LTR-NRC-06-30 NP-Attachment

Presentation Materials Used at April 28, 2006 CROSSFLOW Meeting (Non-Proprietary)

April 28, 2006

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CROSSFLOW System
Performance Monitoring

Overview

- Introduction
- Review of system requirements
- System setup and software components
- Main parts of Algorithm & Communication Layer (ACL)
- Venturi Correction factor "Cf" calculations
- Safeguards and alarms
- Communication and alarms
- Screenshots
- Configuration parameters (*startup.ini*)
- System Monitoring Limit Setting
- Plant Process Computer Alarming/Status Monitoring Example
- Examples of CROSSFLOW/Plant Process Computer System Alarms
- Venturi Correction Factor Historical Data
- CROSSFLOW User's Guidelines

Introduction

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Introduction

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Review of System Requirements

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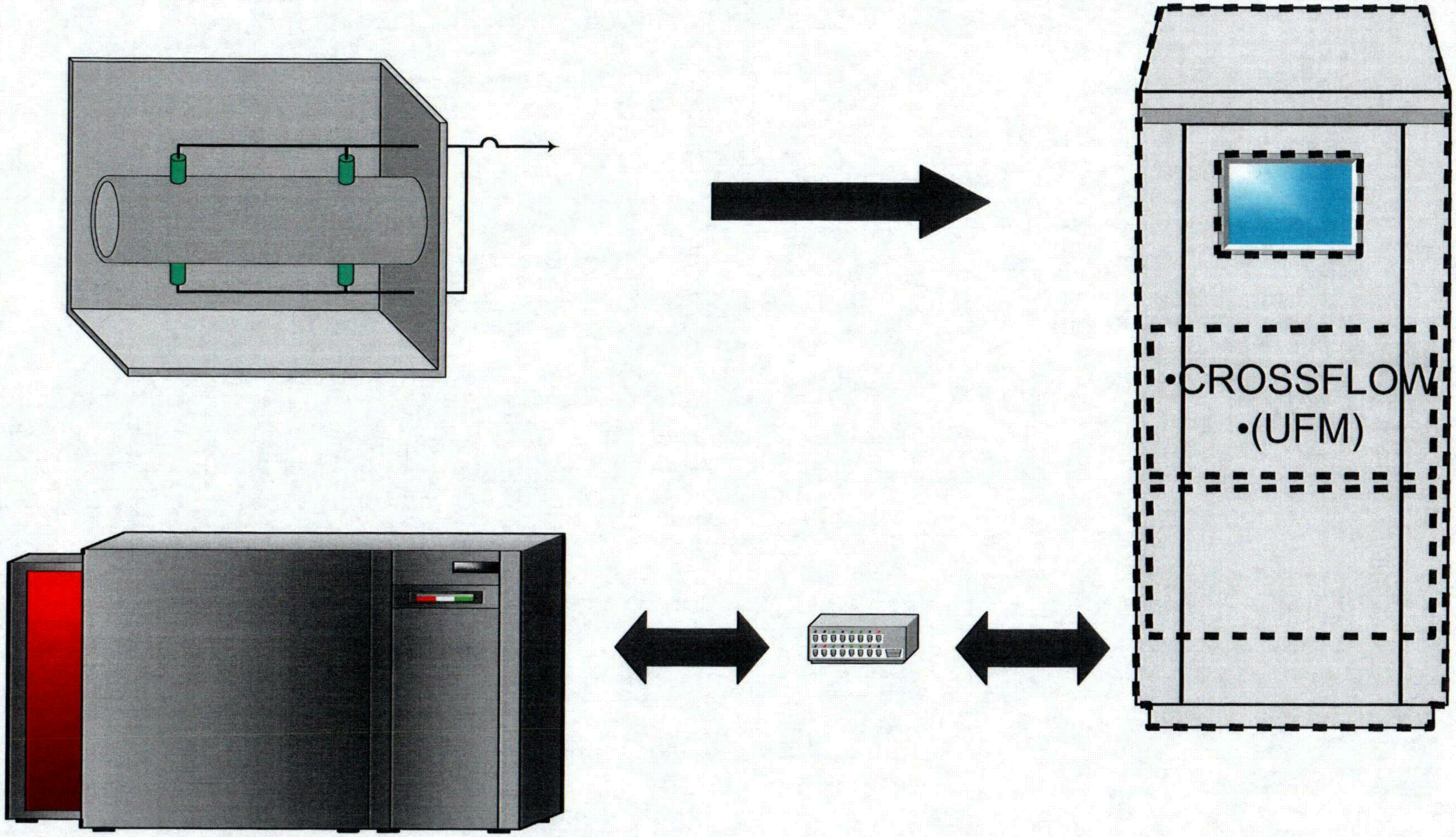
AMAG System Setup



