

ENCLOSURE 2

MFN 06-160

TEPCO/GE UdFlow System for the Measurement of Nuclear Feedwater Flow Rate by Ultrasonic Doppler Technology

Non-Proprietary Version

IMPORTANT NOTICE

This is a non-proprietary version of Enclosure 1 to MFN 06-160, which has the proprietary information removed. Portions of the enclosure that have been removed are indicated by an open and closed bracket as shown here [[]].

TEPCO/GE UdFlow System for the Measurement of Nuclear Feedwater Flow Rate by Ultrasonic Doppler Technology

June 2, 2006

**U.S. Nuclear Regulatory Commission Headquarters
Rockville, Maryland**



Tokyo Electric Power Company, Inc.

Research & Development Center

Thermal Hydraulics & Fluid Structure Dynamics Research Group



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Meeting Objectives

- **Introduce NRC to the TEPCO/GE UdFlow System**
- **Present the reasons for the development of the System**
- **Describe the System hardware**
- **Develop the science behind the System**
- **Discuss the System accuracy Qualification Test results**
- **Detail the future activities and test plans**
- **Present LTR structure and content**
- **Solicit guidance from NRC**



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Introduction: The TEPCO / GE UdFlow System

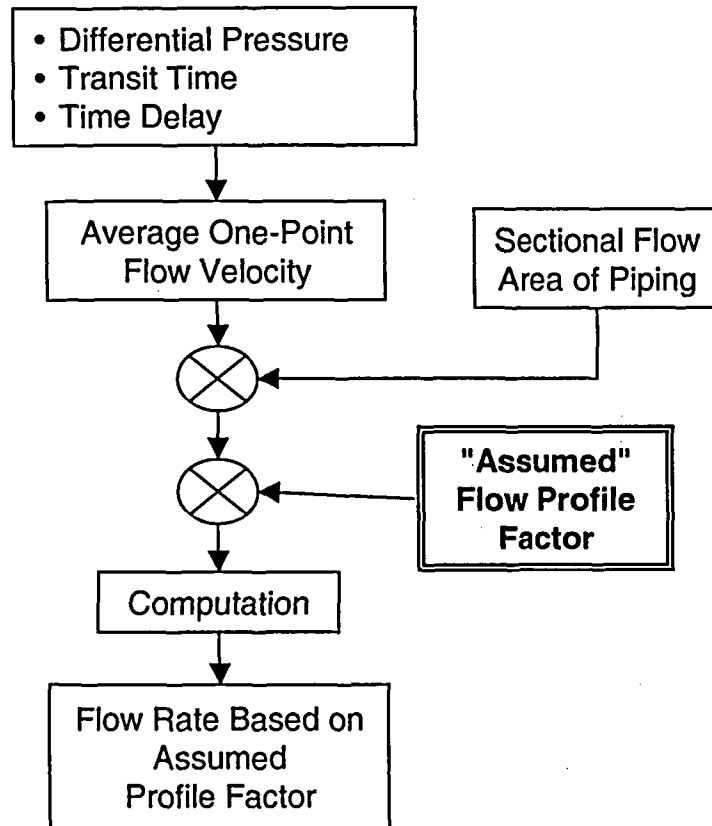
- Feedwater pipe inner surfaces (piping and venturis) become rougher over time, which causes increased inaccuracy in the flow rate measurement.
- Existing ultrasonic flow meters assume a velocity flow profile to calculate feedwater flow rate. The assumed flow profile changes with pipe age.
- TEPCO Research & Development (R&D) has developed an Ultrasonic flow meter [[]].
- TEPCO R&D is collaborating with GE to evaluate, design, test, license, and manufacture this flow meter (the “TEPCO/GE UdFlow System”) for application to BWRs and PWRs.
- [[]]
- GE will be submitting a Licensing Topical Report (LTR) for NRC approval to apply the TEPCO/GE UdFlow System to Measurement Uncertainty Recapture (MUR) power uprates.



