ULTRASONIC FLOW MONITORING OF SDS/ECI FEEDER CHANNELS

Jian Yang and Chunlei Zhao
IM&CS, Ontario Power Generation, Ontario, Canada

Abstract

The indicated flows of some of the instrumented-channels of the CANDU Shutdown System (SDS) and Emergency Cooling Injection (ECI) system can become degraded over time, which will result in reduction of operating margin, nuisance alarms and workarounds. As one mitigation strategy, using Ultrasonic Cross-Correlation Flow Meter (USCCFM) to monitor flow rate of SDS and ECI feeder channels has been implemented in Ontario Power Generation (OPG) Darlington Nuclear Generation Station (DNGS) for years. This paper introduces the methods in data analysis for USCCFM monitoring and the detection of abnormal measurement drift in the feeders' orifice flow meter. Results represented in the paper reveal that the long-term, reliable and stable flow measurement by USCCFM can be used as benchmark when the orifice based Flow Instrument Degradation (FID) occurs.

Keywords: SDS, ECI, USCCFM, FID.

1. Introduction

In CANDU primary side SDS and ECI feeder channels have minimum coolant flow requirement. The margin between the flow measured by orifice plate and the minimum required flow is critical for reactor normal operation. Unexpected margin decrease needs immediate actions to diagnose the cause, which can be either the real coolant flow loss inside feeders or incorrect flow measurement for many reasons, FID is one and has been found in CANDU reactors [1].

In order to ensure credibility of the indicated feeder channel flow measurement, a long term flow monitoring along with a reliable reference is necessary. One direct way is to use a second flow sensor as a reference. USCCFM has been installed and used in OPG DNGS for this purpose due to its characters of non-invasive clamp-on installation, and reliable and stable measurement.

USCCFM has high accuracy in theory; however, for OPG DNGS feeder ultrasonic flow measurement, less than 2% uncertainty is required. Several factors affect the accuracy of ultrasonic flow measurement, like flow profile correction factor and time delay. A quantitative estimation of the uncertainties from factors to meet the uncertainty requirement is stated herein. Finally the comparison between USCCFM and the orifice plate as a diagnose tool for abnormal drift of the orifice flow meters is also illustrated in the paper.

2. USCCFM for DNGS SDS/ECI Feeders

At DNGS, each of SDS1, SDS2 and ECI channel flow indication is provided by orifice flow meter installed in inlet feeder. Changes in orifice characteristics over the years of operation may result in reduced flow readings. Ultrasonic clamp-on transducers have been installed on some of the SDS1, SDS2 and ECI feeders to monitor the change in the output of the orifice meters as a diagnostic tool and reference if FID occurs. Also a long term monitoring of the orifice flow referenced by USCCFM can provide early indication of the orifice degradation mechanism. Ultrasonic flow measurements are carried out using the USCCFM Data Acquisition System (DACS), which can collect and store flow data in files for up to eight flow transmitters simultaneously. The data can then be selected for a more rigorous analysis.

2.1 USCCFM Flow Rate Calculation

USCCFM works on the principle defined by the Equation 1 and Figure 1 below [2].

$$W = C_f \cdot \rho \cdot \frac{L}{\Delta t} A \qquad (1)$$

ρ - water density; L - distance between ultrasonic probes; A - pipe cross-section area; C_f - Flow Profile Correction Factor, and Δt - Time Delay.

