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Strategic Center For Natural Gas (SCNG)

Portable Acoustic Monitoring Package (PAMP) 4th Quarterly Report

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At Dominion Transmission, Inc

Portable Acoustic Monitoring Package (PAMP)

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Portable Acoustic Monitoring Package (PAMP)

Abstract (250 words)

The 1st generation acoustic monitoring package was designed to detect and analyze weak acoustic signals inside natural gas transmission lines. Besides a microphone it housed a three-inch diameter aerodynamic acoustic signal amplifier to maximize sensitivity to leak induced Δp type signals. The theory and test results of this aerodynamic signal amplifier was described in the master's degree thesis of our Research Assistant Deepak Mehra who is about to graduate. To house such a large three-inch diameter sensor required the use of a steel 300-psi rated 4" weld neck flange, which itself weighed already 29 pounds! The completed 1st generation Acoustic Monitoring Package weighed almost 100 pounds. This was too cumbersome to mount in the field, on an access port at a pipeline shut-off valve.

Therefore a 2nd generation and truly Portable Acoustic Monitor was built. It incorporated a fully self-contained Δp type signal sensor, rated for line pressures up to 1000 psi with a base weight of only 6 pounds! This is the Rosemont Inc. Model 3051CD-Range 0, software driven sensor, which is believed to have industries best total performance. Its most sensitive unit was purchased with a Δp range from 0 to 3" water. This resulted in the herein described 2nd generation: Portable Acoustic Monitoring Package (PAMP) for pipelines up to 1000 psi! Its 32-pound total weight includes an 18-volt battery. Together with a 3 pound laptop with its 4-channel data acquisition card, completes the equipment needed for field acoustic monitoring of natural gas transmission pipelines, see below.



Figure 1 - WVU 2nd Generation Portable Acoustic Monitoring Package (PAMP) for Natural Gas Transmission Pipelines at Pressures up to 1000 psi.

Portable Acoustic Monitoring Package (PAMP)

Executive Summary

The 1st generation acoustic monitoring package was designed to detect and analyze weak acoustic signals inside natural gas transmission lines. Besides a microphone it housed a three-inch diameter aerodynamic acoustic signal amplifier to maximize sensitivity to leak induced Δp type signals. The theory and test results of this aerodynamic signal amplifier was described in the master's degree thesis of our Research Assistant Deepak Mehra who is about to graduate. To house such a large three-inch diameter sensor required the use of a steel 300-psi rated 4" weld neck flange, which itself weighed already 29 pounds! The completed 1st generation Acoustic Monitoring Package weighed almost 100 pounds. This was too cumbersome to mount in the field, on an access port at a pipeline shut-off valve.

Therefore a 2nd generation and truly Portable Acoustic Monitor was built. It incorporated a fully self-contained Δp type signal sensor, rated for line pressures up to 1000 psi with a base weight of only 6 pounds! This is the Rosemount Inc. Model 3051CD-Range 0, software driven sensor, which is believed to have industries best total performance. Its most sensitive unit was purchased with a Δp range from 0 to 3" water. This resulted in the herein described 2nd generation: Portable Acoustic Monitoring Package (PAMP) for pipelines up to 1000 psi! Its 32-pound total weight includes an 18-volt battery. Together with a 3 pound laptop with its 4-channel data acquisition card, completes the equipment needed for field acoustic monitoring of natural gas transmission pipelines.

The high sensitivity of the Rosemount instrument eliminates the need for the three inch diameter aerodynamic signal amplifier used in the 1st generation Acoustic Monitoring Package, with its heavy housing. Reprogramming its software can increase the 0 - 3" water Δp range of this sensor. However it was found advantageous to use a mechanical range modifier in the form of a needle-valve and a 1 liter accumulator. This way one can extend its Δp range many fold by simply turning a knob. The actual range amplification factor can be calculated later from the recorded data signal. Additional instruments included in the PAMP are a pressure tolerant microphone, linear from 70 to 16,000 Hertz and an Omega pressure transducer with a frequency response up to 3 dB. The entire plumbing tree consist mainly of stainless steel nipples with $\frac{1}{2}$ " and $\frac{1}{4}$ " NPT thread and small high pressure steel fittings. Only the microphone required a $\frac{3}{4}$ " NPT stainless steel nipple and fittings. The result was an easy to operate and well balanced plumbing tree with a total weight of 32 pounds, which including a 3 pound 18 volt DC rechargeable battery to power all sensors. One person can manage to install this portable package in the field on the pipeline. The four sensors are hooked up to pre-amplifiers included in the Omega Model DAQP-208H data acquisition system for lap-top use. The next objectives are to continue instrument calibration and record gas pipeline noise in a variety of different locations.

Portable Acoustic Monitoring Package (PAMP)

4th Quarterly Progress Report

July 5, 2003 by
West Virginia University
Project: DE-FC26-01NT41324,
Acoustic Detecting and Locating Gas Pipe Line Infringement

I. Introduction

The 1st generation acoustic monitoring package was designed to detect and analyze weak acoustic signals inside natural gas transmission lines. Besides a microphone it housed a three-inch diameter aerodynamic acoustic signal amplifier to maximize sensitivity to leak induced Δp type signals. The theory and test results of this aerodynamic signal amplifier was described in the master's degree thesis of our Research Assistant Deepak Mehra who is about to graduate. To house such a large three-inch diameter sensor required the use of a steel 300-psi rated 4" weld neck flange, which itself weighed already 29 pounds! The completed 1st generation Acoustic Monitoring Package weighed almost 100 pounds. This was too cumbersome to mount in the field, on an access port at a pipeline shut-off valve.

Therefore a 2nd generation and truly Portable Acoustic Monitor was built. It incorporated a fully self-contained Δp type signal sensor, rated for line pressures up to 1000 psi with a base weight of only 6 pounds! This is the Rosemont Inc. Model 3051CD-Range 0, software driven sensor, which is believed to have industries best total performance. Its most sensitive unit was purchased with a Δp range from 0 to 3" water. This resulted in the herein described 2nd generation: Portable Acoustic Monitoring Package (PAMP) for pipelines up to 1000 psi! Its 32-pound total weight includes an 26-volt battery. Together with a 3 pound laptop with its 4-channel data acquisition card, completes the equipment needed for field acoustic monitoring of natural gas transmission pipelines.