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Overview of Software Components

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ACL Modules

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Main Parts of Algorithm (OVCC)

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Instantaneous Correction Factor (Cfi)

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Quality of Cfi

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Limit Filter for Cfi

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Correction Factor, Cf (Long Buffer)

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Quality of Cf (Long Buffer)

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Uncertainty Check (Long & Short Buffer)

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Limit Check on Cf

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Correction Factor, Cfs (Short Buffer)

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Quality of Cfs (Short Buffer)

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Sudden Change in Cf

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CFRnew and CFR

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OVCC Algorithm Alarms

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ComPro's Functions

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ComPro Alarms

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Maintenance Screens

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CROSSFLOW Measurement Screen

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OVCC Maintenance Screen

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Startup.ini Setting File

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Startup.ini Setting File

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Startup.ini Setting File

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Startup.ini Setting File

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Startup.ini Setting File

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Startup.ini Setting File

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Limit Settings in Algorithm & Communication Layer

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Limit Settings in Algorithm & Communication Layer (cont..)

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CROSSFLOW & Plant flow instrumentations flow indications

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Simulated Cfi & Cf for Buffer Length of 100

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Simulated Cfi & Cf for Buffer Length of 200

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Cf Variation within Upper & Lower Cf Limit Alarm Settings

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CROSSFLOW & Venturi Flow Trends

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Cfi & Cf Trends

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Setting Sudden Change Limit

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Plant Process Computer Alarming/Status Monitoring Example

Primary & Backup Plant Computer Status for CROSSFLOW System

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Primary & Backup Plant Computer Status for CROSSFLOW System

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Primary & Backup Plant Computer Status for CROSSFLOW System

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Primary & Backup Plant Computer Status for CROSSFLOW System

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Primary & Backup Plant Computer Status for CROSSFLOW System

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Plant Computer Status for CROSSFLOW System

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Plant Computer Status for CROSSFLOW System

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Plant Computer Status for CROSSFLOW System

