmission properties of transducer wedges, pipe walls, transducer elements, cables and electronics are known.

There are two other classes of uncertainties in LEFM measurements worth noting:

a) Observational errors due to the randomly varying character of feedwater flow—Feedwater flow is highly turbulent; additionally it is continuously controlled to maintain steam supply inventory. Both turbulence and control lead to significant short term variations in flow rate. Consequently, a single observation of this variable will not likely yield an accurate calculation of the reactor thermal power at the time of the observation. It is therefore necessary to take multiple measurements of feedwater flow over a period of time sufficient to ensure thermal equilibrium between reactor core power and steam plant power. The residual observational error in this procedure must be accounted in assessing the overall flow measurement error. By convention, the LEFM error accounting includes this observational error in the time measurement category, although strictly speaking it is a property of the fluid system itself and not 'chargeable' to the instrument.

b) Computational errors associated with the flow calculation software and processor—The time measurements and data processing of the LEFM are essentially entirely digital; there are therefore no drift type signal processing errors of the kind normally associated with analog instruments. There are however a number of iterative routines used in the execution of the algorithm, and the processor has the assortment of truncation and series approximation errors normally associated with digital processors. Analyses and tests have demonstrated that all errors of this kind are negligible (less than 1 in 10,000) in LEFM flow measurements.

The bounds of the errors (or, more precisely, uncertainties) in each of the four major categories—hydraulic, acoustic, geometric, and time measurements— for Caldon LEFMs are discussed in the paragraphs that follow.

Hydraulic Uncertainties

The uncertainties embedded in the process of relating the diametral axial velocity measured by an externally mounted LEFM to the bulk average axial velocity are characterized as a profile factor uncertainty. Likewise, the uncertainties in relating the four weighted velocity chord length products measured by an internal LEFM to volumetric flow are characterized as a profile factor uncertainty. For external systems profile factors can range, realistically, from 0.93 to 1.00. The uncertainty in this parameter, for a typical external mount installation, is around +/- 0.7%. The range of profile factors in a chordal installation is much narrower—the value usually falling between 0.994 and 1.002. As might be expected, the uncertainty in profile factor is also smaller for a chordal system, ranging from 0.2 to 0.4%.

What are the contributors to profile factor uncertainty? For both external and chordal systems they are as follows:

- *Facility Uncertainties:* The weigh tank scale, water thermometers, and fill-time-measuring hardware (all of which make up the flow standard for the profile factor determination) have uncertainties typically certified to be less than 0.25%

- *Measurement Uncertainties:* As has been described in Appendix A, the profile factor is determined by the quotient of weigh-tank-measured flow and the flow as measured by a test LEFM whose profile factor is exactly 1.000. This test instrument is not perfect; its uncertainties contribute to the overall uncertainty in profile factor. For external system model tests, measures are taken to reduce these uncertainties as much as possible, by using a machined pipe section with accurate and uniform internal diameter and wall thickness measurements, and by using multiple acoustic paths in each measurement plane to reduce random timing and acoustic errors. Nevertheless, the contribution to profile factor uncertainty of the test LEFM for external systems is relatively large- as much as 0.6%. For chordal systems, the measurement uncertainty is much smaller; this advantage follows from the use of the actual spool piece in the profile factor measurement. Consequently, geometric uncertainties do not have to be carried in either the profile factor uncertainty or in the flow measurement in the plant, since any biases due to dimensional tolerances are embedded in the profile factor itself. With only time measurement uncertainties contributing, the measurement uncertainty in profile factor for a chordal system is typically in the 0.1% range.