The PAMP has been tested on a transmission line at Dominion Transmission's North Summit storage facility. Recommendations by Dominion personnel have led to some minor modifications to the unit's electronics. A background noise-testing plan has been developed with the assistance of Dominion Transmission. Once modifications have been completed and arrangements have been made with Dominion Transmission the cataloging of common background noise will begin.

II. Experimental

A. 1st Generation Acoustic Monitoring Package

The WVU 1st Generation Acoustic Monitoring Package utilized a combination of sensing devices contained in a removable sensor housing. The four sensors installed were:

- 1) A 0.5 inch diameter B & K model 4133 microphone, 3 Hz-40 KHz
- 2) A mono phono-graph moving coil sensor, audible frequency range
- 3) A Piezo-electric pressure transducer with a max reading of 400 psi
- 4) The WVU designed floating 3" diameter diaphragm to detect flow transient induced pressure ramp type signals.

The WVU acoustic ramp-signal sensor with aerodynamic signal amplification used a rigid container connected to the pipeline by three items: a small needle valve and in parallel with it two small spring loaded check valves mounted for flow in opposite directions. The valves limited the pressure difference between the container and the pipeline to their set value, for example ± 1 psi. The passage of any ramp function inside the pipeline produced a proportional pressure differential between the container and the pipeline, which can safely be measured by a ± 1 psi differential pressure commercial available transducer. This allowed the detection of pipeline pressure transients down to 10 Pascal per second! The total sensor pack weight was 96 lbs without batteries.

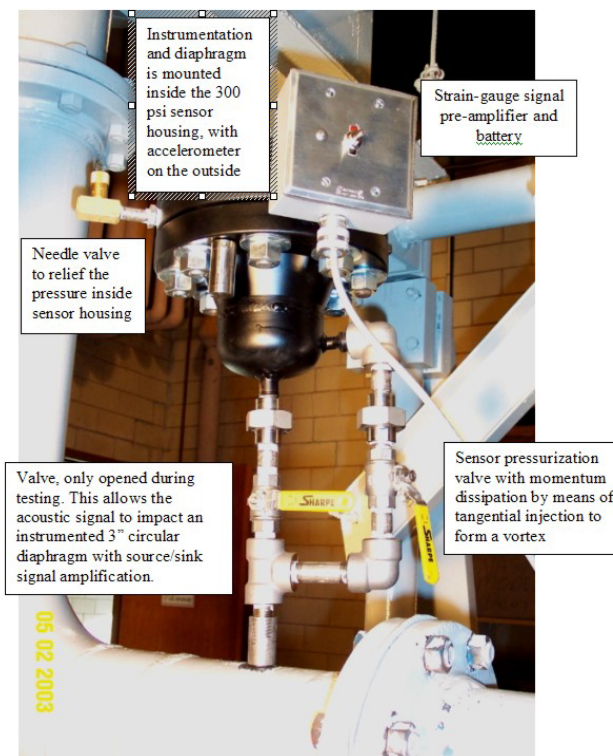


Figure 2 – WVU 1st generation Acoustic Monitoring Package for 300 psi gas pipeline with source/sink type aerodynamic signal amplifier

B. 2nd Generation Acoustic Monitoring Package (PAMP)

The weight problem of the 1st generation acoustic monitoring package with its 4" flanged pipe, was solved by finding the Rosemont Inc. Model 3051CD-Range 0, self contained Δp type signal sensor, rated for line pressures up to 1000 psi and a base weight of only 6 pounds! This unit is software driven and is believed to have industries best total performance. The lowest range unit was purchased with a Δp range from 0 to 3" water. This allowed the construction of a 2nd generation: Portable Acoustic Monitoring Package (PAMP) for pipelines up to 1000 psi. The high sensitivity of this instrument eliminated the need for the three-inch diameter aerodynamic signal amplifier, with its associated heavy housing. Although this sensor's software can be reprogrammed to increase its range, for this instrumentation development phase it was found advantageous to use a simple needle-valve and a 1 liter accumulator to extend its Δp range up to ten fold by adjusting a knob. In addition to a pressure tolerant microphone, linear from 70 to 16,000 Hertz an Omega pressure transducer is used with a frequency response up to 3 dB. The entire plumbing tree consisted mainly of steel schedule 80 nipples of $\frac{1}{2}$ " and $\frac{1}{4}$ " NPT, only the microphone required a $\frac{3}{4}$ " NPT nipple and fittings. The result was a well laid-out and balanced plumbing tree with a weight of 26 pounds, including an 18 volt DC rechargeable battery to power the Δp sensor. This portable acoustic monitoring package (PAMP) is quite manageable for installation in the field by one person.

The Natural gas transmission line WVU instrumentation tree has been designed to:

Measure the following signals electronically:

- 1) Pipeline internal acoustic sounds by means of one or more microphones
- 2) Pipeline external acoustic sounds by means of one or more microphones
- 3) Pipeline very low frequency pressure waves and zero frequency step functions by means of a delta p sensor, with 1000 psi overload protection, and sensitivity operating range adjustable down to 3 inch water pressure, controlled by needle valve E setting and tank volume
- 4) Pipeline temperature with thermocouple
- 5) Pipeline pressure with high frequency response piezoelectric transducer.

Measure the following signals with dial gages:

- 1) Pipeline pressure in psig
- 2) Instrumentation tree accumulator pressure in psig
- 3) Pipeline very low frequency pressure waves and zero frequency step functions by means of a 10 psi delta p sensor with 1000 psi overload protection

The following four ball valves are used to isolate instruments in the pipeline tree.

- 1) Valve (A) is the gas pipeline access valve below mounting flange tapped with $\frac{1}{2}$ " NPT.
- 2) Valve (B) is a $\frac{1}{4}$ " ball valve closest to the access flange
- 3) Valve (C) is the $\frac{1}{2}$ " ball valve on centerline with valve 1, providing unobstructed access to the natural gas transmission line.
- 4) Valve (D) is a $\frac{1}{4}$ " ball valve to bleed instrumentation tree, located furthest away from tree centerline.

Valves E and F should only be adjusted to alter the instrumentation response rate.