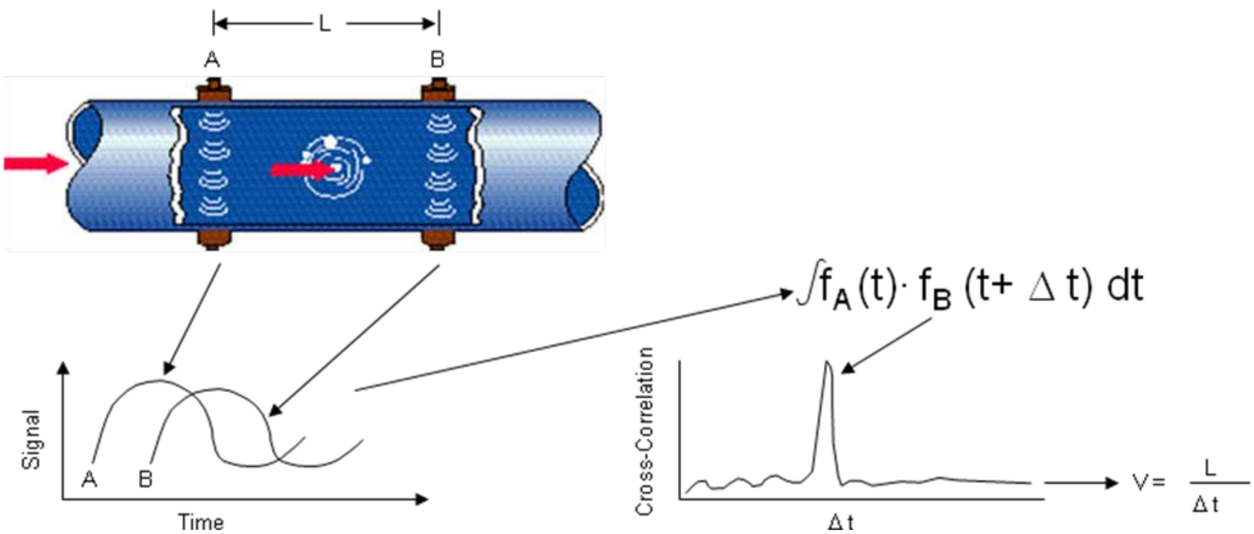

Figure 1: Time Delay Measurement Principle

Physically only Time Delay is measured by USCCFM in real-time. Flow rate is then calculated by Equation 1 inside DACS afterwards. As in Figure 1, Time delay is measured by the peak position on the curve of cross correlation of phase-demodulated signals between upstream and downstream.

Distance between upstream and downstream probes and pipe cross section area are measured after the probe assembly and during transducer installation, by caliper and ultrasonic wall thickness meter, and corrected by Young Modulus of Elasticity for Metals, based on the temperature of feeder. Water density is calculated with the temperature and pressure of the heavy water inside feeder.

Amongst the parameters in Equation 1, the most challenging one is the flow profile correction factor (FPCF). Illustrated as Figure 2, by curve-fitting after large amount of hydraulic lab tests for a fully developed flow in a long straight pipe, FPCF is a function of Reynolds Number only. However, in reality, FPCF value can be different i.e., off the curve if the condition is beyond the lab test conditions.