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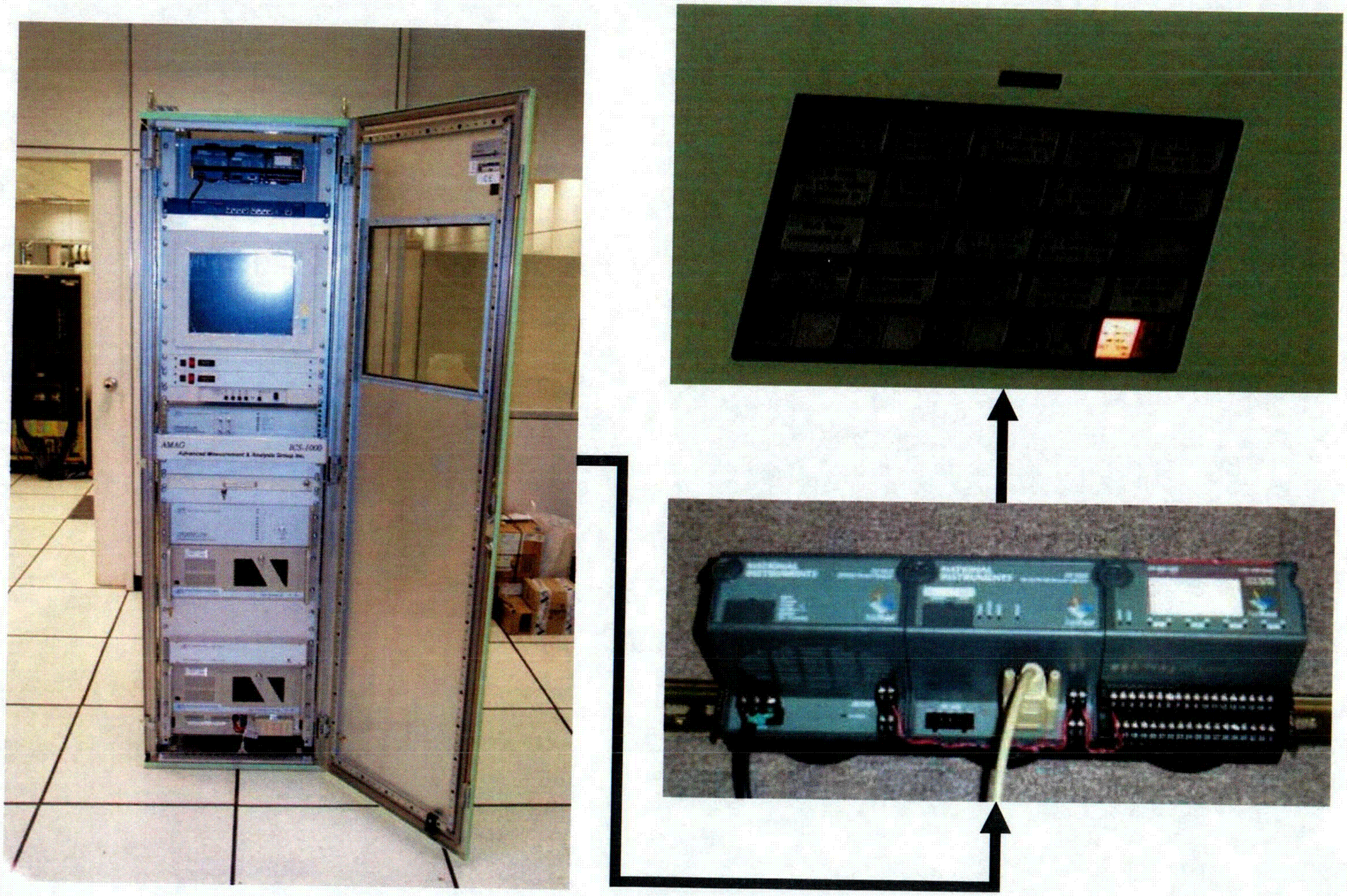
Plant Control Room Alarming Annunciations



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Examples of CROSSFLOW/Plant Process Computer System Alarms

Plant Flow Instrumentation Readings

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Sample Plant Flow Instrumentation

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Plant Flow Instrumentation & CROSSFLOW Measurement

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Plant Flow Instrumentation & CROSSFLOW Measurement

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Alarm due to Existence Of Outliers

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Venturi Correction Factor Trend

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Cf Out of Limit / Venturi Fouling Example

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Venturi Correction Factor Trend

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Cross-correlation Ultrasonic Flow Measurement System Theory

April 28, 2006

Agenda

- Introduction
- CROSSFLOW Overview
- Analytical Modeling of Cross-correlation Ultrasonic Flow Measurement
- CROSSFLOW System Performance Monitoring
- Next Steps
- Wrapup

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CROSSFLOW Theory (4/28/2006)

- **The purpose of this meeting is to answer the first question.**
  - Westinghouse/AMAG have been systematically investigating and demonstrating the behavior of the CROSSFLOW meter.
  - Penn State ARL have been working with us to perform testing and analysis of UFM technology
  - CROSSFLOW operation can be explained by cross-correlation analytical model
- **The diagnostics and monitoring of the CROSSFLOW system in the plant applications will also be discussed.**

CROSSFLOW Overview

W.L. Brown

P.D. Lysak

Overall approach to address CROSSFLOW issues

- In response to CROSSFLOW licensing and plant performance issues and NRC questions, it was recognized in early 2004 that a more comprehensive, systematic, in-depth approach was needed to address the complex nature of CROSSFLOW issues.
- It was decided that a robust approach similar to that supported by US NRC and successfully applied by Westinghouse to address licensing issues related to AP600 and AP1000 plants and LOCA codes such as Best Estimate WCOBRA/TRAC would be applied to CROSSFLOW.

