National Energy Technology Laboratory
Strategic Center For Natural Gas (SCNG)

6th Quarterly Progress Report

Reporting Starting Date: October 1, 2003
Reporting Ending Date: December 31, 2003
Report Issue Date: January 5, 2004

Project: DE-FC26-02NT41324
Acoustic Detecting and Locating Gas Pipe Line Infringement

TITLE:
UPDATED POWER POINT PRESENTATION FOR NATURAL GAS TECHNOLOGIES II, FEB 2004

by
West Virginia University

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Disclaimer

ABSTRACT

The power point presentation for the Natural Gas Technologies II Conference held on February 8-11, 2004 in Phoenix AZ, published the presentations made at the conference, therefore required all presenters to submit their presentation prior to November 2003. However in the remainder of year, significant new test data became available which were incorporated in the actual presentation made at the Natural Gas Technologies II Conference. The 6th progress report presents the updated actual slide show used during the paper presentation by Richard Guiler.

EXECUTIVE SUMMARY

The updated presentation made at the Natural Gas Technologies II Conference is a complete status report of progress made on the WVU project: Acoustic Detecting and Locating gas Pipe Line Infringement. The most difficult task was to select and test the performance of suitable instruments for safe operation inside natural gas pipelines at pressures up to 1000 psi. Problems include instrument degradation and failure under pressure, limitations to exposure of natural gas to voltages above 6 volt, finding instruments sensitive enough to deal with weak acoustic pressure signals, keeping the system leak free, lightweight and portable with the power supply at a distance of at least 15 feet from the gas pipeline to comply with the gas company fire safety rules. Finding suitable and portable data acquisition equipment. At this stage we feel we have accomplished these tasks and are ready to do field surveys as soon as the weather breaks.

Natural Gas Technologies II Conference and Exhibition,
February 8-11, 2004 in Phoenix, Arizona.

Instrumentation for Surveying Acoustic Signals in Natural Gas Transmission Lines

Presented by Research Assistant Richard Guiler
and his co-authors
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This research has greatly benefited from the suggestions and guidance received from our contract monitor Daniel Driscoll at
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Strategic Center For Natural Gas (SCNG)
U.S. Department of Energy # DE-FC26-02NT41324

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INTRODUCTION

- **Thirty percent of the energy produced in the United States comes from natural gas supplied through more than 300,000 miles of transmission lines.**

- **Corrosion of the pipe wall and third party damage are a major causes of leaks.**

- **DOT statistics from 1994-2001 lists 224 man-made third party incidents on transmission lines resulting in: 7 death, 35 injuries and $167 million in property damage (Huebler, 2002).**

-With a pipeline infringement are associated three types of signals:

a) a step function produced by the onset of a leak or third-party damage
b) a ramp function resulting from step function signal attenuation
c) a wide range of frequencies produced by the escaping supersonic jet.

Acoustic Signal

Pipeline Leak External Signal Characteristics

A supersonic jet of escaping gas generates external acoustic energy with a wide frequency spectrum (1kHz-1MkHz), the majority of which is confined to the moderately high frequency portion (175kHz-750kHz), (Shack, 1980).

Pipeline Leak Internal Signal Attenuation

Viscous effects, wall-damping effects, and molecular relaxation all contribute to the attenuation of high frequency acoustic signals. Rocha, 1989 found that only relatively low frequencies acoustic signals are useful for practical leak detection methods. Acoustic frequencies on the order of 10 Hz can propagate in the gas for distances on the order of 100 miles.

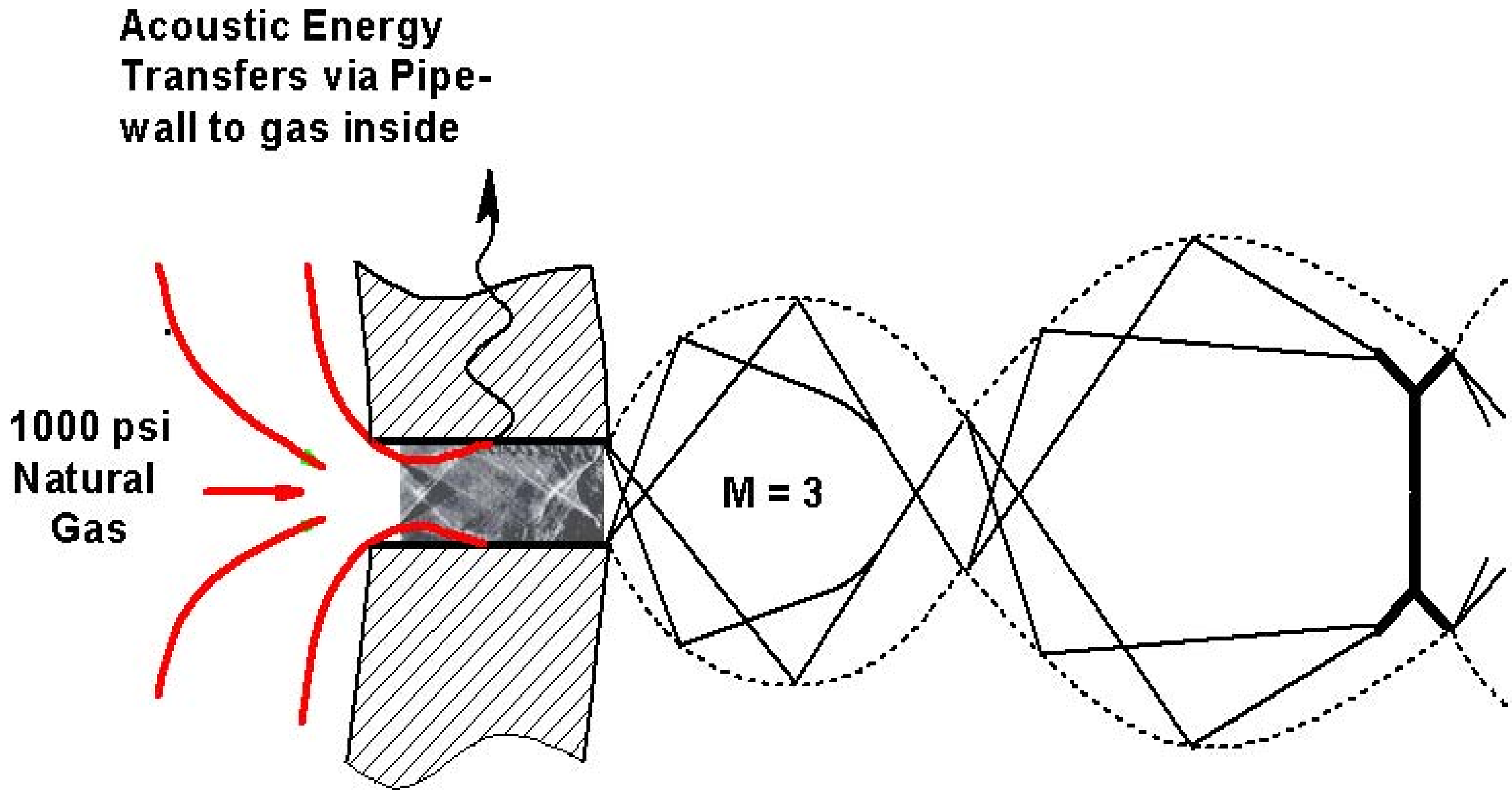
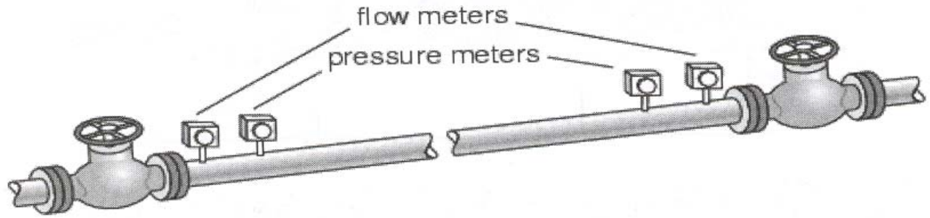