Valve Manipulation Sequence for Gas-line Instrumentation Tree (GIT)

- 1) Always start after making sure that all valves (A), (B), (C) and (D) are closed
- 2) Mount instrumentation tree on access flange.
- 3) Open valve (A) and read pipeline pressure on pressure dial gage 1
- 4) Open valve (B) and notice on pressure dial gage 2 that tree pressure rises slowly, rate controlled by needle valve (F) setting.
- 5) Open valve (C) after: both dial gages 1 and 2 read the same pipeline pressure. and 10 psi delta p gage reads zero and expose microphones by means of an unobstructed 1/2" pipe to the natural gas transmission line.
- 6) Activate instrumentation data acquisition system
- 7) Upon completion of all tests, turn off data acquisition system
- 8) Close valve (A)
- 9) Close valve (B)
- 10) Close valve (C)
- 11) Open valve (D) to discharge pressure from instrumentation tree
- 12) Close valve (D) and remove instrumentation trees from access flange.

Nomenclature:

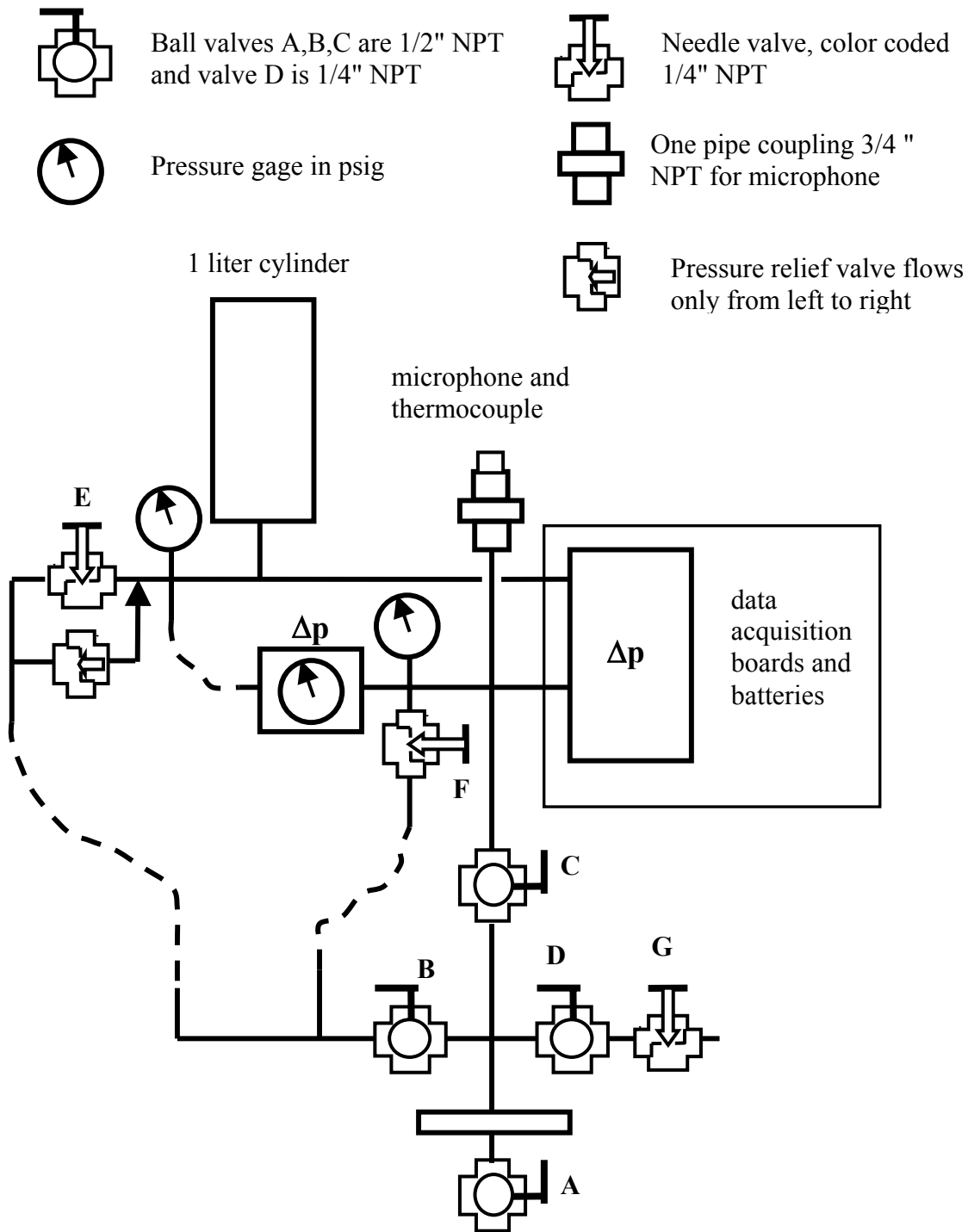


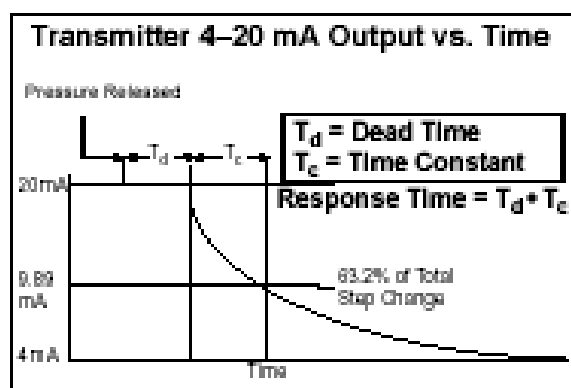
Figure 3 - Schematic of Portable Acoustic Monitoring Package (PAMP)

C. Selected Instrumentation

Differential Pressure Transmitter

The sensor technology in the Rosemont Model 3051 allows for optimal performance of unprecedented $\pm 0.075\%$ reference accuracy, resulting in total operating performance of $\pm 0.15\%$. The Model 3051 also has a five-year stability of $\pm 0.125\%$. Transmitter stability is a critical measure of transmitter performance over time. Through, aggressive simulation testing, and operational history the Model 3051 has proven its ability to maintain performance over a five-year period under the most demanding process conditions. This transmitter stability reduces calibration. In dynamic applications, speed of measurement is as important as repeatability. The Model 3051 responds

up to eight times faster than the typical Smart pressure transmitter to detect and control variations quickly and efficiently. Superior dynamic response yields more accurate measurements to reduce variability and increase profitability. Coplanar platform enables complete point solutions. The versatile coplanar platform design enables the right process connection for all your pressure applications. The Model 3051 has a scalable, flexible design, which includes performance diagnostics and control diagnostics - such as plugged impulse line detection and statistical process monitoring - to evaluate the performance of the entire measurement system. This system provides user-configurable transmitter-resident function blocks, such as PID, Math, and signal characterization.