Overall approach to address CROSSFLOW issues

- The approach involves applying the Phenomena Identification and Ranking Table (PIRT)/Scaling process in conjunction with Mathematical Model Development to design and Scaled Testing to accomplish the following primary goals:
  - **Capture important phenomena (PIRT) at an in-depth level to assess CROSSFLOW technology application in ideal as well as non-ideal hydraulic-acoustic conditions.**
  - **Develop a CROSSFLOW Mathematical Model to support basic theory and principle of CROSSFLOW operation including turbulence.**
  - **Obtain data to support CROSSFLOW Mathematical Model validation and method of extrapolation of scaled CROSSFLOW test data to full scale plant conditions.**
  - **Provide insight into previous tests conducted at Alden, NRC, and Wyle test facilities in support of addressing NRC questions.**
- To provide some level of independence, particularly in the area of CROSSFLOW noise related issues, Westinghouse and AMAG partnered with acoustic and turbulence experts from the Applied Research Laboratory (ARL) of Penn State University in support of this effort.

CROSSFLOW PIRTs

CROSSFLOW PIRTs

- For purposes of PIRT, Testing, and Mathematical Model development, CROSSFLOW issues were grouped into two major categories:

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- Phenomena Identification and Ranking Tables established for major phenomena affecting CROSSFLOW were developed in conjunction with external experts from ARL/PSU.

PIRT for Noise Issues

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PIRT for Hydraulic Issues

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CROSSFLOW Mathematical Model

Background to CROSSFLOW Mathematical Model

Basic Requirements to Measure Feed Water Mass Flow and Calibrate Flow Measurement Device such as CROSSFLOW

- To obtain a measurement of total feed water mass flow for given fluid density and pipe area, measurement of bulk velocity (average axial velocity in feed water pipe) of feed water flow is required.
- In principle, any flow measurement device that is to be used must be capable of measuring some physical parameter(s) of the feed water flow that can be related (via calibration) to the bulk velocity of the feed water flow.
  - Devices such as venturi, orifice, or nozzle obtain differential pressure measurement from which bulk velocity can be inferred.
  - Device such as CROSSFLOW (cross-correlation ultrasonic flow meter) obtains convection velocity of turbulent structures which can be related to bulk velocity.
- To allow, in principle, calibration of the flow measurement device to the feed water bulk velocity, it is further required that the physical parameter(s) measured by the flow measurement device respond to changes in the bulk velocity of the feed water flow.
- For CROSSFLOW, this means that, the convection velocity of turbulent structures measured must, in principle, be capable of responding to changes in bulk velocity of feed water flow.

Summary of Basic Requirements for CROSSFLOW

- In principle, then CROSSFLOW must meet the following requirements as a flow measurement device for feed water flow:
  - **Turbulent structures must exist in pipe flow.**
  - **CROSSFLOW must be able to detect turbulent structures and obtain associated convection velocity.**
  - **Motion of turbulent structures (convection velocity) must respond to changes in bulk velocity.**
  - **Convection velocity must be related to bulk velocity.**

Existence, Visualization, Measurement, and Tracking of Turbulent Structures

Existence and Visualization of Turbulent Structures

- Existence and visualization of turbulent structures in high Reynolds number flow was successfully addressed by experimenters such as Brown and Roshko (1974).
  - Brown and Roshko, "On Density Effects and Large Structures in Turbulent Mixing Layers", 1974, Journal Fluid Mechanics.
- Much work has since been performed in visualization of high Reynolds number turbulent flow associated with free shear layers, jets , wall boundary layers, and pipes. A sample of the work is included in:
  - Thurow, B; Lampert, W; Samimy, M (2000) "Mhz rate imaging of large scaled structures within a high speed axisymmetric jet", AIAA paper 2000-0659.
  - Papamoschou, D; Bunyajitradulya A (1997) "Evaluation of large eddies in compressible shear layers", Phys. Fluids 9:756-765.
- Visualization of turbulent structures is nicely captured in references such as the following:
  - Van Dyke, M "An Album of Fluid Motion", 1982; The Parabolic Press.
  - Samimy, M "A Gallery of Fluid Motion", 2003, Cambridge University Press.

Measurement and Tracking of Turbulent Structures

- Turbulent structures can be measured and tracked using two-point flow visualization techniques or using two-point correlation measurements with hot wire anemometry or laser doppler velocimetry (LDV).
  - Smith, KM; Dutton, JC (1999) "A procedure for turbulent convection velocity measurements using time correlated images", Exp. Fluids 27:244-250.