Figure 1 - Schematic of 1000 psi gas leaking through a 2-D fracture with 60% streamline contraction, to create Mach 2 flow inside fracture, slowed by Mach discs but reaccelerated to Mach 3 outside pipe. Acoustic energy may also transfer past the sonic barrier via the boundary layer separation bubble to the gas inside.

Acoustic Identification of Leaks



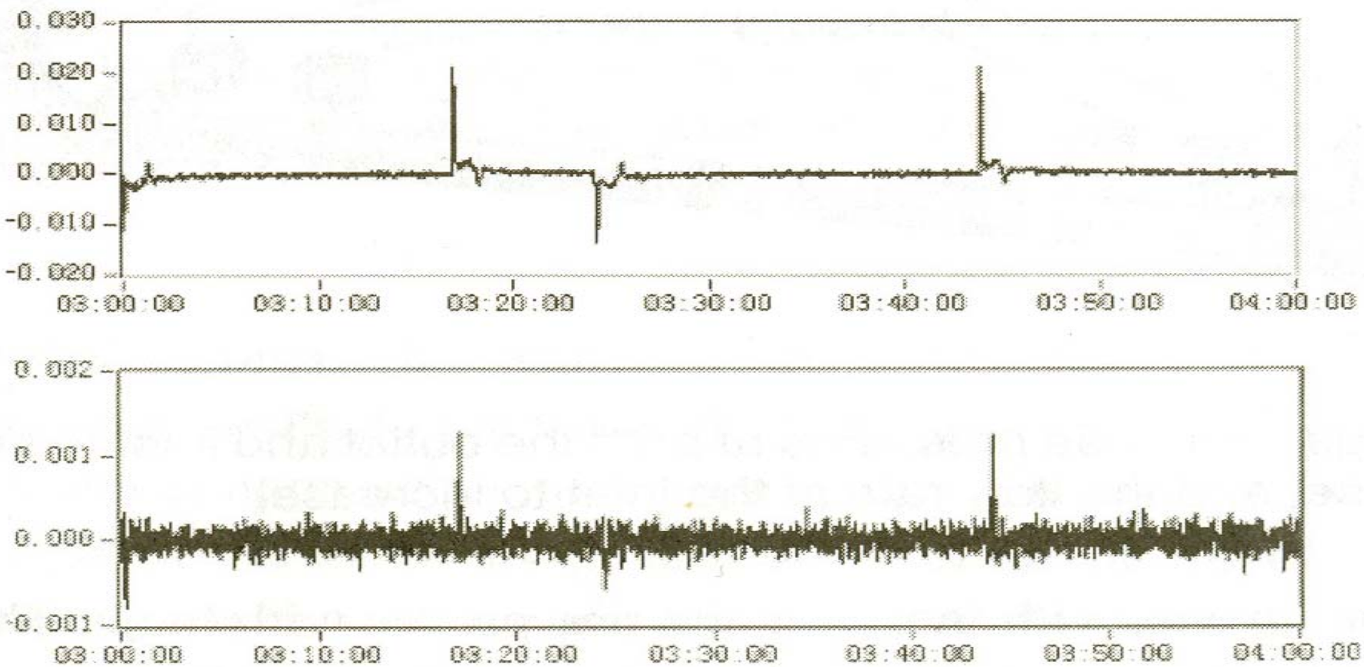


Figure 2 - Oil theft detected acoustically within a 60 km stretch of pipeline. Upper plot is a wavelet transform at inlet, lower at outlet. A 20 min theft started at 3.00 pm, another at 3.24 pm. Data by Zhuang Li, College of Engineering, Tianjin U., China.

WVU 1st Generation Natural Gas Transmission Line Monitoring Package

Figure 3 - WVU 1st generation of natural gas transmission line acoustic monitoring package ended up weighing 94 pounds, it was unmanageable for field-testing.

1) **A 0.5 inch B & K model 4133 transducer type microphone, 3 Hz-40 Khz**

2) **A Piezo-electric pressure transducer with a max reading of 400 psi**

3) **A WVU designed floating 3" diameter ΔP sensor for ramp and step function transient signals.**

2nd generation Portable Acoustic Monitoring Package (PAMP)

Designed for natural gas transmission lines operating up to 1000 psi

1) A 3/8” diameter capacitor microphone with 70Hz to 16kHz linear response.
2) A Δp sensor, with 1000-psi overload protection, Rosemont model 3051, with its 3 inch water operating range and sensitivity 0.1% of span equal 0.75 Pa. or (91 dB).
3) A high precision needle valve in series with a one-liter accumulator tank used to quickly extend the Δp sensor operating range from 3” water to 100” water without loss in sensitivity.
4) A laptop with 4-channel PCMCIA type A/D converter and amplifier with data analysis software.
5) A remote aluminum battery/switch box connected to the plumbing tree by a 25 foot shielded extension chord was required to satisfy safety regulations.
6) A 1000-psi pipeline pressure gage.
7) A 10-psi differential pressure gage.
8) A computer/electronics platform with sunscreen completes the 36-pound package.