	4 - 20 mA (HART [®] protocol) ⁽¹⁾	Fieldbus protocol ⁽³⁾
Total Response Time ($T_d + T_c$) ⁽²⁾ :		
Model 3051C/P, Ranges 2-5:	100 ms	152 ms
Range 1:	255 ms	307 ms
Range 0:	700 ms	752 ms
Model 3051T:	100 ms	152 ms
Model 3051H/L:	Consult factory	Consult factory
Dead Time (T_d)	45 ms (nominal)	97 ms
Update Rate	22 times per second	22 times per second

(1) Dead time and update rate apply to all models and ranges;
analog output only

(2) Nominal total response time at 75 °F (24 °C) reference conditions.

(3) Transmitter fieldbus output only, segment macro-cycle not included.

Table 1 – Model 3051 dynamic response

Process-Wetted Parts**Drain/Vent Valves**

316 SST, Hastelloy C, or Monel material
(Monel not available
with Model 3051L or 3051H)

Process Flanges and Adapters

Plated carbon steel, CF-8M (Cast version of
316 SST, material
per ASTM-A743), Hastelloy C, or Monel

Wetted O-rings

Glass-filled TFE (Graphite-filled TFE with
isolating diaphragm
Option Code 6)

Process Isolating Diaphragms**Model 3051L Process Wetted Parts****Flanged Process Connection****(Transmitter High Side)****Process Diaphragms, Including Process
Gasket****Surface:**

316L SST, Hastelloy C-276, or Tantalum

Extension

CF-3M (Cast version of 316L SST, material
per
ASTM-A743), or Hastelloy C. Fits schedule
40 and 80 pipe.

Mounting Flange

Zinc-cobalt plated CS or SST

Reference Process Connection**(Transmitter Low Side)****Isolating Diaphragms**

316L SST or Hastelloy C-276

CF-3M (Cast version of 316L SST, material
per

ASTM-A743)

Non-Wetted Parts**Electronics Housing**

Low-copper aluminum or CF-3M (Cast
version of 316L SST,
material per ASTM-A743). NEMA 4X, IP
65, IP 66

Coplanar Sensor Module Housing

CF-3M (Cast version of 316L SST, material
per ASTM-A743)

Bolts

Plated carbon steel per ASTM A449, Type
1: Austenitic 316
SST, ASME B 16.5 (ANSI)/ASTM-A-193-
B7M, or Monel

Sensor Module Fill Fluid

Silicone or inert halocarbon (inert not
available with Model
3051CA or Model 3051H). Model 3051T
uses Fluorinert®
FC-43

**Process Fill Fluid (Model 3051L and
3051H only)**

3051L: Syltherm XLT, D.C. Silicone 704,
D.C. Silicone 200, inert, glycerin and water,
Neobee M-20 or
propylene glycol and water
3051H: inert, Neobee M-20, or D.C.
Silicone 200

Paint

Polyurethane

Cover O-rings

Buna-N

Table 2 – Rosemount model 3051 material specifications

Factory Mutual (FM) Approvals

E5 Explosion proof for Class I, Division 1, Groups B, C, and D.

Dust-Ignition proof for Class II, Division 1, Groups E, F, and

G. Dust-Ignition proof for Class III, Division 1.

T5 ($T_a = 85\text{ }^{\circ}\text{C}$)

Factory Sealed

I5 Intrinsically Safe for use in Class I,

Division 1, Groups A, B, C, and D; Class II, Division 1,

Groups E, F, and G; Class III, Division 1 when connected

per Rosemount drawing 03031-1019 and 00268-0031

(When used with a HART communicator); Non-incendive for

Class I, Division 2, Groups A, B, C, and D.

Temperature Code:

T4 ($T_a = 40\text{ }^{\circ}\text{C}$)

T3 ($T_a = 85\text{ }^{\circ}\text{C}$)

NEMA Enclosure Type 4x

Factory Sealed

ATEX Marking: Ex II 1 GD T80°C

EEx ia IIC T5 ($T_{amb} = .60\text{ to }+40\text{ }^{\circ}\text{C}$)

EEx ia IIC T4 ($T_{amb} = .60\text{ to }+70\text{ }^{\circ}\text{C}$)

Dust Rating: T80 °C ($T_{amb} .20\text{ to }40\text{ }^{\circ}\text{C}$) IP66

CENELEC Approved Entity Parameters

$U_i = 30\text{ V}$

$I_i = 200\text{ mA}$

$P_i = 0.9\text{ W}$

$C_i = 0.012\text{ }\mu\text{F}$

SPECIAL CONDITIONS FOR SAFE USE (X):

When the optional transient protection terminal block is installed,

the apparatus is not capable of withstanding the 500V insulation

test required by Clause 6.4.12 of EN50020:1994 or Clause 9.1 of

EN50021:1998. This must be taken into account when installing the apparatus.