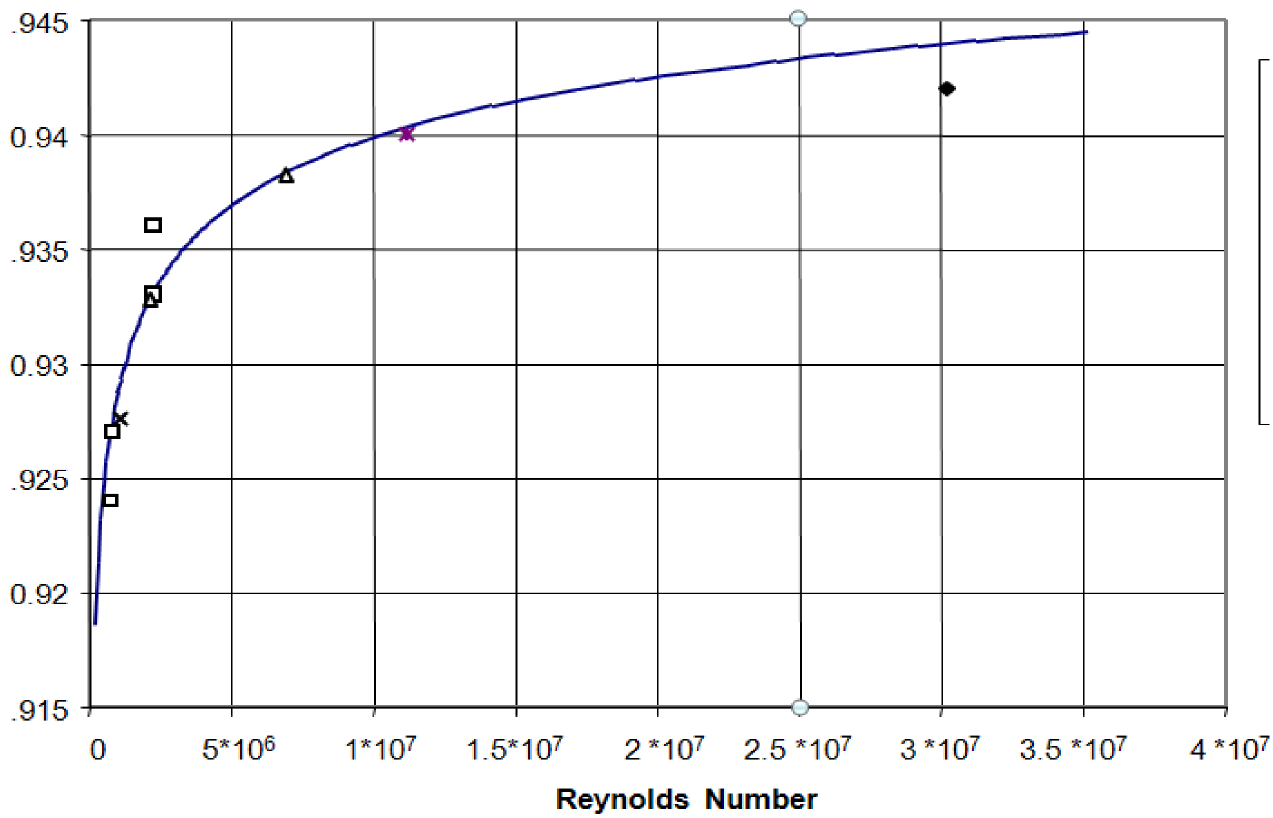

Figure 2: Experimental curve of FPCF vs. Reynolds Number

2.2 USCCFM Data Analysis

A predominated uncertainty contributor in the USCCFM flow rate calculation comes from FPCF (its uncertainty requirement is less than 1%). It is a challenge to get an accurate FPCF for each individual feeder. Another major uncertainty contributor comes from time delay measurement. To minimize the uncertainties from FPCF and time delay, a relative flow monitoring method is proposed.

The relative flow monitoring method is based on the assumption that for each individual feeder FPCF keeps constant in the full power operation. The method uses one measurement point as the beginning, and all other measurements afterwards are normalized by this beginning point. The relative flow change can be expressed as $\frac{W_{current}}{W_{beginning}} \times 100\%$. Because the feeder inlet temperature is well controlled within 1~2°C, and changes in ρ, L, and A can be ignored (very insignificant), so based on Equation 1 only time delay is remained over the operating period (as expressed in Equation 2):

$$\left(\frac{W_{current}}{W_{beginning}}\right) \times 100\% = \left(\frac{\Delta t_{beginning}}{\Delta t_{current}}\right) \times 100\% \qquad (2)$$

Equation 2 expressed that the relative flow change can be determined by time delay measurement only. This will make easier for a long term flow monitoring. The data process of the time delay measurements is performed off-line in two steps and will be discussed in the next two sections.

2.2.1 Filtering of Time Delay Data

The purpose of this step is to remove data points, which are outside the 3-Sigma Interval around the mean value. During 100% full power of CANDU reactor, feeder flow stays in stable status, noises from mechanical and electrical power sources may create some offset points on the measurement. These offset data do not represent true flow and need to be filtered out. For example, Figure 3 refers to data without filtering, and Figure 4 is the result after filtering.