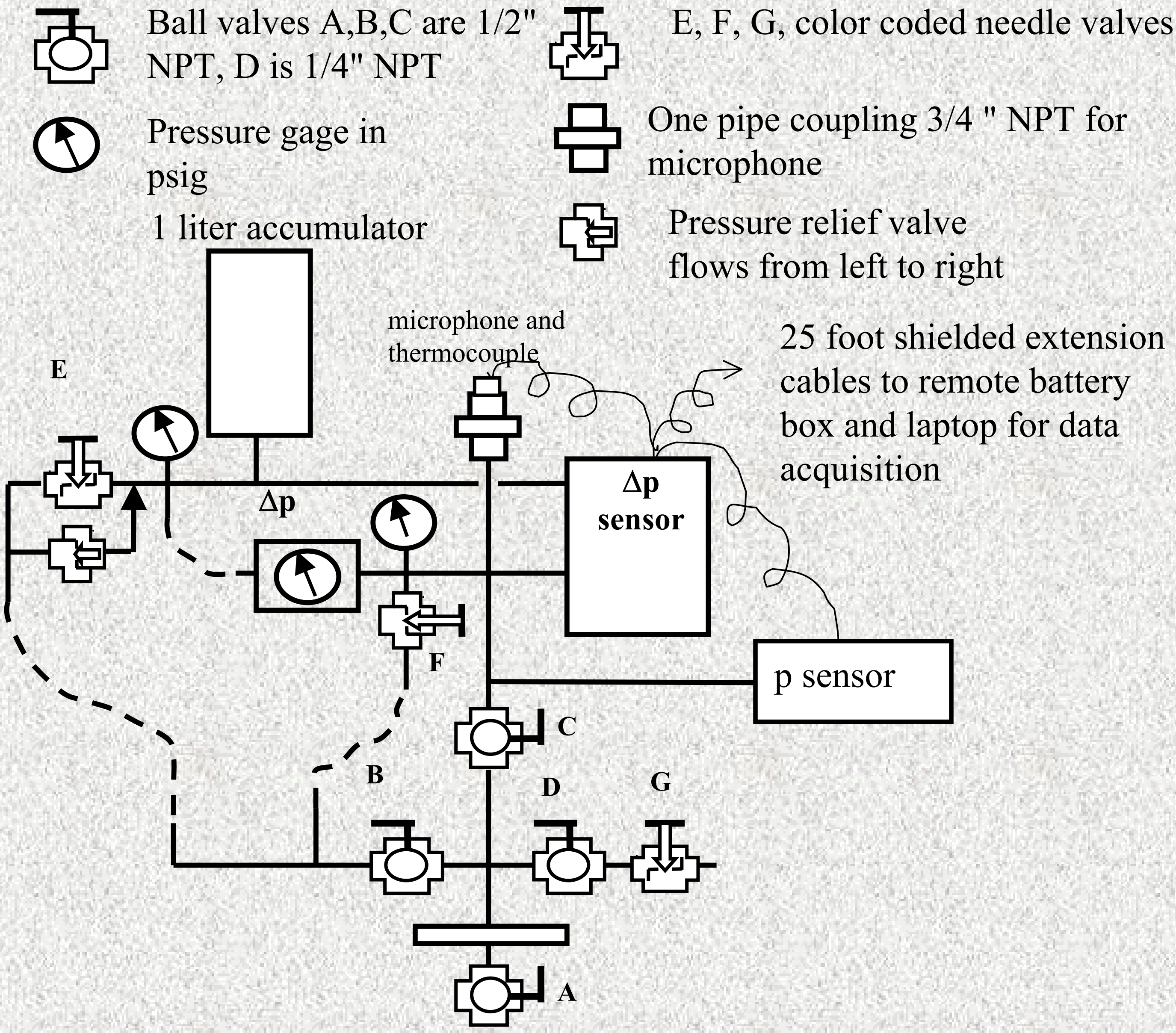


Figure 4 - Schematic of the Portable Acoustic Monitoring Package (PAMP)

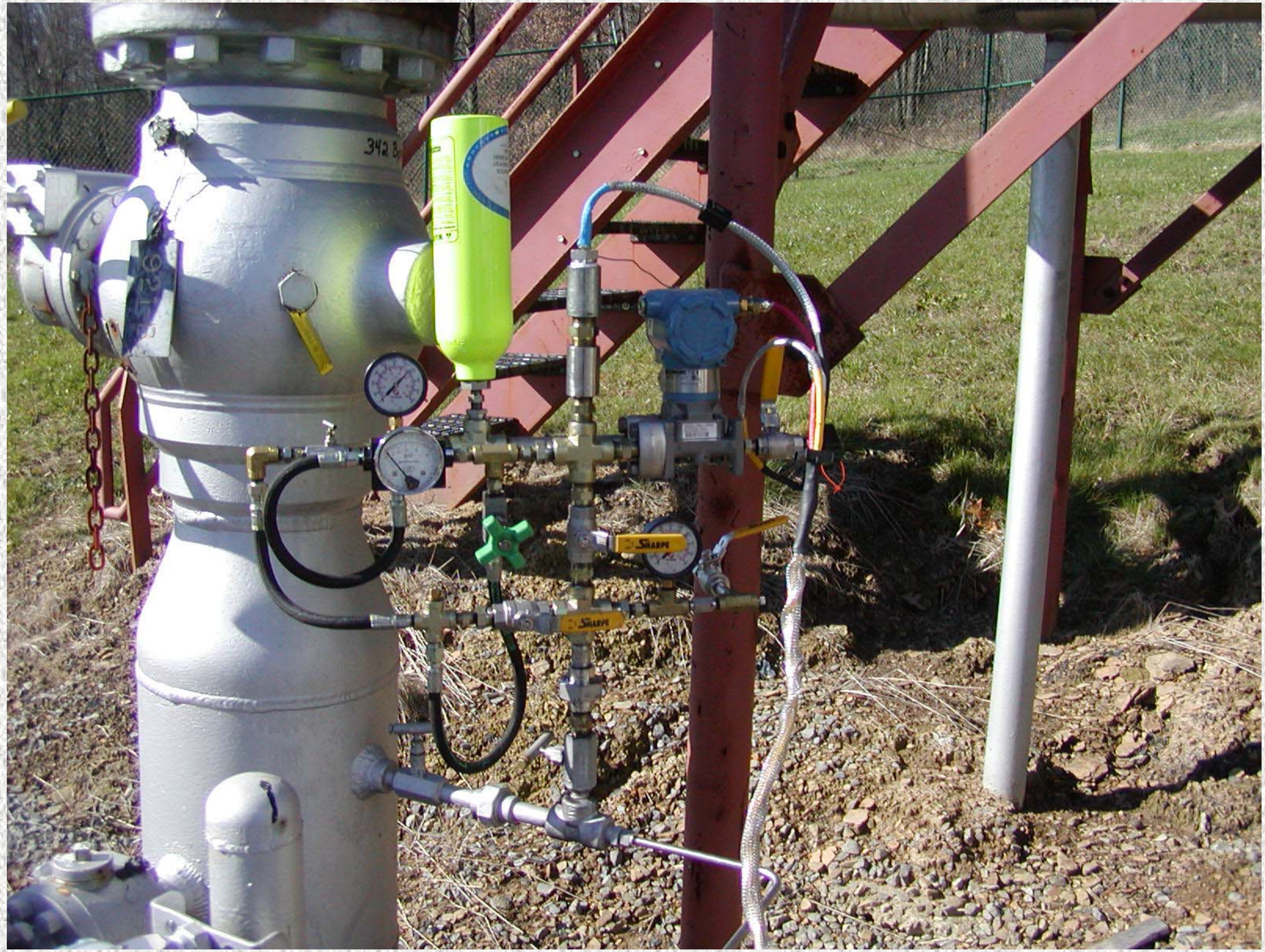
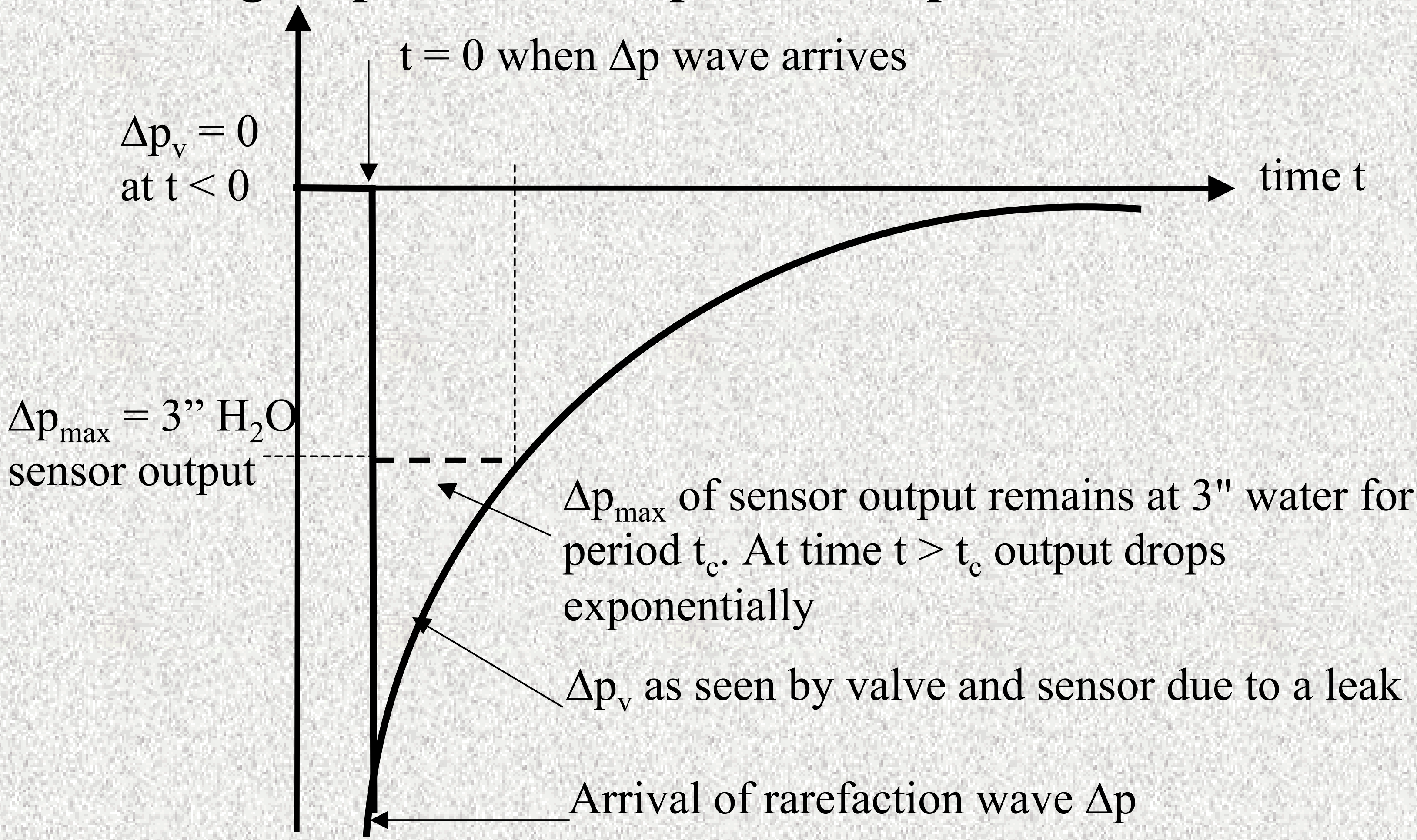