FM Approved Entity Parameters for Model 3051C	FM Approved for Class I, II, III, Division 1 and 2, Groups:
$V_{max} = 40\text{ V dc}$	A–G
$I_{max} = 165\text{ mA}$	A–G
$I_{max} = 225\text{ mA}$	C–G
$I_{max} = 160\text{ mA}$ (Option Code T1)	A–G
$P_{max} = 1\text{ W}$	A–G
$C_i = 0.01\text{ }\mu\text{F}$ (Output Code A)	A–G
$C_i = 0.042\text{ }\mu\text{F}$ (Output Code M)	A–G
$L_i = 10\text{ }\mu\text{H}$	A–G
$L_i = 1.05\text{ mH}$ (Output Code A with T1)	A–G
$L_i = 0.75\text{ mH}$ (Output Code M with T1)	A–G

Table 3 – Rosemount model 3051 hazardous location specifications

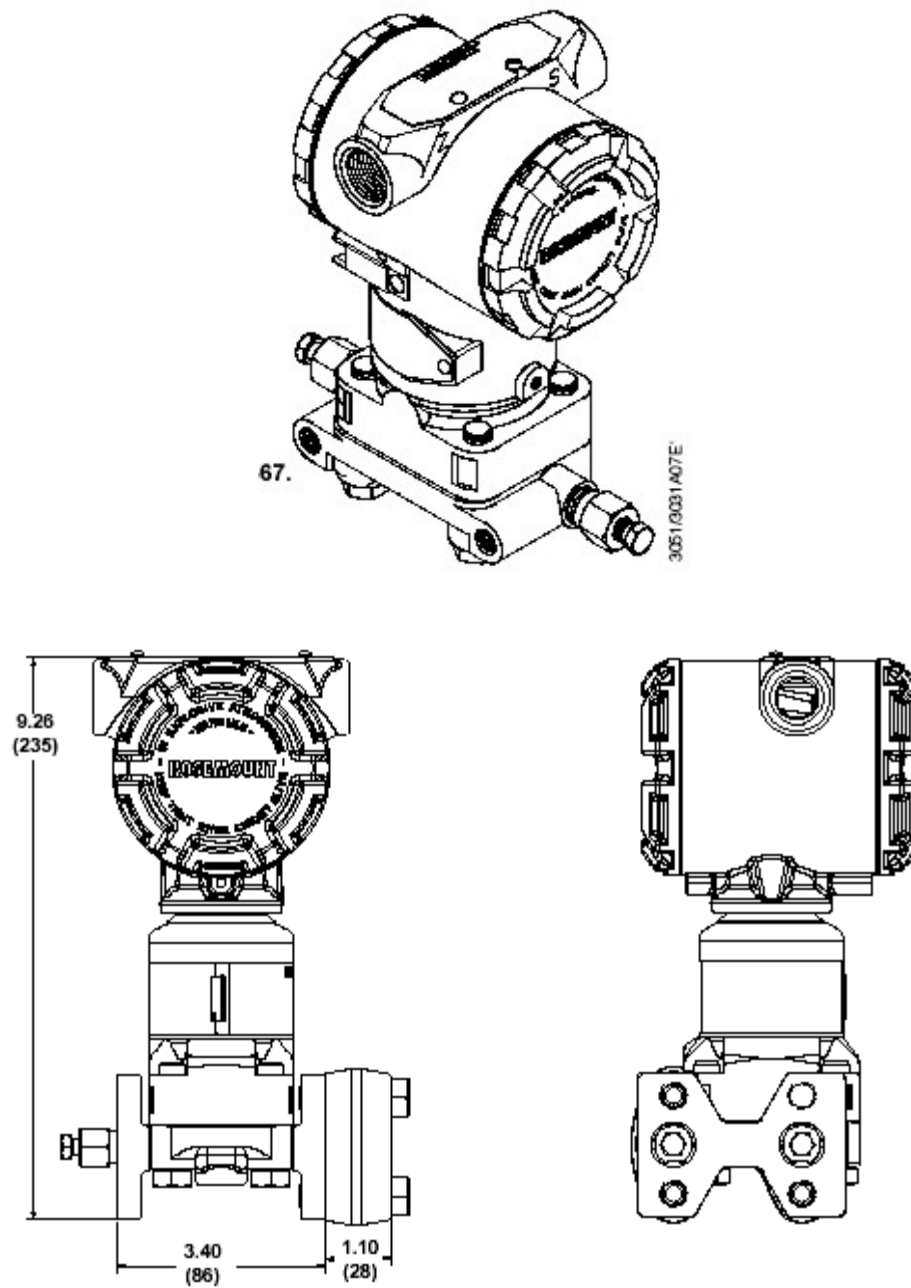


Figure 4 – Schematics of Rosemount model 3051 differential pressure transmitter with a 3 inch of water range.

Optimus Omni-directional 1/8" Dynamic Microphone

The Optimus model 3031 microphone is a high-quality omni-directional microphone. It has a wide frequency response and accurate sound pick-up. It's electret element - provides an excellent frequency response of 70 - 16,000 Hz and a sensitivity of -65 dB (+/- 3 dB). The omni-directional patten - allows full 360-degree sound pick up.

Directivity:..... Omnidirectional
Frequency Response:..... 70 - 16,000 Hz
Impedance (at 1,000 Hz):..... 1 kOhm
Sensitivity (at 1,000 Hz):..... -65 dB (+/- 3 dB)
(0 dB = 1V/microbar)

Cable Size:

Length:..... 4 ft. 10 in (147 cm)
Diameter:..... 5/32 in (2 mm)
Plug:..... 1/8-inch (3.5 mm) Diameter, Mono Type
Power supply:..... Cat 230-0105; 1.5 V
Weight:..... 25 grams

Table 4 - Optimus model 3031 microphone specifications



Figure 5 – Model 3031 microphone installed in 3/4" high pressure feed-through

Omega model PX-105 fast acting transducer

The Model PX105 pressure transducer is a high gain strain gage device with a hybrid amplifier providing a conditioned output. The 5 volt output is capable of driving control, indicator, or alarm circuitry directly without external amplification. A unique stainless steel pressure chamber is designed to insure circuit protection from corrosive media and the outer case is made of Valox for protection against harsh environments. This combination assures the Model PX105 performance to continue within original specification limits. Typical media used with the PX105 include oil, gases, saline solution, hydraulic fluids, alcohol, acids, and gasoline. The Model PX105 may be easily mounted on a printed circuit board using the two mounting holes or by supporting it from the stainless steel pressure port. Many applications require a threaded pressure port. The internal voltage regulator allows the use of economical unregulated power sources from 8-20 Vdc.

PX105 transducers will withstand high overloads. If the overload rating is exceeded, electrical failure may occur. As a safety feature, the transducers have been designed to withstand much higher burst pressure than the pressure, which will cause permanent damage.