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Existing Flow Meters

Flow Meter Algorithm



**Flow Rate Based on
"Assumed" Flow Profile**

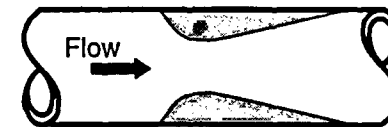


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Existing Flow Meters

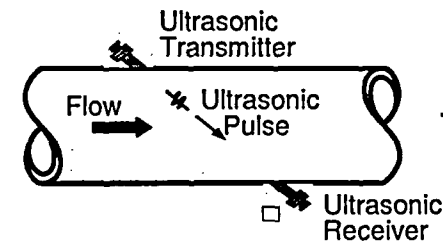
Parameter

- Venturi



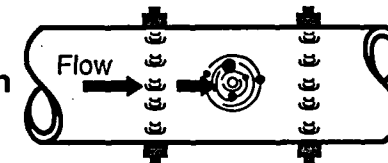
Differential Pressure

- Time of Flight



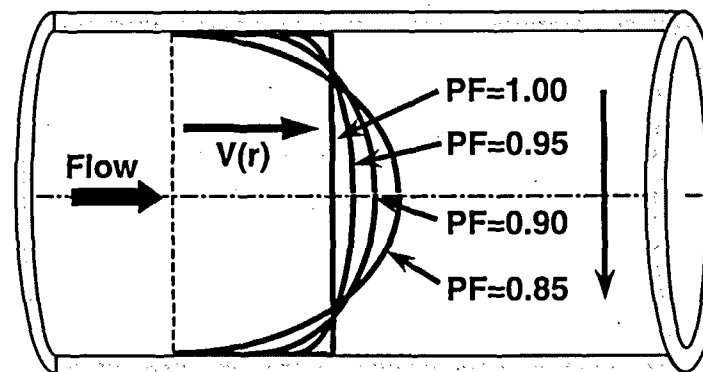
Transit Time

- Cross Correlation



Time Delay

- Flow Profile Factors (PF) are determined by velocity profiles.
- Velocity profile is a function of Reynolds Number and pipe inner surface roughness.



Plant Ages

Inner Surface
Becomes
Rougher

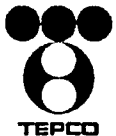
PF Changes
(Lower)

Feedwater Flow Nozzle Inner Surface Degradation

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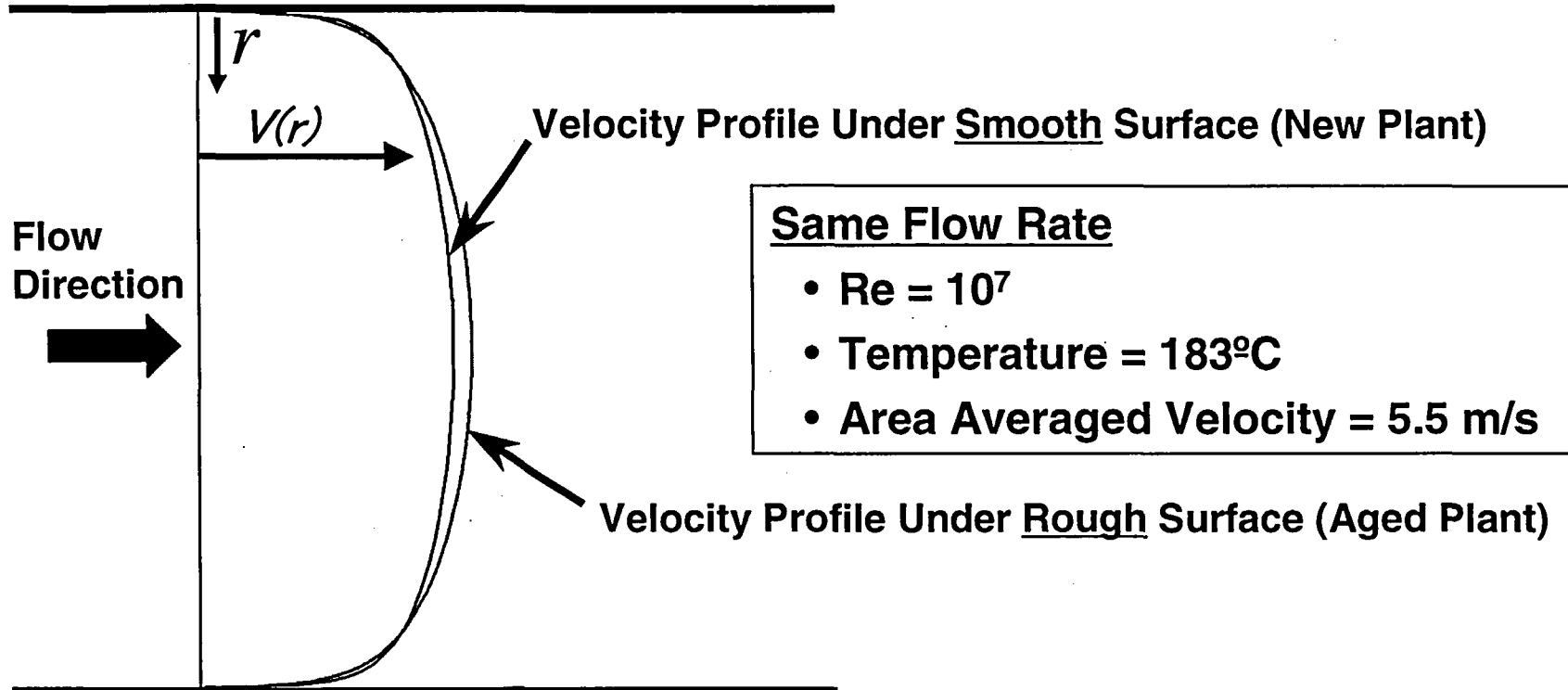
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- Changes in inner surface roughness cause changes in flow velocity profile, which will affect flow meter accuracy (for flow meters that use a flow profile factor)