Two-point Correlation and Comparison with Velocity Covariance in Reynolds Stress

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Turbulence in Relation to Bulk Motion

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Larger Scales of Turbulence Strongly Interact with Mean Flow

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ASME HISTORIC LANDMARK GARFIELD THOMAS WATER TUNNEL

ANALYTICAL MODELING OF ULTRASONIC CROSS-CORRELATION FLOW METER

Peter D. Lysak
David M. Jenkins
Dean E. Capone

April 28, 2006

AMAG

Westinghouse

Overview

- Description of analytical model
  - Basic explanation of how flow meter works
  - Stochastic model relating demodulated signal and turbulent flow
  - Validation of turbulence correlation modeling assumptions

- Model validation from 2005 Water Tunnel experiment

Principle of Operation

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Cross-Correlation

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Phase Modulation

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Formulation of Stochastic Model

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Terminology

- Bulk velocity – volumetric flow rate divided by pipe area
- Mean velocity – the time-averaged velocity at a point
  - Only concerned with axial component
- RMS velocity – root mean square of fluctuating velocity at a point
  - In general there are three components
  - In isotropic turbulence, all three components have the same value
- Turbulent length scale – integral scale of turbulence spatial correlation function
  - In general there are numerous components
  - In isotropic turbulence, there are two values and only one is independent (longitudinal integral length scale)
- Convection velocity – the apparent velocity obtained from the time delay in the cross-correlation function

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Cross-Correlation of Demodulated Signal

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Turbulence Spatial Correlation Model

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Turbulence Space-Time Correlation Model

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Example – Two Point Correlations in a Pipe Flow

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Frequency-Domain Implementation

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Convection Velocity

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Water Tunnel Experiment

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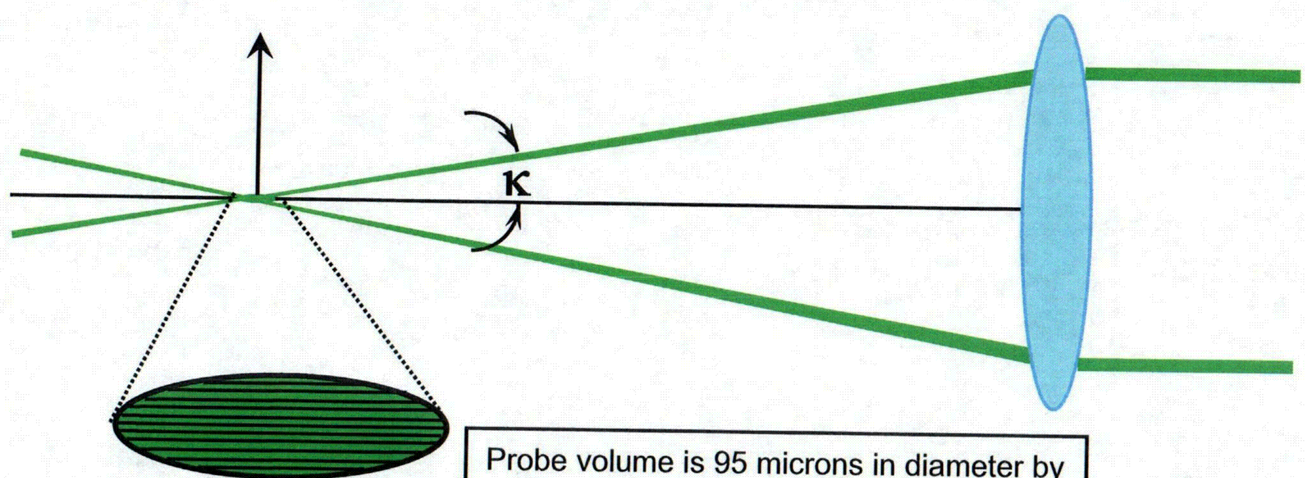
Laser Doppler Velocimetry

- Light scattered by small particles is used to measure fluid velocity
  - Small particles follow the flow with good fidelity
- Two parallel laser beams are focused to a common point
  - Parallel and uniformly spaced interference fringes are formed
- Particles moving through the fringe pattern scatter light
  - The scattered light intensity is modulated at a frequency proportional to velocity perpendicular to the interference fringes
  - This modulation frequency is measured to determine the velocity



Probe volume is 95 microns in diameter by 1.4 mm in length

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Example – Water Tunnel LDV Spectra

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Example – Demodulated Signal

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Additional Validation of Modulation Effect

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Use of CFD with Model

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CFD Example – Turbulent Boundary Layer

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Piping CFD Simulations

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Model Results – Fully Developed Flow

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Model Comparison to Experimental Data

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Conclusions

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