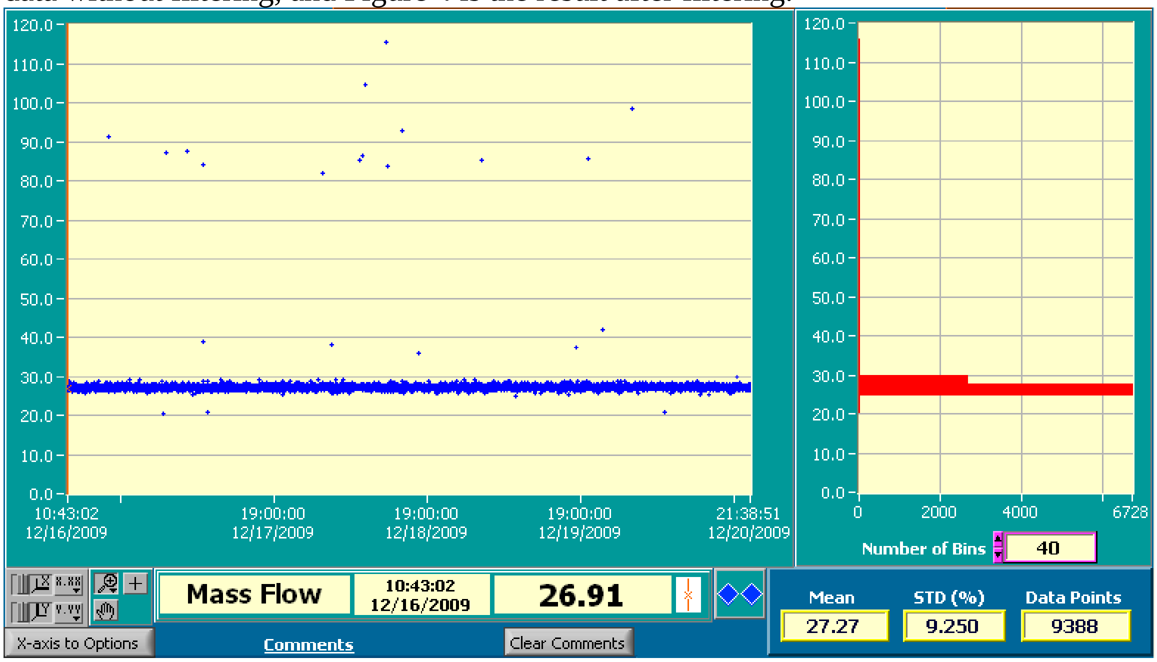

Figure 3: USCCFM measurements without filtering

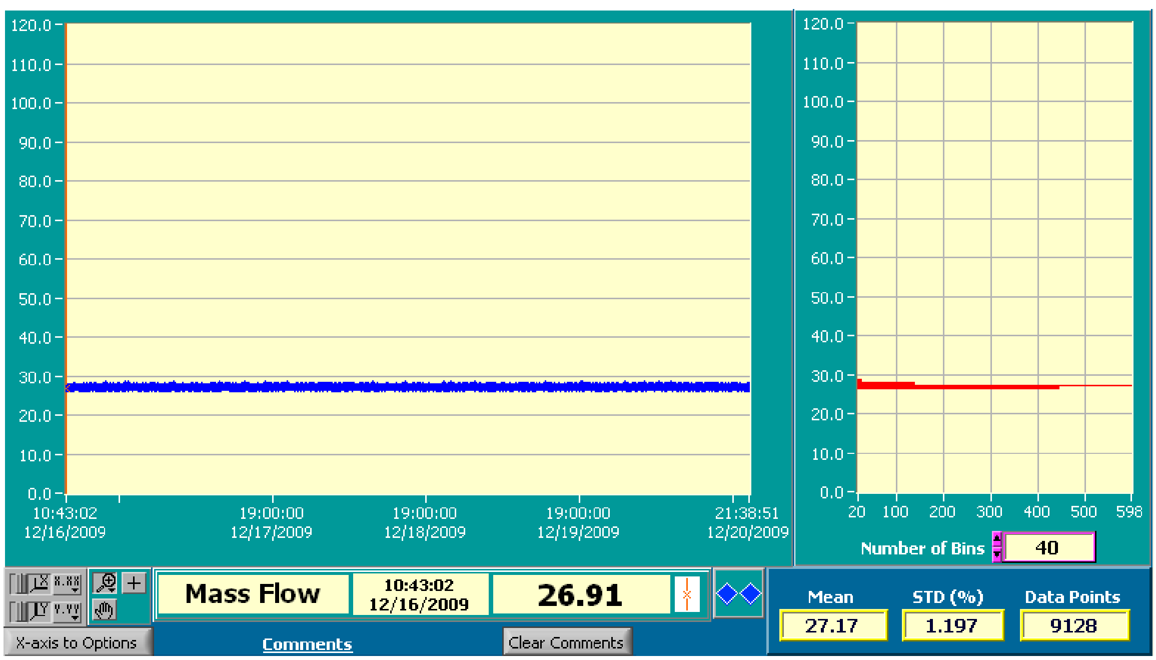

Figure 4: USCCFM measurements after filtering

In the example, after filtering (260 points among total 9388 points have been filtered), the mean value is changed by 0.4% only, while the standard deviation is decreased by eight times.

2.2.2 Average of Time Delay Data for Monitoring

Uncertainty for time delay measurement is calculated by Equation 3[3].

$$\sigma = \frac{C_{95\%}(N)}{\sqrt{N}}\left[\frac{1}{(N-1)}\sum_{i=1}^{N}(TD_i - \overline{TD})^2\right]^{\frac{1}{2}} \qquad (3)$$

N -Point number of measurements, $C_{95\%}(N)$ -Factor for 95% intervals, $\overline{TD}$ -Mean of time delay measurements.

For USCCFM data collected on eight channels, after filtering, at least one thousand points can be collected in 24 hours (i.e. in average about 50 points per hour). A 95% interval statistical uncertainty for daily average is 0.07% for the example above (i.e., hourly average at 0.33%). Although daily and hourly averages all meet the 2% uncertainty requirement for ultrasonic feeder flow measurement, daily average is used for the long term monitoring.

3. Comparison of Flow Monitoring by Orifice Flow Meter and USCCFM

The relative flow monitoring applies to both USCCFM and orifice flow meter measurements to provide a picture of flow instrumentation performance. Two kinds of trends can be produced:

1. Relative flow historical trends of daily average of orifice and USCCFM measurements.
2. Subtraction of two historical trends above.

In trend 1 daily averages of both ultrasonic and orifice flow meters started from the same beginning point as a baseline are presented in relative percentage, whereas trend 2 gives the difference between flow measurements by two technologies. Two examples of SDS feeder channels with the similar design and function are given in Figure 5a (the one having some degradation issues) and Figure 5b (the one without degradation).

From Figure 5a it can be seen that “micro-flow trends” i.e., daily changes including outage, refuel or any valve adjustment, match reasonably well between two measurements, but “macro-flow trends” i.e., based on the long term trend (e.g., monthly changes) are different. The flow measured by orifice flow meter shows its abnormality as “down ->up-> down” in a range of -4.5%, while USCCFM flow trend demonstrates a relatively stable state. In the subtraction of the two trends, the difference of two measurements has been illustrated in the graph at the right side. Figure 5b shows another example of a channel without any sign of flow degradation i.e., a good match between USCCFM and orifice flow meter.