- *Modeling and Extrapolation Uncertainties:* The principal uncertainty in the fluid system model constructed at the hydraulic test facility usually relates to the impact of the fluid system configuration upstream of the section that has been modeled (the space limitations of the test facility necessarily restrict the extent of the model). This uncertainty is often characterized by measuring the change in profile factor for intentionally induced flow field distortions at the inlet to the model. If there is no effect, the modeling uncertainty is nil; if there is an effect, its magnitude can be used as a conservative basis for characterizing modeling uncertainty. In hydraulic situations where swirl is present, the rotation of an asymmetric axial profile can introduce a modeling uncertainty, since the swirl velocity may not be exactly the same in the plant as in the model. This uncertainty is usually bounded by conducting several profile factor measurements with the acoustic paths at various angular orientations relative to the coordinates of the fluid system. The range of profile factor values provides a basis for bounding this uncertainty. Finally, the shape of the axial profile can vary with Reynolds number, primarily due to changes in the thickness or character of the boundary layer. The changes are usually small to insignificant for Reynolds numbers in the 3 million to 20 million range that typifies the difference in model versus plant Reynolds numbers. However, occasionally some sensitivity to Reynolds number is found for the range of velocities covered by the model test. In such cases, Caldon's procedure has been to extrapolate results using a logarithmic fit, as described in Appendix A.
The uncertainty associated with the extrapolation is established by the statistical uncertainty of the fit. The aggregate modeling and extrapolation uncertainty for externally mounted LEFMs is usually no greater than 0.3%; the comparable uncertainty for

chordal systems is typically somewhat smaller.

- Observational Uncertainties: The flows employed in the weigh tank testing are turbulent; hence they vary significantly in time. Because the LEFM is a sample data system and the number of flow samples for each weigh tank run is therefore finite there is a random observational error inherent in the profile factor measurement. But the LEFM sample rate is high, so this error rarely exceeds 0.1%.

Acoustic Uncertainties

In Appendix A, it has been noted that acoustic uncertainties are important only to externally mounted time-of-flight systems. For these systems, the acoustics determine the angle between the raypath and the pipe axis, whereas the raypath is determined mechanically in chordal systems.

The principal acoustic uncertainty relates to the boundary condition that is used, in combination with Snell's Law, to determine the path angle. It will be recalled from Appendix A, that if the transducers are acoustically close, the equivalent ray emerges perpendicular to the face of the transmitting transducer, while if the transducers are acoustically distant, the equivalent ray connects the transducer centers. To minimize acoustic uncertainties, Caldon employs a unique, proprietary procedure that ensures that, whether the transducers are acoustically close or distant, they are located such that the same path angle is obtained with either assumption. The residual acoustic uncertainties with this procedure relate primarily to (1) the precision of the transducer placement on the pipe, (2) the accuracy with which the fluid sound velocity is measured (by the cross path), (3) the accuracy with which the ultrasound propagation velocity of the transducer wedge is measured (as part of factory quality assurance testing), and (4) the accuracy with which the ultrasound propagation velocity in the steel pipewall is known. The acoustic uncertainties of a typical external system aggregate to 0.3 to 0.4%.

Geometric Uncertainties

The locations selected for externally mounted LEFMs in the field are normally based on hydraulics and access; it is consequently necessary to deal with the imperfections of commercial steel pipe in determining the input dimensions for the flow computation algorithm. The variability of the pipe is also a principal contributor to the geometric uncertainties of an external system. To reduce uncertainties insofar as practical, multiple measurements of the outside pipe diameter are made using certified calipers, the measurements encompassing the axial extent of the acoustic paths in each measurement plane. Similarly, multiple measurements of wall thickness are made, in the way of each transducer location, using certified ultrasonic wall thickness gages designed for high temperature service (most external meter installations are made with the feedwater pipes at full operating temperature). The geometric uncertainty must also include an allowance for imperfections in the dimensional corrects for thermal expansion/contraction. The aggregate geometric uncertainty due to standards, observation, pipe variability and thermal expansion is typically around +/- 0.25% for an external system.

As has been pointed out, the geometric uncertainties owing to spool piece fabrication tolerances are embedded in the profile factor of a typical chordal LEFM. Nevertheless, an evaluation of the potential biases owing to the as-built dimensions of the spool piece is made to ensure that the measured profile factor accords with the expected value for this parameter. This practice provides assurance that no major, undetected experimental error has affected the critical profile factor measurement.

There are two small geometric uncertainties that may be carried for chordal systems. One is due to the uncertainties in thermal expansion and contraction. It is normally less than 0.1%. The second has to do with the alignment of the spoolpiece relative to the upstream pipe. It is bounded by a calculational procedure and also is usually less than 0.1%.

Time Measurement Uncertainties

To provide an understanding of the uncertainties in the time measurements of an LEFM, it is necessary first to provide a brief description of the signal processing employed by the instrument. The sequence of events in the measurement of the time-of-flight of a single electrical/acoustic pulse is:

1) A master controller initiates pulse transmission and simultaneously starts the time measurement by directing counts from an electronic clock into a counter.