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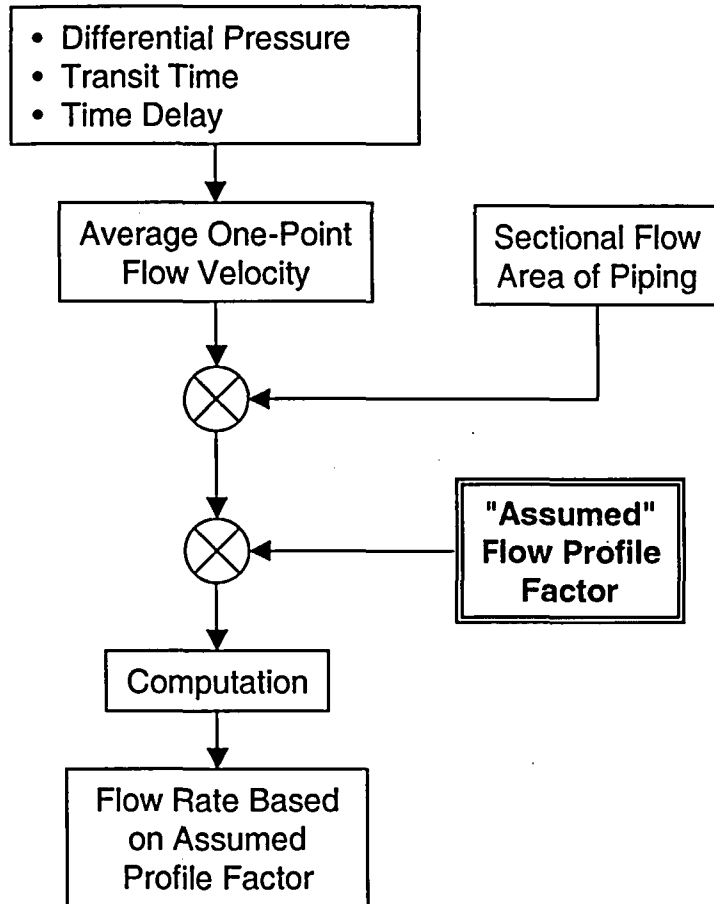
Profile Factor Effect on Existing Flow Meters



- Different velocity profiles (New Plant and Aged Plant) for the same flow rate, require different profile factors for accurate flow meter measurement
- Impossible to simulate actual (changing) plant conditions during flow meter factory testing of existing flow meters
 - Surface roughness (corrosion)
 - Reynolds Number
 - Pipe configurations (flow disturbance, biased flow)