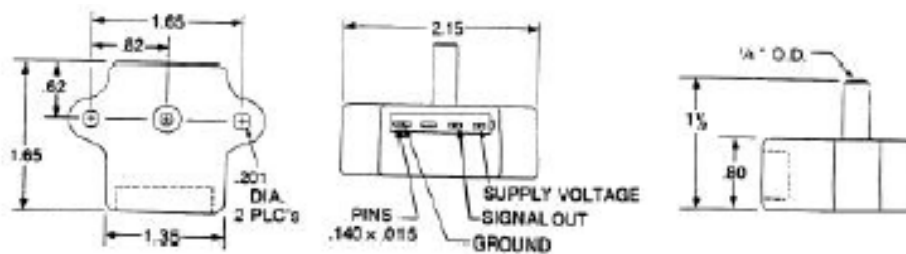


Figure 1. Mechanical: Ranges 0-6 to 0-50 PSI

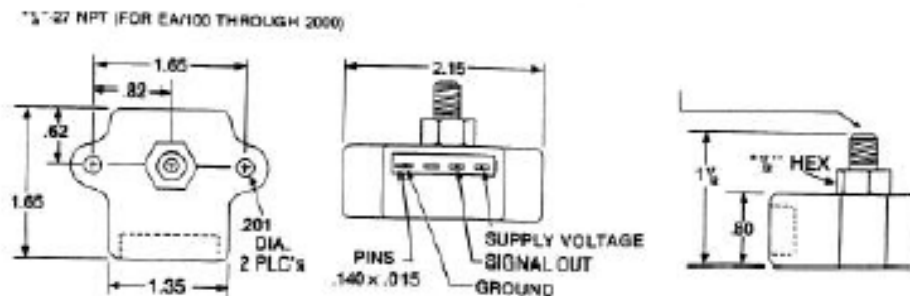


Figure 6 – Schematic of the Omega model PX-105 transducer

PX105 SPECIFICATIONS AT 25°C

PARAMETER	PRESSURE RANGE									UNITS
	5, 15, 25			50, 100, 200			500, 1K, 2K			
	MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	
Full Scale Output (FSO)	4.90	4.95-5.05	5.10	4.90	4.95-5.05	5.10	4.90	4.95-5.05	5.10	Vdc
Null Offset	.85	.95-1.05	1.15	.85	.95-1.05	1.15	.85	.95-1.05	1.15	Vdc
Linearity (Best Fit)		±.5	±.10		±.2	±.5		±.2	±.5	% FSO
Hysteresis		±.25			±.25			±.25		% FSO
Temperature Error										
Null 0° to 85°C		±.01	±.02		±.01	±.02		±.01	±.02	% FSO/°C
-55° to 0°C + 85°C TO 125°C		±.02			±.02			±.02		% FSO/°C
Sensitivity 0° to 85°C		±.01	±.02		±.01	±.02		±.01	±.02	% Bdg/°C
-55° to 0°C + 85°C TO 125°C		±.02			±.02			±.02		% Bdg/°C
Stability (1 Year)		±.10			±.10			±.10		% FSO
Frequency Response		10			10			10		KHz
Supply Voltage (V)	8		20	8		20	8		20	Vdc
Supply Current (Quiescent)		15			15			20		mA
Output Current										
Source	10			10			10			mA
Sink	5			5			5			mA
Pressure Overload			2x			2x			1.5x	Rated Pressure
Burst Pressure	20x			10x			5x			Rated Pressure
Operating Temperature	-55° to 125°C									
Storage Temperature	-65° to 150°C									

*FSO is the voltage change between minimum and rated pressure.

For Example: NOM V_O = 1.00 V @ Null Pressure, NOM V_O = 6.00 V @ Rated Pressure, FSO = (6.00-1.00) = 5.00 V.

Table 5 – Omega model PX-105 transducer specifications

D. Data Acquisition

The Omega DAQP-208 is a Type II PCMCIA data acquisition card with 4 differential or 8 single ended 12-bit A/D input channels (expandable to 128), with a maximum sampling rate of 100 kHz, and programmable gains of 1, 2, 4, or 8, which provide ranges of ± 1.25 V, ± 2.5 V, ± 5 V, to ± 10 V. A high gain option is also available providing gains of 1, 10, 100 or 1000, for ranges of ± 0.01 V, ± 0.1 V, ± 1 V, to ± 10 V. The DAQP-208 is also equipped with two 12-bit D/A output channels. The outputs can be updated individually when writing to the corresponding D/A port, or simultaneously when a synchronization signal comes. The DAQP-208 has a 2 K data FIFO which will significantly reduce CPU overhead, and a scan FIFO of 2048 entries, each of which can be specified with an input channel and its associated gain. It has a selectable scan speed of 10 ms to 40 ms per channel. Data acquisition may be initiated by a trigger signal or by using the DAQP-208's pre-trigger capability. The DAQP-208 has a 24-bit auto-reload pacer clock which generates accurate sampling rates from 0.006 Hz to 100k Hz using an internal or external clock source. The pacer clock is actually a 24-bit auto-reload frequency divider. It contains a 24-bit divisor register, a 24-bit counter, and internal clock pre-scaler and a clock source multiplexer. The DAQP-208 also has a 16-bit timer/counter with an auto-reload and readout latch, which provides independent timing for the D/A channels, and operates with internal or external clock source and gate controls. The DAQP-208 is compatible with the DasyLab signal-processing package. Signal Conditioning/Expansion is possible through the SignalPro line of signal conditioners. These signal conditioners allow the DAQP-208 to read most process sensors and provides channel expansion up to 256 inputs. Drivers are also included for numerous third-party software packages including Labtech Notebook, DasyLab support, LabVIEW, and SnapMaster.