Figure 5 - Second generation Portable Acoustic Monitoring Package (PAMP) weighing only 36 pounds mounted on a transmission line from Dominion Transmission Inc.

Figure 6 - Aerodynamic Δp sensor range amplifier showing response to a step function pressure transient



AERODYNAMIC STEP FUNCTION Δp SENSOR RANGE AMPLIFIER

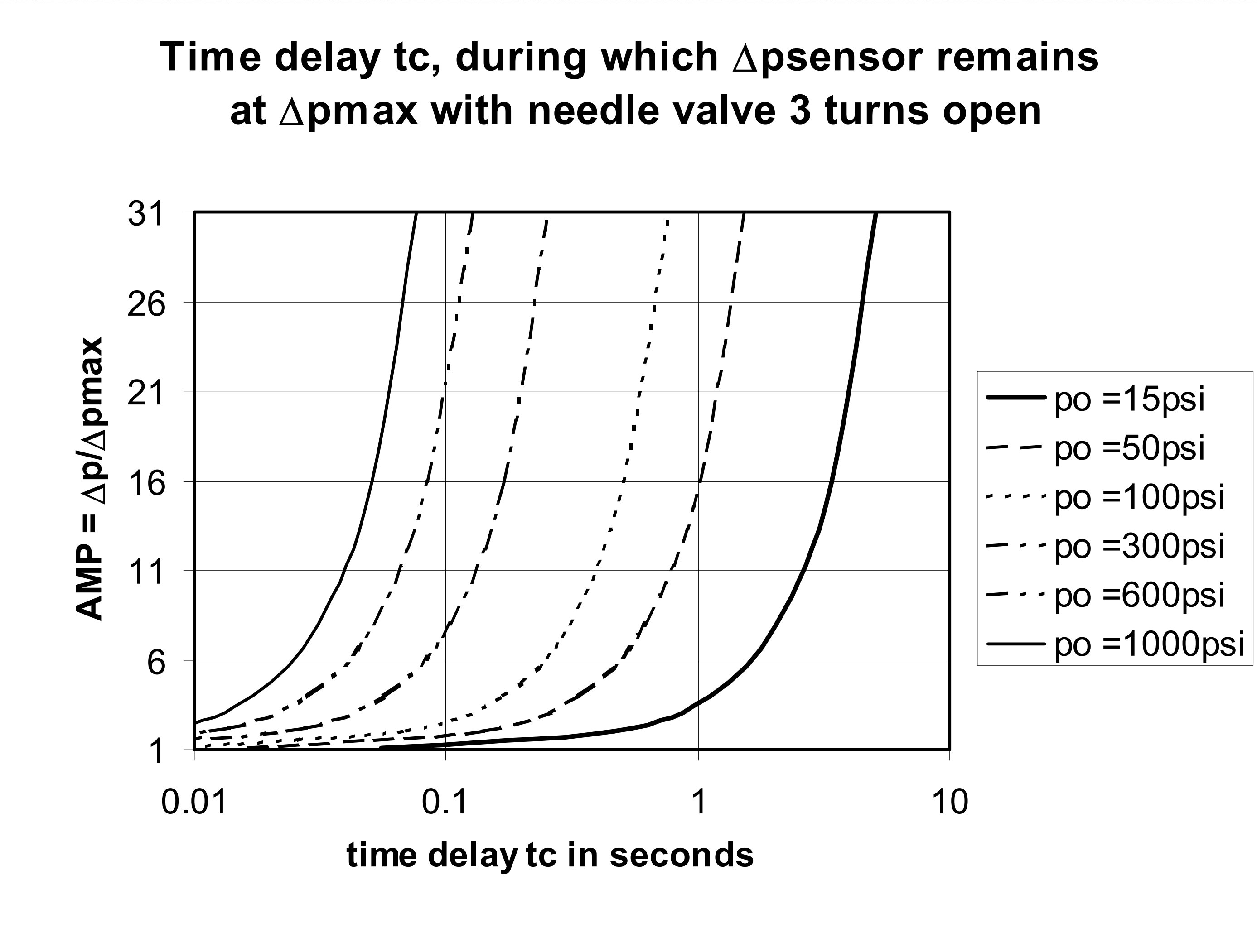


Figure 7 - Time delay t_c in seconds, shows Δp up to 3” water step function signal range amplification AMP.