Flow Meter Methodology Comparison

Existing Methodology



**Flow Rate Based on
"Assumed" Flow Profile**



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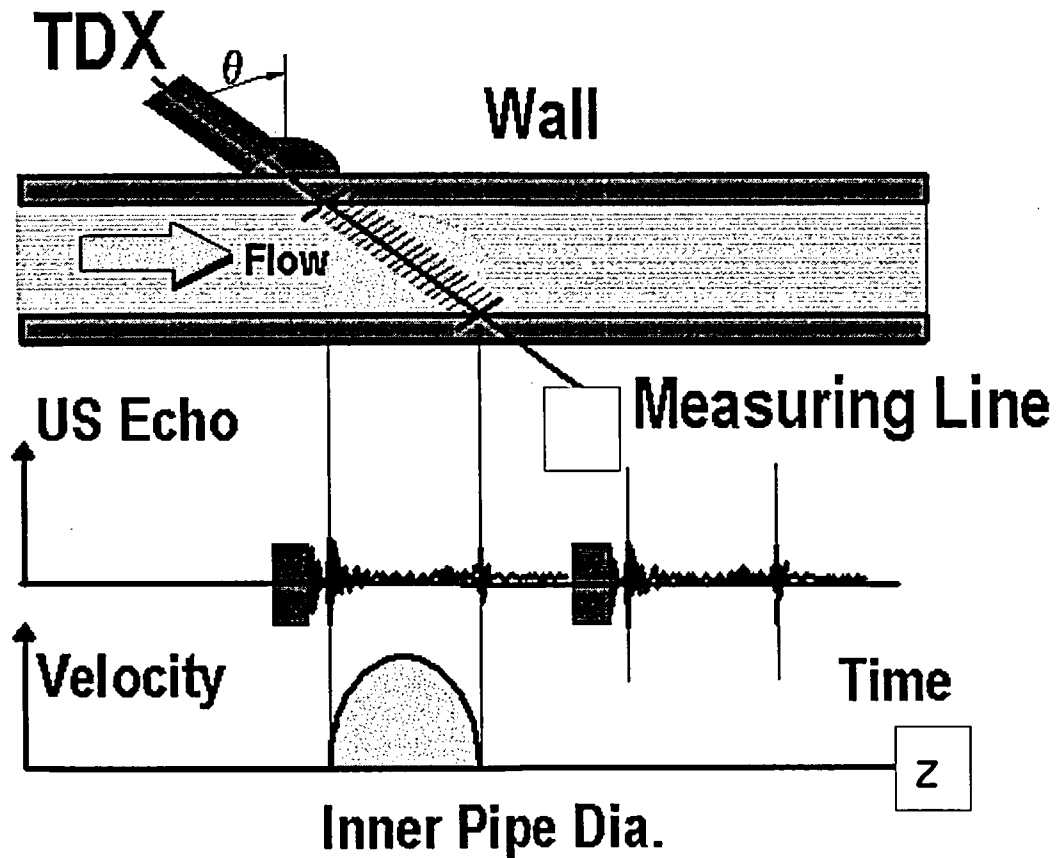
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TEPCO/GE UdFlow System Science