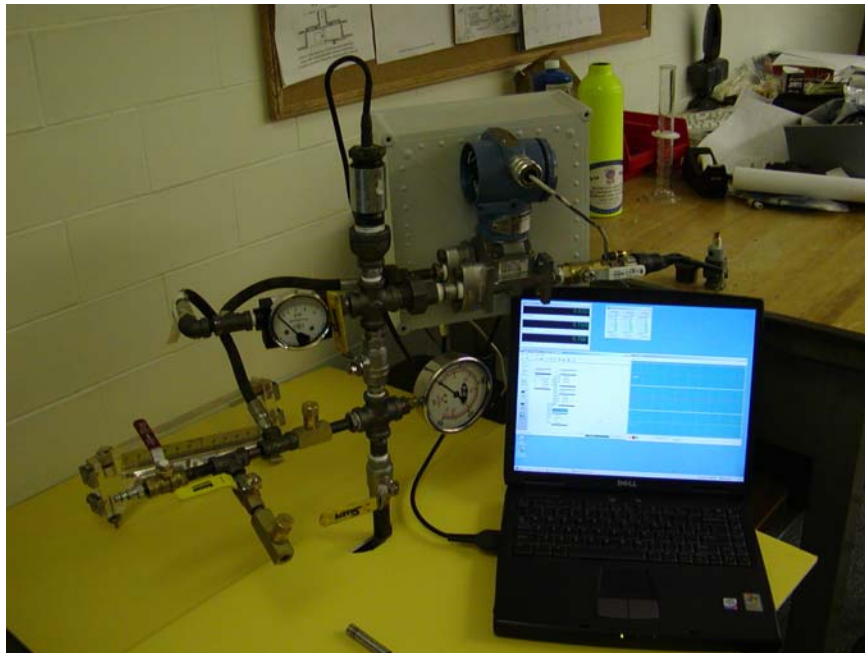


Figure 12 – PAMP with data acquisition unit recording data on 3 channels

IV Results and Discussion

Aerodynamic Δp sensor range amplifier

The Rosemont Inc. differential pressure sensors, are Industry's best total performers. These instruments are safe for use up to line pressures of 1000 psi and are software adjustable in their operating range upward from its minimum value. Also the update rate is adjustable from a minimum of 22 times per second on downward. Thus this instrument is not suitable for measuring signals in the audible frequency range, but very suitable for measuring transient compression and expansion waves associated with sudden pipeline flow rate changes, such as with a piston compressor or the starting and stopping of a leak. For monitoring the audible and higher frequency rate, a microphone and a piezo-electric pressure transducer are used.

Pipeline access for acoustic integrity monitoring instrumentation is limited to a ½"NPT access ports found adjacent to pipeline shut of valves. Because of the long distance between those valves, signal attenuation may be significant. Therefore the most sensitive of all available instruments was selected which is Model 3051CD-Range 0. Its software allows adjusting the range upward up from $\Delta p = 0$ to 3 inch water, with an accuracy of 0.1% of span. Or accuracy is 0.003 inches of water = 0.75 Pa (91.4 dB sound pressure level in decibels = $20 \cdot \log(p \text{ in Pa/Pref}=0.00002 \text{ Pa})$).

Using software to adjust the operating range of the differential pressure sensor is quite elaborate, and not suitable for field trials on a pipeline. Therefore a convenient manual range amplifier was developed at WVU. It allows adjusting the range of the instrument by turning the knob of a color-coded needle valve, which has 10 divisions per turn. Its principle of range amplification is that while one side of the differential sensor is open to the pipeline, the other side is connected to a one-liter accumulator via an adjustable needle (throttle) valve. During outflow transients, the two sides of the instrument drop in pressure at a different rate, which is indicative of the amplitude of the rarefaction wave. This differential pressure sensor arrangement is intended only for measuring step function type acoustic rarefaction waves associated with the sudden opening of a fracture or valve, but not those associated with slowly opening corrosion fractures. The combination of needle valve and accumulator increases the usable range of the instrument:

- 1) with the needle valve closed there is no change in usable range.
- 2) with the needle valve slightly open, an out of range Δp signal will decay to within range, after a constant max signal for a unique time period (t_c), followed by an exponential decay to zero. This is shown schematically in Figure below.

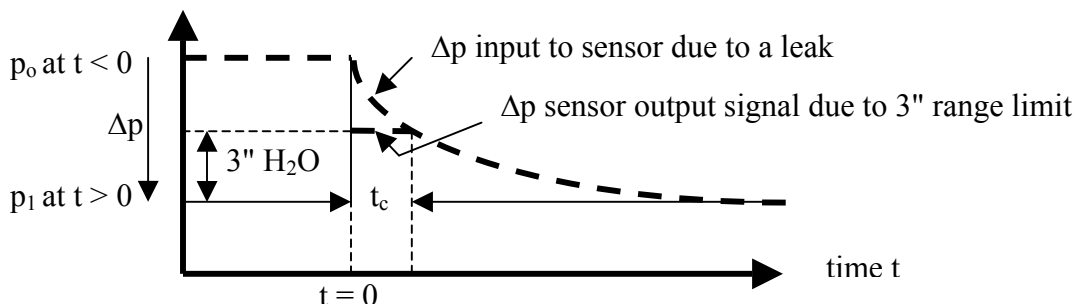


Figure 7 – Pressure time relationship for range amplifier

The measured time period (t_c) can be used to calculate the range amplification factor $Amp = (\text{input step function signal amplitude}) / (3'' \text{ water instrument range})$. During instrument development and calibration, it is much easier to keep the output signal within range by simply turning the knob on a needle valve than by reprogramming the Rosemont instrument software.

Relationship between needle valve setting and the range amplification factor Amp.

During a simulated leak the associated rarefaction wave induces a small out flow rate Q (scfh) through the needle valve. Flow will be low subsonic in a high-pressure pipeline, because the ratio of $\Delta p/p_0$ will be very small. Therefore the gas flow can be considered incompressible and isothermal with density $\rho = p_0/(R*T)$. For example consider methane at pressure $p_0=300$ psia = 2068 bar, temperature $T= 80^\circ\text{F}=300^\circ\text{K}$ and gas constant $R=3109 \text{ ft}\cdot\text{lb}/\text{slug}\cdot\text{R} = 519.6 \text{ J}/\text{kg}\cdot\text{K}$ has density $\rho=p_0/(R*T)=0.0257 \text{ slug}/\text{ft}^3 = 13.27 \text{ kg}/\text{m}^3$.

Because of flow friction inside the valve of area A , only a small fraction of the Δp signal across the valve, will be available to accelerate the flow to a high velocity. That is why the valve is not calibrated with respects to its physical open area A but instead to flow coefficient (cv). The valve knob turns is calibrated against 150 degree F oil flow rate in gallons per minute (GPM) . The coefficient cv is defined by:

$cv = \text{GPM} * \text{SQRT}(Gf/\Delta p)$. Here (Δp) is the pressure ratio across the valve and Gf is the dimensionless ratio of oil density to that of water.