AERODYNAMIC RAMP FUNCTION dp/dt SENSOR

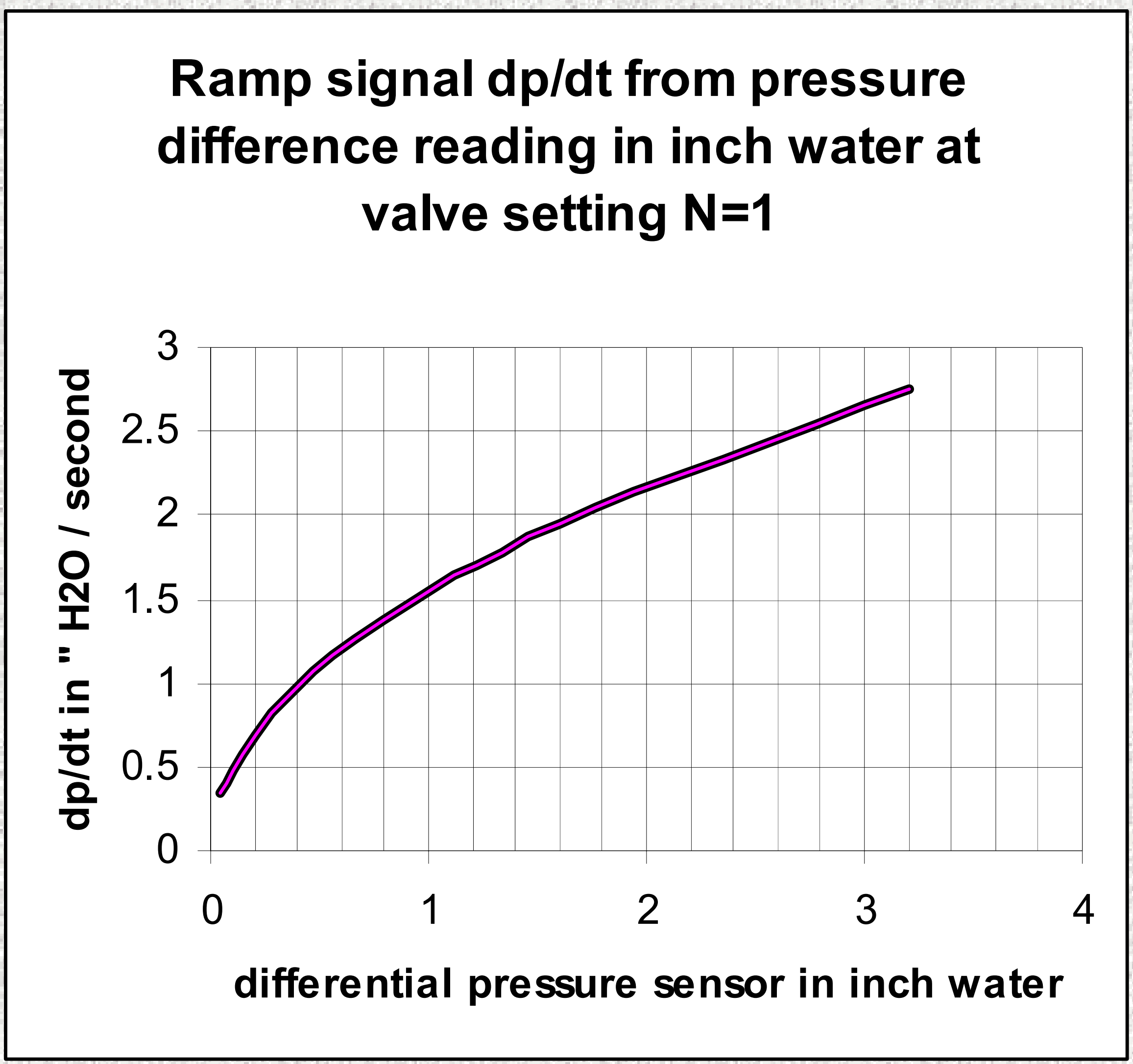


Figure 8 - AERODYNAMIC RAMP FUNCTION dp/dt SENSOR

With needle valve N=1 turn open, a steady gage delta pressure reading indicates a dp/dt ramp function as shown

Field Data Acquisition

Figure 9 - PAMP and data acquisition unit installed on a natural gas transmission line in West Virginia. Computer, shielded cables and plumbing tree are clearly visible.

Figure 10 - Dominion Transmission Inc. 900-psi 24-inch transmission line access near Waynesburg, PA. Engineers Jim Parsons, Bill Ruffner, John Hart and WVU research assistant Richard Guiler next to the "Portable Acoustic Monitoring Package" (PAMP).