2) Electrical energy from a pulse generator is directed through a solid state multiplexer, thence through a cable to a piezoceramic transducer.

3) The piezoceramic transducer converts some of the electrical energy in the pulse into mechanical (acoustic) energy.

4) The acoustic energy transits the non fluid media between the transducer and the fluid whose flow is being measured. If there are several media, some of the energy will be reflected at each interface; the balance will make its way into the next medium.

5) Some of the acoustic energy enters the fluid medium and transits it, aided, impeded, or unaffected by the fluid flow, depending on the direction of the pulse. The energy that does not enter the fluid is reflected back into the non fluid medium.

6) Some of the acoustic energy emerges from the fluid medium and enters the non fluid medium on the opposite side of the pipe from which it started its journey. It transits the non fluid media and reaches the receiving piezoceramic transducer.

7) The receiving transducer converts the acoustic energy into electrical energy.

8) The electrical energy transits the cable connected to the receiving transducer, through a multiplexer to an electronic receiver which amplifies it.

9) After it is amplified, the pulse is detected by an electronic detector, which senses the zero crossing of a selected half cycle of the received pulse (usually the second or third half cycle). Upon detection of the zero crossing, the accumulation of clock counts in the time measuring counter is stopped.

The sequence above might apply, for example, to the transmission of a pulse diagonally in the direction of flow, as described in Appendix A. When, next, transmission in the direction opposing flow occurs, the transducer roles are reversed; the transducer that formerly transmitted becomes the receiver and the former receiving transducer becomes the transmitter. Caldon uses the same transmitting and receiving electronics for both sequences, so that in determining the difference in the times of flight of the two acoustic pulses, electronic delays play no part. This is important; it will be remembered from Appendix A that it is the time difference that is a principal determinant in the fluid velocity determination. Note also that since the acoustic pulses traverse essentially identical paths, no other non fluid delay affects the determination of time difference. It is therefore appropriate to list the elements that contribute to uncertainty in the time measurement, devoting special attention to those than are not inherently offset in the time difference determination:

- Wander or drift in the frequency of the clock count generator

- The resolution of the clock count— The precision clock currently used by Caldon has a 10 nanosecond count width; consequently no single time measurement can be more precise than this figure. The uncertainty is reduced however by averaging multiple samples for each time measured.

- The repeatability of the zero crossing detector

-Random noise, which, by adding to or subtracting from the received pulse sinusoid can alter the time at which the detected zero crossing occurs. This uncertainty is likewise reduced by multiple samples

- Coherent noise (usually energy that has transited around or along the pipe wall instead of the fluid) that also can alter the zero crossing of the received signal. Averaging does not usually reduce this error because the phase relationship between signal and noise varies very slowly in time.

- Non reciprocal delays— the multiplexers that are used to switch electronics can cause unequal delays in upstream and downstream pulse transmissions. Also, electrical reflections in transducer cables can create unequal delays.

The aggregate effect of these elements is an uncertainty in the measurement of the time difference for a single path of an externally mounted LEFM in the 8 nanosecond range. Typically chordal systems possess somewhat better performance—their error is rarely more than 5 nanoseconds—because the coherent noise tends to be lower in these systems.

Because the time difference error is denominated in seconds, the flow measurement error that results is in volumetric flow rate units, not per cent. In this regard it is not like the other uncertainties of the LEFM—hydraulic, acoustic and geometric—which produce uncertainties that are expressed as percent of reading.
Time difference errors are random biases; the error for one path is combined as the root sum square with the errors of other paths. As a percentage of rated flow in a typical external system the error due to time difference usually ranges from 0.2 to 0.3%. The error in chordal systems is smaller, both because the time difference error is smaller and because the time difference at rated flow is larger (the chordal path angle produces a larger axial velocity projection). At rated flow in a chordal system the error due to time difference is normally not greater than 0.15%.