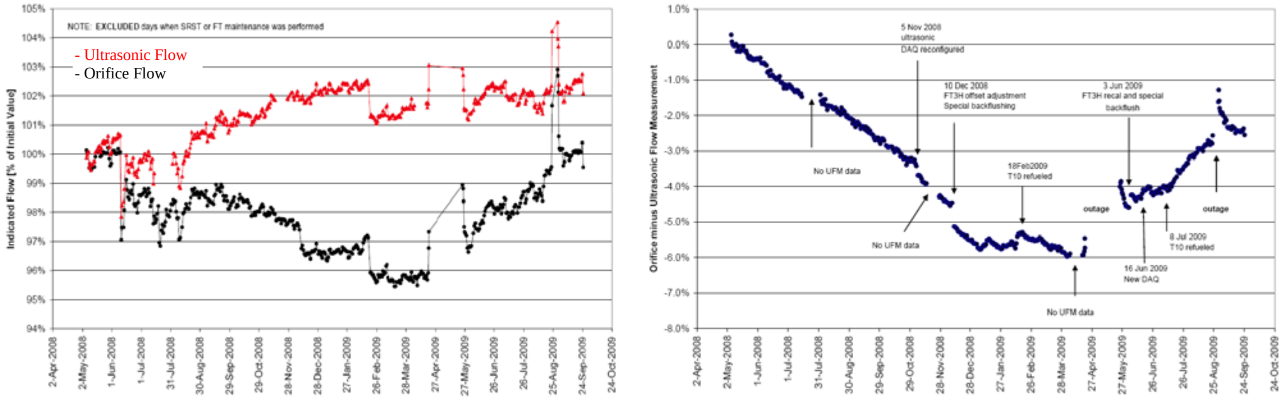

Figure 5a: Example 1 - Orifice flow meter performance monitoring by USCCFM

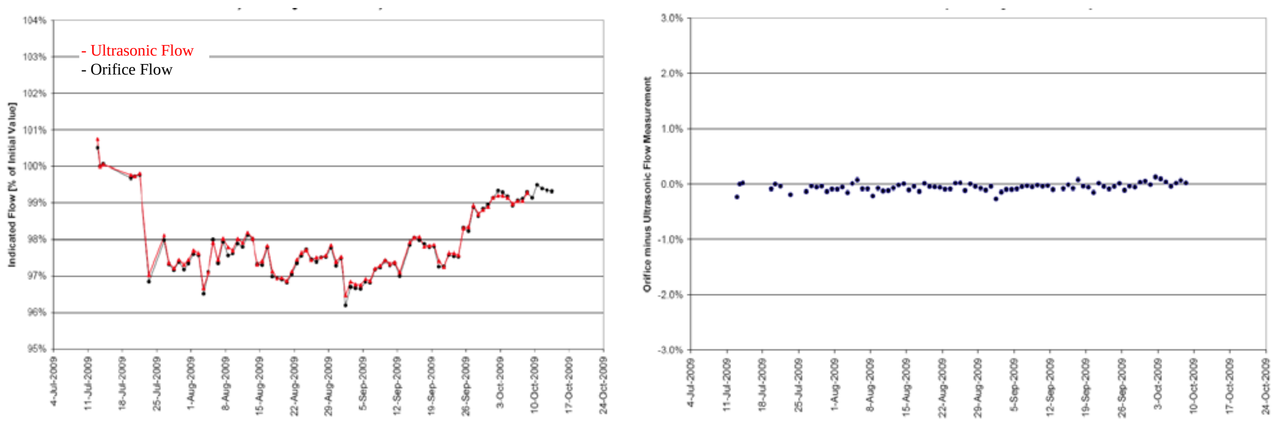

Figure 5b: Example 2- Orifice flow meter performance monitoring by USCCFM

4. Conclusion

The USCCFM has been installed and used in OPG DNGS to monitor feeder inlet channel flows for some SDS1, SDS2 and ECI channels. The USCCFM data collected demonstrate that there has been no significant reduction of the actual coolant flow inside safety feeder channels during steady-state reactor operations, which provide a solid reference for continuous plant operation in a safe mode. Using relative monitoring method it clearly reflects any abnormal performance of the monitored orifice flow meter. In addition, the long term monitoring of the plant orifice-based flow with USCCFM can be used to predict potential alarms or reactor trip, help to understand of the orifice degradation mechanism, and provide early warning for plant to take actions ahead of the critical time.

5. References

[1] Won Young Yun, "An Approach to Reduce Measurement Uncertainty of Feeder Line Flow-rate by Cross Calibration with Ultrasonic Flow Meter (UFM) for Korean CANDU Plant". 2007 International Congress on Advances in Nuclear Power Plants, France, May 13-18, 2007.

[2] M.S.Beck and A. Plaskowski, "Cross Correlation Flow Meters Their Design and Application". Published under Adam Hilger imprinted by IOP Publishing Ltd (ISBN 0-85274-532-X).

[3] ASME PTC 19.1-2005, "Test Uncertainty" Copyright©2006, The American Society of Mechanical Engineers.