Results and Discussion

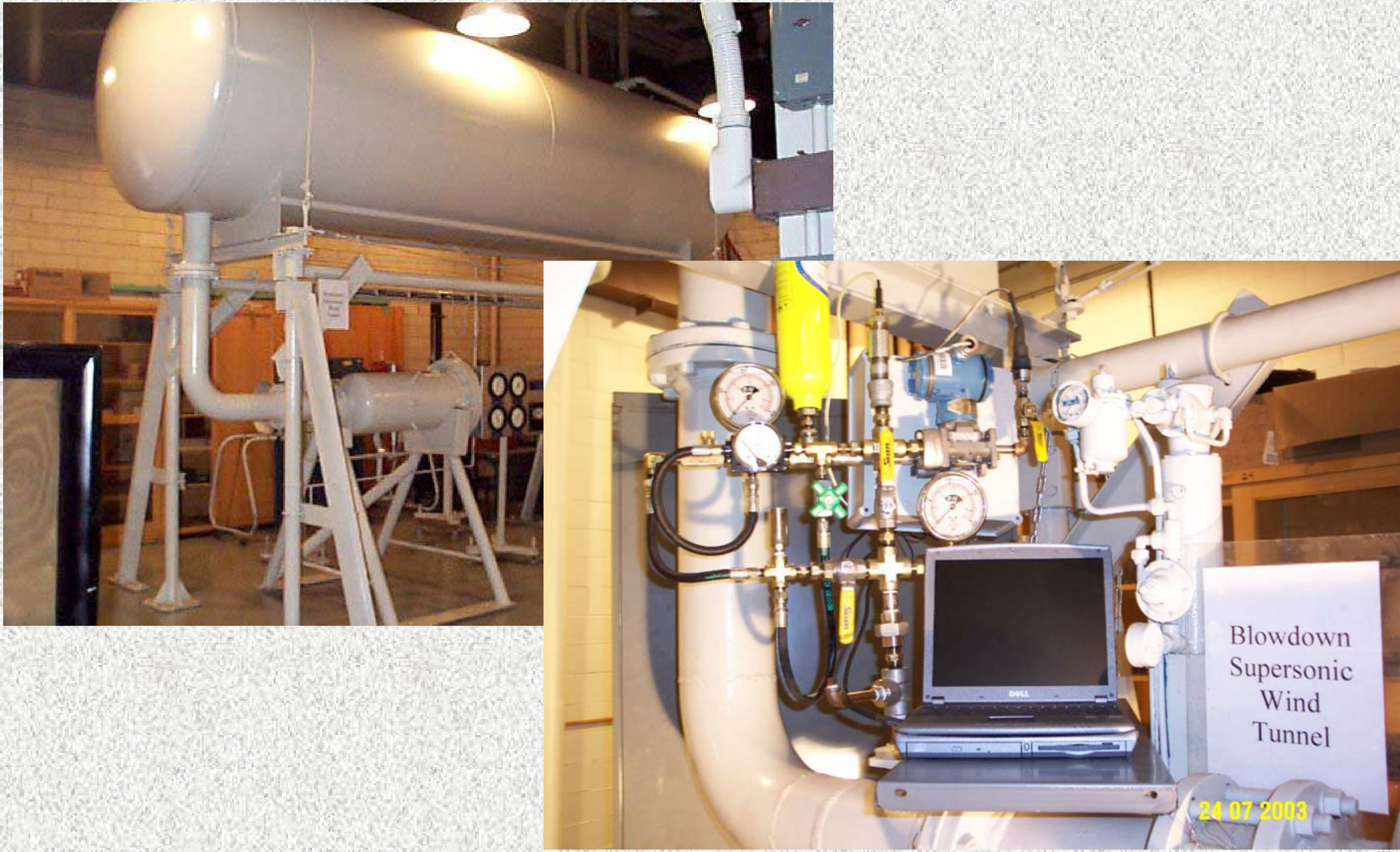


Figure 11 - WVU Blow-down supersonic wind tunnel where the acoustic signal of various leak geometries will be recorded. PAMP installed on 8” line from main storage tank.

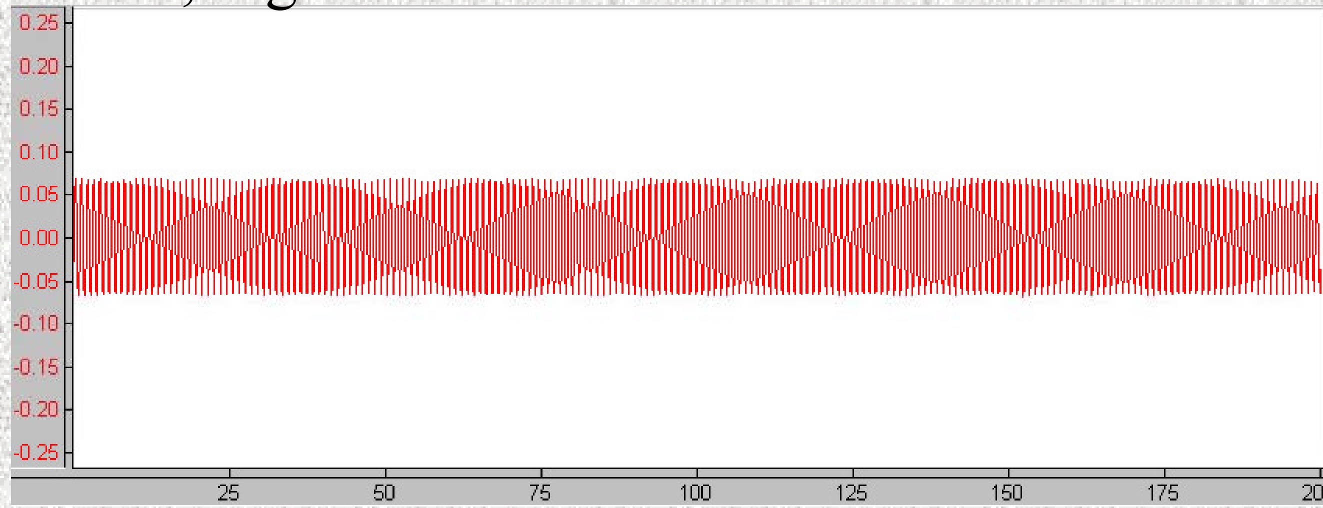
Results and Discussion

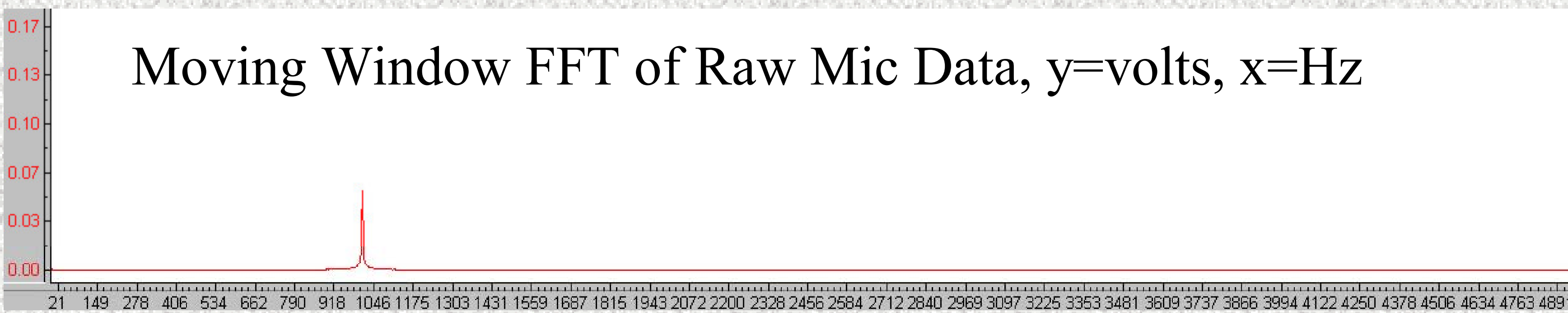
Noise Source	Location	Pressure	Special Considerations
Reciprocation Compressor	North Summit Storage Facility, PA	> 3000 psi	Due to excessive pressures only pipe wall and airborne signals will be recorded.
Reciprocation Compressor	Salt Well Road WV Compressor Station,	~200-350 psi	Record signal at typical RPM setting and characterize
Reciprocation Compressor	Gilmer Compressor Station, OH	~850 psi	Record Data at 2 -3 locations on the transmission line as well as airborne and pipe wall compressor signals. Use signals recorded on the transmission line to study attenuation and signal Doppler effect due to gas flow.
Turbine Compressor	Waynesburg, PA	>2000 psi	Due to excessive pressures only pipe wall airborne signals will be recorded.
Acoustic Flow Meter	Salt Well Road WV Compressor Station,	~200-350 psi	To characterize flow noise
Rotary Flow Meter	Salt Well Road WV Compressor Station,	~200-350 psi	To characterize flow noise
90 degree turn in Line	Salt Well Road WV Compressor Station,	~200-350 psi	To characterize flow noise
Tee in line	Salt Well Road WV Compressor Station,	~200-350 psi	To characterize flow noise
Gate Valve	Salt Well Road WV Compressor Station,	~200-350 psi	To characterize flow noise
Gate Valve	Salt Well Road WV Compressor Station,	~200-350 psi	The record signal associated with opening and closing of a main line valve.
Gas blow off through 1/2" port	Salt Well Road WV Compressor Station,	~200-350 psi	To characterize flow noise
Gas blow off through 1/2" port	Gilmer Compressor Station, OH	~850 psi	Record Data at 2 -3 locations on the transmission line as well as airborne and pipe wall compressor signals. Use signals recorded on the transmission line to study attenuation and signal Doppler effect due to gas flow.
Various leak geometries	West Virginia University, Supersonic Wind Tunnel, WV	0-200 psi	Record and characterize noise generated by various leak geometries at various pressures and flow rates.