- Pulsed Ultrasonic Echography
- Instantaneous Doppler Shift Frequency

$$z = cT / 2$$

$$v = cf_D / 2f_0$$

z - Distance Traveled

v - Flow Velocity

c - Sound Velocity

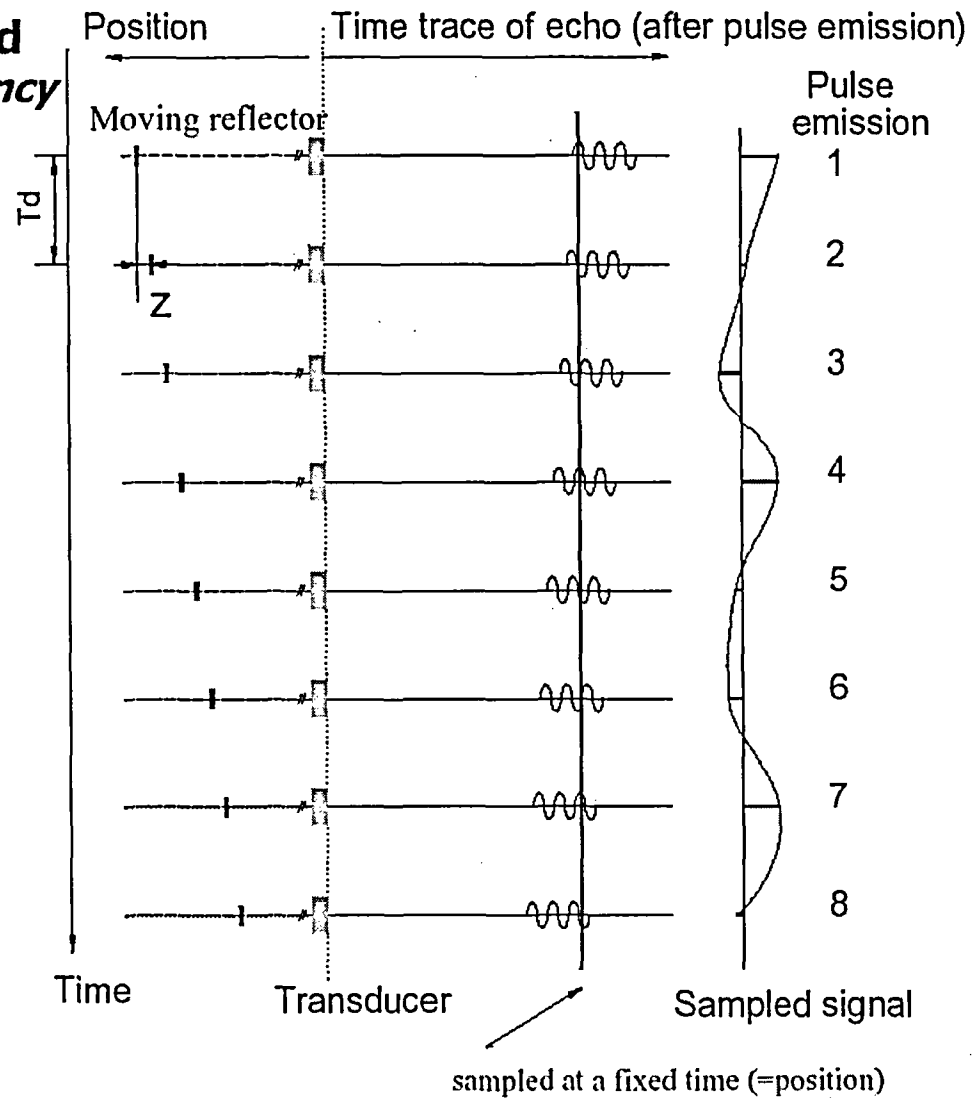
f_D - Doppler Frequency

T - Time Between
Pulses

f_0 - Basic Frequency

TEPCO/GE UdFlow System Science

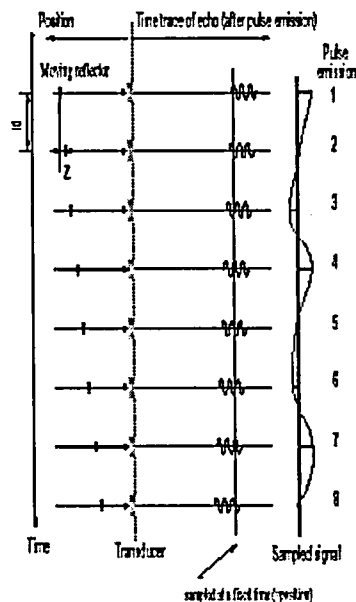
Ultrasonic Doppler Method *Detection of Doppler frequency*