The total time of flight measurement, less the non fluid delays, is important to the sound velocity determination and is also used in Caldon's proprietary algorithm that determines the applicable assumption for boundary conditions relative to the determination of acoustic path angle for externally mounted LEFMs. The factors discussed relative to the measurement of the time difference also affect the measurement of time itself, but since a typical time of flight is 350 to 600 microseconds, an error of a few nanoseconds does not count for much. The most significant uncertainty related to determining the time of flight in the fluid medium is the uncertainty in the non fluid delays. Caldon employs a proprietary procedure to determine non fluid delays in the cross path of external LEFMs and on all paths of chordal LEFMs. The uncertainty in the non fluid delay as measured with this procedure is in the 150 to 200 nanosecond range.

Non fluid delays in the diagonal paths of external systems are calculated using factory-measured properties and dimensions. The uncertainties of this process are greater than those of the field measurement; consequently, the uncertainty in the fluid time of flight for the diagonal path is greater—in the 300 nanosecond range. Again, the diagonal path time of flight is used in Caldon's algorithm for external systems in the determination of the path angle.

Uncertainties in Property Measurements

The principal uncertainties in the determination of temperature and density are:

(1) the geometric uncertainties in the fluid acoustic path length,

(2) the uncertainties in the time of flight measurement, including the uncertainties in the non fluid delay, and

(3) the uncertainties in the temperature/pressure/ sound velocity correlation and the temperature/pressure/density correlation.

These uncertainties typically aggregate to a temperature uncertainty of about 1.5 degrees and a density uncertainty of 0.1 to 0.15%.

On-Line Assessment of Uncertainties

LEFM systems are unique in that they provide means for checking and, if necessary, revising uncertainties in each of the categories that affect their performance. These means are employed as part of commissioning an instrument for flow measurement service, and periodically thereafter, to confirm that performance has not changed. A summary of on-line checks follows.

1. Field Verification of Hydraulics

If they are significant, changes in hydraulic profile can manifest themselves in changes in the velocities measured by the LEFM, relative to the bulk average axial velocity. In an external system such changes may be detected by (a) a change in the axial velocity computed for one measurement plane relative to that computed for the other, or (b) a change in the cross (transverse) velocity in either measurement plane relative to the axial velocity for that plane. In chordal system, the magnitude of the four individual path velocities relative to one another defines the hydraulic profile with a high degree of precision. This capability not only allows detection of hydraulic changes but also permits quantitative verification of profile factor testing in the field.

Validation capabilities notwithstanding, changes in the hydraulic profile at a specific measurement location in the field are not often encountered, excepting the gradual and well behaved flattening due to increasing fluid velocity and decreasing fluid viscosity (with increasing temperature). Caldon's experience does include a few instances of *bona fide* change. One example: A heater bypass line upstream of a Caldon chordal instrument was placed in service. The bypass-header geometry was such that, with the bypass in operation, a swirl was produced. The presence of the swirl was readily detected by the change in chordal velocities, relative to each other. The data also permitted an evaluation of the net change in axial profile. It was negligible; accordingly no increase in hydraulic uncertainty was required.

2. Field Verification of Acoustics

As discussed previously, acoustic uncertainties are negligible in chordal LEFMs. They do, however, play an important part in determining the uncertainty of an externally mounted LEFM flow measurement. Caldon employs proprietary procedures to verify the acoustics and, in particular, to confirm that the path angle accords with the assumptions of the algorithm. These procedures employ measurements made by the instrument itself and include:

- The relative magnitudes of received signals traveling in opposite directions on the same acoustic path

- The relative magnitudes of the times of flight of cross and diagonal paths in the same acoustic plane

- The relative magnitudes of axial separation distances of diagonal path transducers (a) calculated from the acoustics and (b) measured with calipers

3. Field Verification of Dimensions

In a typical external mount installation the key dimensions are of course measured in the field. Caldon's experience has shown that they do not change significantly. This accords with expectations; the technical literature would predict several mils of erosion or, alternately, several mils of corrosion product buildup in the straight pipe sections where LEFMs are installed (this is in contrast to the throats of flow nozzles where high flow velocities can promote the deposition of tens of mils of corrosion products). Nevertheless significant changes in the dimensions of the pipe in which an external LEFM is installed can be detected by trending the ratio of the times of flight of the cross paths of the two measurement planes (erosion/corrosion will rarely occur at exactly the same rate at different locations). The same technique is applied to chordal systems by trending the ratio of the short path times of flight and the ratio of the long path times of flight.