Table 1 – West Virginia University initial test schedule to record gas transmission line typical noise sources using the PAMP

Results and Discussion, Figure 12

Raw Microphone Data y=volts, x=ms





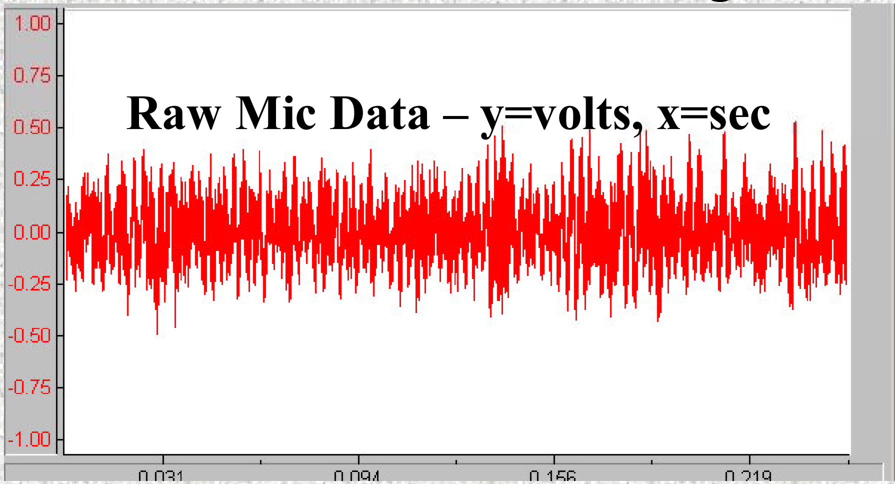
Moving Window FFT of Raw Mic Data, y=volts, x=Hz

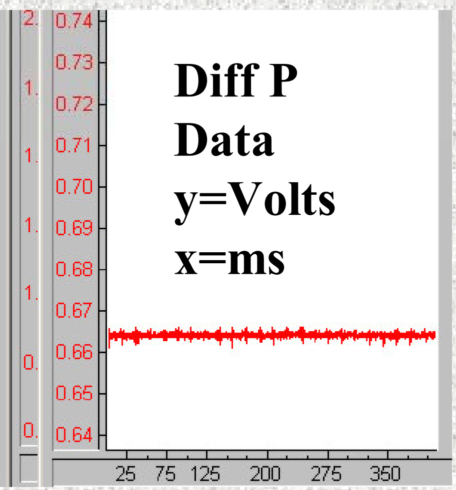
PAMP Microphone Calibration

Internal Optimus 3031 Microphone, 0 CFM, 1 ATM, filename: 020604k

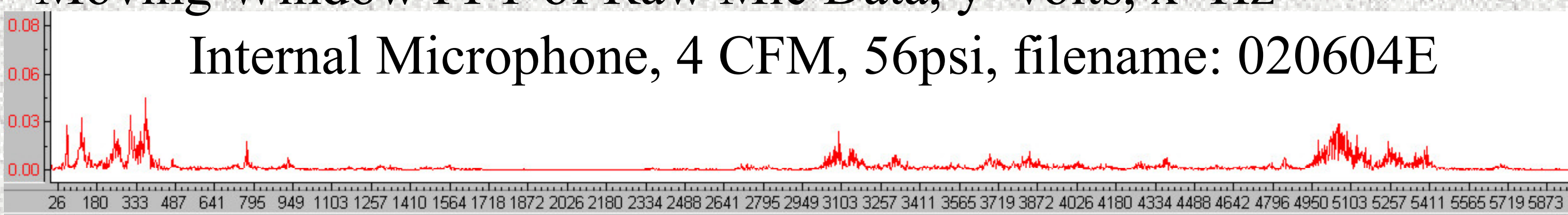
104dB, 1000Hz Sound calibrator

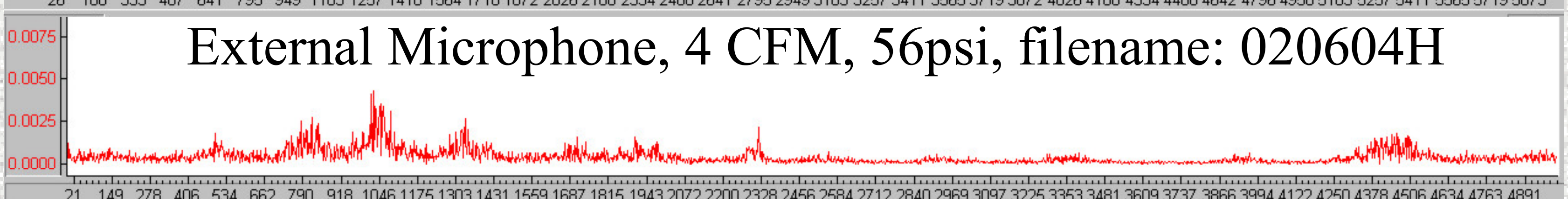
Results and Discussion, Figure 13





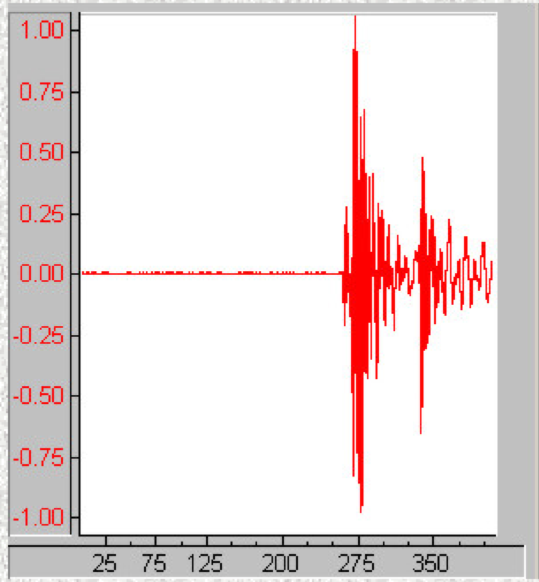
Moving Window FFT of Raw Mic Data, y=volts, x=Hz