TEPCO/GE UdFlow System Science

Ultrasonic Doppler Method

Detection of Doppler frequency



$$\phi = f_0 T_d$$

$$d\phi/dt = f_0 dT_d/dt$$

$$T_d = 2z/c$$

$$dT_d/dt = (2/c) dz/dt = 2v/c$$

$$d\phi/dt = 2vf_0/c = f_D$$

TEPCO/GE UdFlow System Science

Ultrasonic Doppler Method

Measurement limitation

- From Nyquist sampling theorem

$$f_{D \max} < f_{\text{prf}}/2 \Rightarrow V_{\max} < c f_{\text{prf}}/4f_0$$

- Maximum depth

$$P_{\max} = c/2f_{\text{prf}}$$

- Measurement constraint

$$V_{\max} P_{\max} < c^2/8f_0$$

TEPCO/GE UdFlow System Science

Ultrasonic Doppler Method

Characteristics and specifications

- Spatial resolution
$$dz = cT_d / 2$$
- Velocity resolution
$$dv = c f_D / 2 f_o$$
- Maximum depth
$$P_{\max} = c/(2f_{\text{prf}})$$
- Maximum velocity
$$V_{\max} = cf_{\text{prf}}/(4f_0)$$



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Qualification Tests – NIST, Nmi, Nmi - J

- “Proof-of-Principle” testing was conducted at:
 - NIST – U.S. National Institute of Standards and Technology
 - Nmi – Nederlands Meetinstituut
 - Nmi-J – Japan National Institute of Advanced Industrial Science and Technology

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Qualification Tests - CENAM

- **“Statistically significant” testing was conducted at CENAM, Centro Nacional de Metrología, in January 2006.**
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Qualification Tests - Specifics

Facility	Liquid	Flow Condition	Pressure	Reynolds Number	Temperature
NIST	Water	Stable, Well-controlled	Atmospheric (pump head)	4.0E5 to 2.7E6	Ambient
Nmi-J	Water	Stable, Well-controlled	Atmospheric (pump head)	1.0E6 to 2.0E6	Ambient
Nmi	Water	Stable, Well-controlled	Atmospheric (pump head)	8.5E4 to 1.8E5	Ambient
[[]]

Flow Profile Measurement – Nuclear FW Conditions

Test Specification

Thermal-Hydraulic Conditions Similar to Actual BWR Plant

Type of Liquid: Water

Flow Condition: Stable, Controlled

Pressure: 7.6 MPa

Reynolds Number: 1.6×10^7

Temperature: 216 °C

Flow Rate: 3200 t/h

Feedwater Piping

Inner Diameter: 500 mm

Wall Thickness: 28 mm

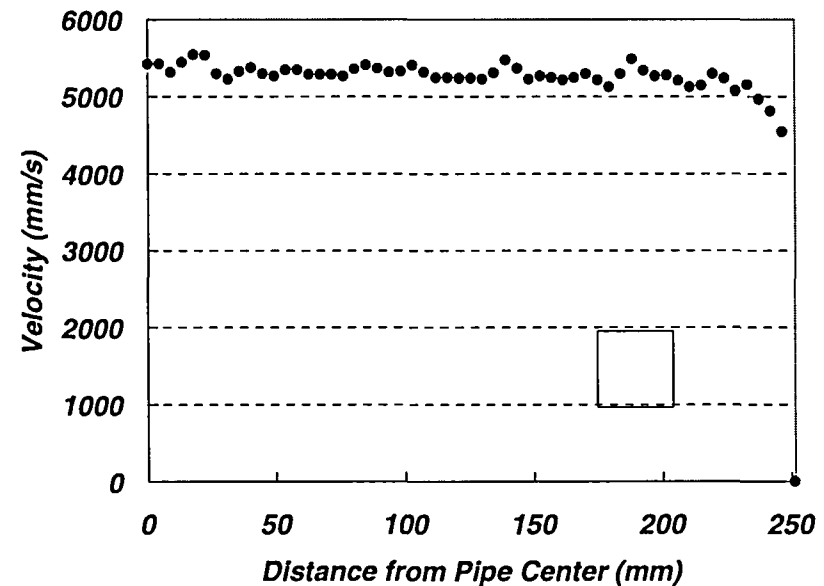
Material: Carbon Steel

Results

- A velocity profile was obtained using a single transducer.
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Instantaneous Velocity Profile Across the Pipe Cross-Section



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Conclusion

- **A new type of ultrasonic Doppler flow meter has been developed that can**
[[]]
- [[]]
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- **By improving feedwater flow rate measurement accuracy, an operating nuclear power plant can apply to NRC for an increase in power output.**
- **To allow the application of this flow meter to an operating nuclear power plant, GE requests US NRC review and approval of GE's LTR, to be submitted in September 2006.**



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