4. Field Verification of Time Measurements

Caldon employs the measures outlined below to confirm the validity of the LEFM time-of-flight measurements on-line. Except where otherwise noted the same measures are used for external and chordal systems.

- Automatic testing of transmitter, receiver, and multiplexing electronics is provided. The tests are designed to detect changes in receiver and multiplexer delays which could otherwise cause undetected biases in time and time difference measurements. The automatic test will also detect certain transducer failures which would otherwise cause biases due to imperfect transducer reciprocity.

- The automatic test system employs a solid state clock independent of the clock used to measure the transit times of the acoustic pulses. The test system is arranged so that the test clock checks the transit time clock. To ensure that the precision of the transit time clock fully complies with design requirements, an additional operator-initiated test is performed periodically, using a traceable time measuring standard.

- Random and coherent noise are periodically measured with the instrument on line, to ensure that potential biases from these sources remain within their design allowances.

- On external systems, the non fluid delays of the cross paths are measured periodically on line, using a proprietary Caldon procedure. These data, in combination with the ratio of the cross path time of flight to the diagonal path time of flight provide assurance that the total non fluid delays for these paths have not changed unacceptably.

- On chordal systems, the average non fluid delay can be computed from the long and short path times of flight. By trending the result of this calculation, any significant change in non fluid delay will be detected.

Summary of Uncertainties

Table 1 lists numerical values for the uncertainties of a typical 2 plane (two cross paths and two diagonal paths) externally mounted LEFM. For each category, random and systematic error elements are listed. It should be noted that most feedwater flow LEFM applications require two or more flow measurements; the flow in each of the two main feed headers is normally measured in boiling water reactors, while in pressurized water reactors the flow to each steam generator is often measured. Accordingly, the uncertainty in total feedwater flow, on a percentage of rated flow basis, is usually less than the bottom line of Table 1, since the multiple measurements will statistically reduce all of the random error components and some of the systematic components.

Table 2 presents numerical values for the uncertainties of a typical 4 plane chordal system. Again random and systematic uncertainties are segregated; again total flow measurement accuracy will be better than the figure quoted in the table if multiple loop measurements are made.

From the tables it is seen that an external system will generally achieve an overall accuracy in the 1% range; a chordal system is significantly better—usually in the 0.4% range.

Table 1

Typical Uncertainty Elements for a 2 Plane Externally Mounted LEFM

Category	Parameter	Classification	Sensitivity Coefficient Weighted Uncertainty, 1 plane	Sensitivity Coefficient Weighted Uncertainty, 2 planes
Hydraulics	Profile Factor	Systematic Random	0.7% nil	0.7% nil
Acoustics	Fluid Path Angle - wedge properties - pipe properties - transducer placement	Systematic Random	0.3% 0.3%	0.3% 0.2%
Geometry	Interior Diameter - outer diameter - pipewall thickness	Systematic Random	0.15% 0.2%	0.15% 0.15%
Time Measurements	Delta t	Systematic Random	0.01% 0.4%	0.01% 0.3%
	t, including non fluid delay	Systematic Random	0.1% 0.15%	0.1% 0.1%

Total Volumetric Flow Uncertainty (Root Sum Square of 2 plane figures): 0.88%

Density Uncertainty including Uncertainty in Temperature Determination: 0.15%

Total Mass Flow Uncertainty: 0.90%

Table 2

Typical Uncertainty Elements for a 4 Path Chordal LEFM

Category	Parameter	Classification	Sensitivity Coefficient Weighted Uncertainty, 4 Paths
Hydraulics	Profile Factor	Systematic	0.3%
		Random	nil
Acoustics	Imbedded in Profile Factor	Systematic	nil
		Random	nil
Geometry	Internal Diameter Path Angle Path spacing Path Length		Imbedded in Profile Factor
	Spool piece Alignment	Systematic	0.1%
		Random	nil
Time Measurements	Delta t	Systematic	0.01%
		Random	0.15%
	t, including non fluid delays	Systematic	0.1%
		Random	0.1%

Total Volumetric Flow Uncertainty (Root Sum Square): 0.38%

Density Uncertainty including Uncertainty in Temperature: 0.15%

Total Mass Flow Uncertainty: 0.41%

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