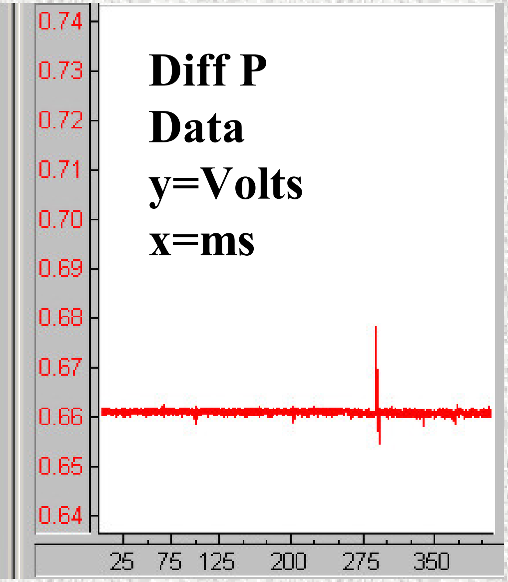


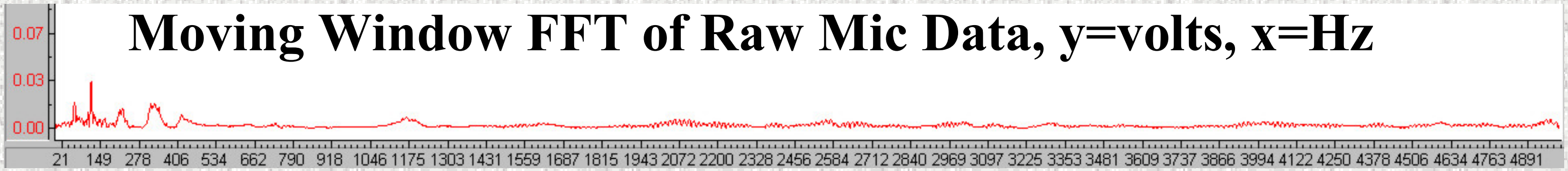


Results and Discussion, Figure 14

Raw Microphone Data y=volts, x=sec

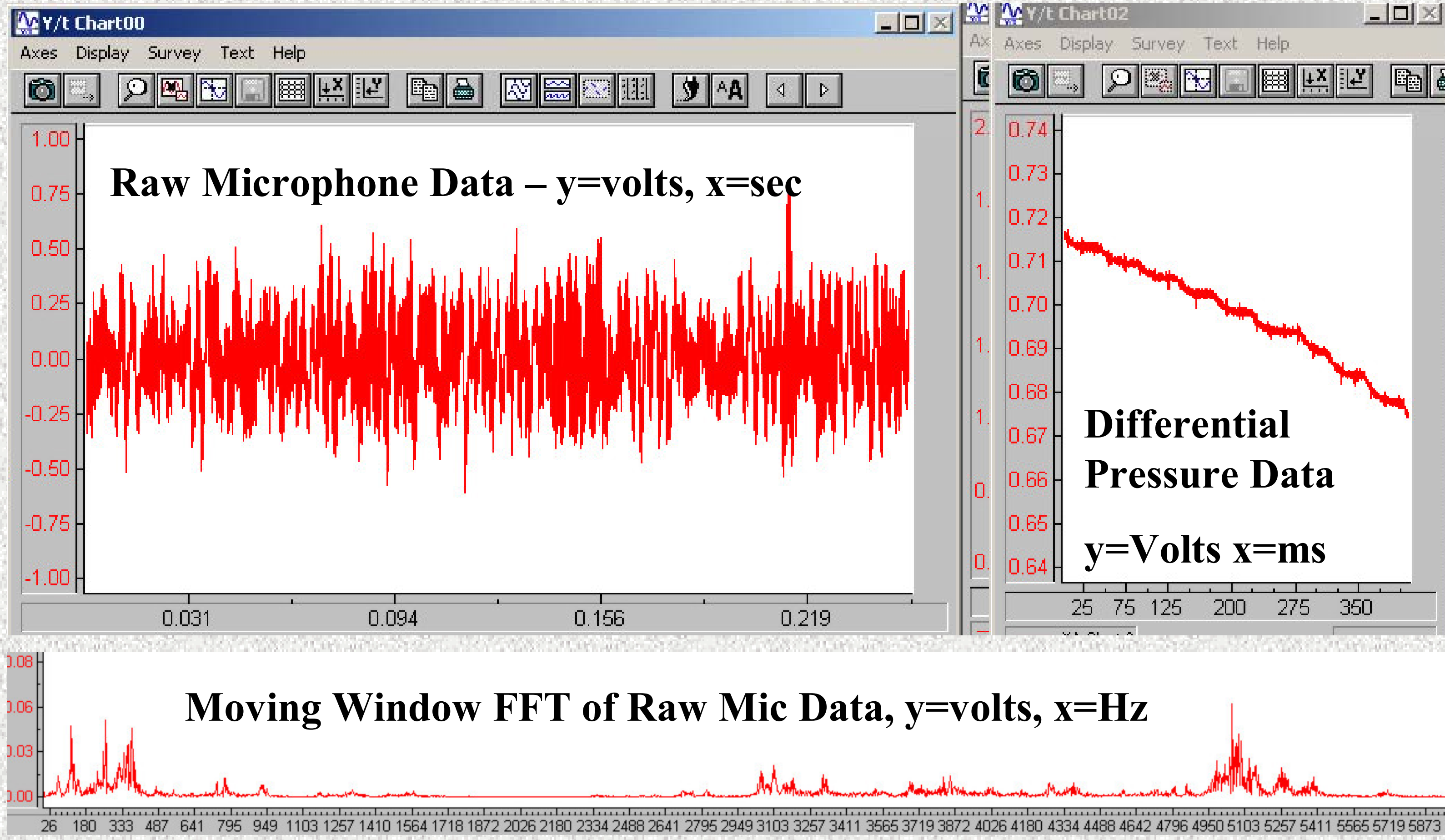






Internal Microphone, 0 CFM, 1 ATM, filename: 020604J
5lb hammer drop on ¾” steel pipe 36” from microphone. Initial drop was 3” with a 1” bounce, both visible on mic data.

Results and Discussion , Figure 15



Internal Microphone, 4-5 CFM, 56-75 psi, filename: 020604D

Note: Differential Gauge

Conclusions

- **Most natural gas transmission lines operate at pressures below 1000 psi, and have ½"pipe thread access test ports located conveniently at each line isolation valve.**

- **The acoustic energy level in natural gas transmission line is quite high and appears to occur mainly in the low frequency range below 3000 Hz.**

Conclusions

There are only four types of instruments required for acoustic monitoring of natural gas pipeline infringements:

1. **A sensitive pressure transducer**

2. **A sensitive differential pressure transducer, with software programmable down to Δp = 3" water full range, with frequency response up to 300 Hz and designed to tolerate a Δp = 1000 psi pressure surge during pipeline connecting/disconnecting.**

Conclusions

3. A max. ½" diameter type microphone with high sensitivity down to minus 40 dB and a linear frequency range to at least 3000 Hz.

4. A GPS based time signal to record the time of passage of an infringement-associated signal, to determine its location from the time of arrival differential at adjacent monitoring stations.

Conclusions

•The Portable Acoustic Monitoring Package (PAMP) developed at WVU has proven to be capable of performing the above mentioned required tasks.

•In cooperation with Dominion Transmission Inc. Pipeline Infringement Engineers, the WVU team has identified specific locations for a series of tests in West Virginia, Pennsylvania and Ohio.

Conclusions

•The purpose of these tests will be to catalog the acoustic signature associated with flow meters, piston type compressors, turbine driven compressors, water blow off valves and pipe-wall mechanical impacts.

•The biggest challenge remains which is to study these acoustic signatures to determine how best to develop software capable of identifying a pipeline infringement, when superimposed on the complex background noise present in all pipelines.