The same (cv) calibration is also low speed gas flow. The relation is then given as:

$Q(\text{scfs}) = 42.2/(144*3600)*cv*[\Delta p *(2*p - \Delta p)/Gf]^{0.5}$, here Gf is ratio of $\rho/\rho_{\text{std air}}$. Because in this application Δp is less than 1% of p_0 one can assume $2*p - \Delta p = 2*p_0$.

In which case: $Q(\text{scfs}) = 42.2/(144*3600)*cv*[2* \Delta p / \rho]^{0.5} [p_0*0.002377(=\rho_{\text{std air}})]^{0.5}$

For the 300 psia natural gas line the ratio $Gf= 0.0257/0.002377=10.82$.

Time period t_c of max. signal indicating delta p range amplification at $p_0 = 300$ psia

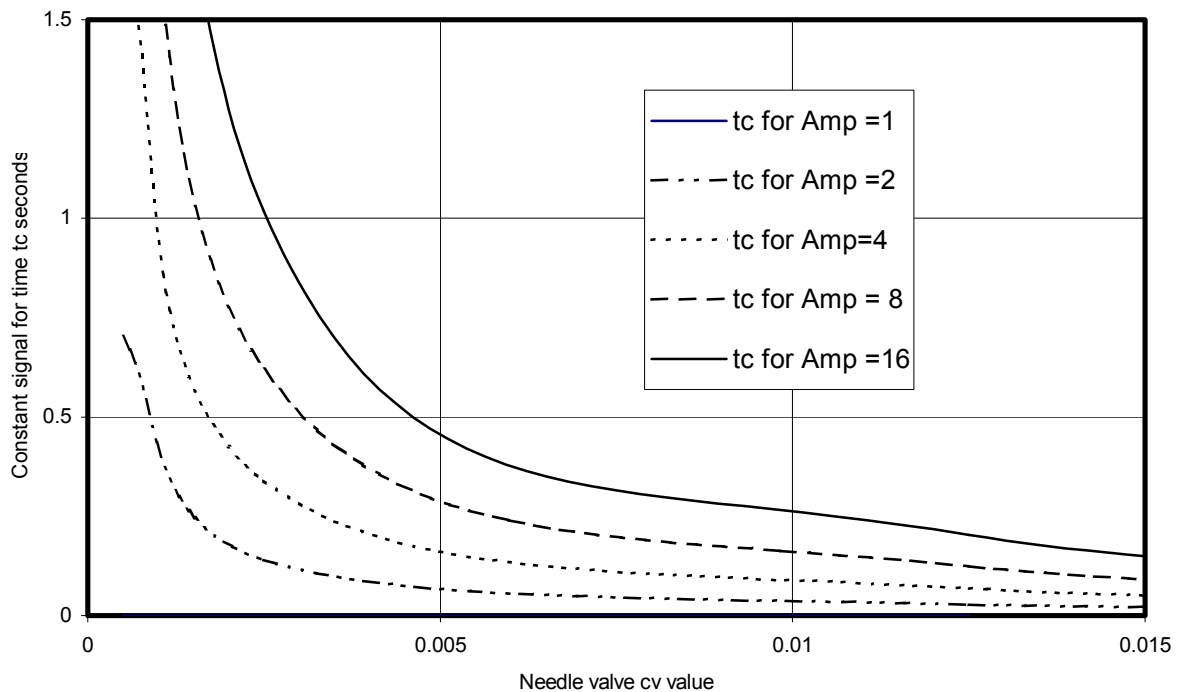


Figure 8 -Typical 1/8th inch NPT needle valve performance

One can also imagine an ideal valve with orifice area A_i and friction free velocity

$$V_i = \sqrt{\frac{2 * \Delta p}{\rho}}. \text{ Then } A_i \text{ becomes a direct function of } c_v \text{ and } p_o, \text{ as } Q = A_i * V_i.$$

Solving for A_i in terms of c_v at a given pressure $p_o = 300$ psia gives:

$$A_i = 42.2 / (144 * 3600) * [p_o * 0.002377 (= \rho \text{ std air})]^{0.5} = 0.000004 * c_v * \text{SQRT}(p_o)$$

For $p_o = 300 * 144$ psfa find: $A_i = 0.000825 * c_v$

Working with friction free areas and velocities simplifies the derivation of the time (t_c) required for the accumulator tank pressure p to drop within 3" water (0.1 psi) of the line pressure: $p_o - \Delta p$.

During this time the sensor output signal will remain steady.

$$Q(\text{scfs}) = 42.2 / (144 * 3600) * (A_i / 0.000004) * V_i * [0.002377 (= \rho \text{ std air})]^{0.5} =$$

From the ideal gas equation find the rate of pressure drop in the $Vol = 1$ liter accumulator

$$\text{pressure } p: \frac{dp}{dt} = \frac{RT}{V_{ol}} * \frac{dm}{dt}. \text{ Using } -Q(\text{scfs}) = \left[\frac{dm}{dt} * \frac{1}{\rho} = \frac{dm}{dt} * \frac{RT}{p_o} \right] = \frac{dp}{dt} * \frac{Vol}{p_o}$$

Substituting Q from above and solving for the rate of pressure drop $\frac{dp}{dt}$ gives:

$$[42.2 / (144 * 3600)] * c_v * \sqrt{2 * p_o / G_f} * \frac{p_o}{Vol} * dt = \frac{-dp}{\sqrt{(p - (p_o - \Delta p))}}. \text{ Integrating gives the delay}$$

time period (t_c) for p to drop from p_o to $(p_o - \Delta p + 3" \text{ water})$.

$$t_c = (\sqrt{\Delta p / p_o} - \sqrt{3" H_2O / p_o}) * \left(\frac{V_{ol}}{A_v} \right) \sqrt{\frac{1}{RT}} \text{ defining the } \Delta p \text{ sensor range amplification factor}$$

$$Amp = \frac{\Delta p}{3" H_2O} \text{ gives: } Amp = \left[\frac{t_c A_v}{Vol * 3" H_2O / p_o} \sqrt{\frac{RT}{2}} + 1 \right]^2 \text{ This allows one to calculate the range}$$

amplification any rarefaction wave when Δp exceeds 3" H_2O , see Figures 9-11.

Inviscid flow of natural gas through orifice A_i at $p_o = 300$ psia

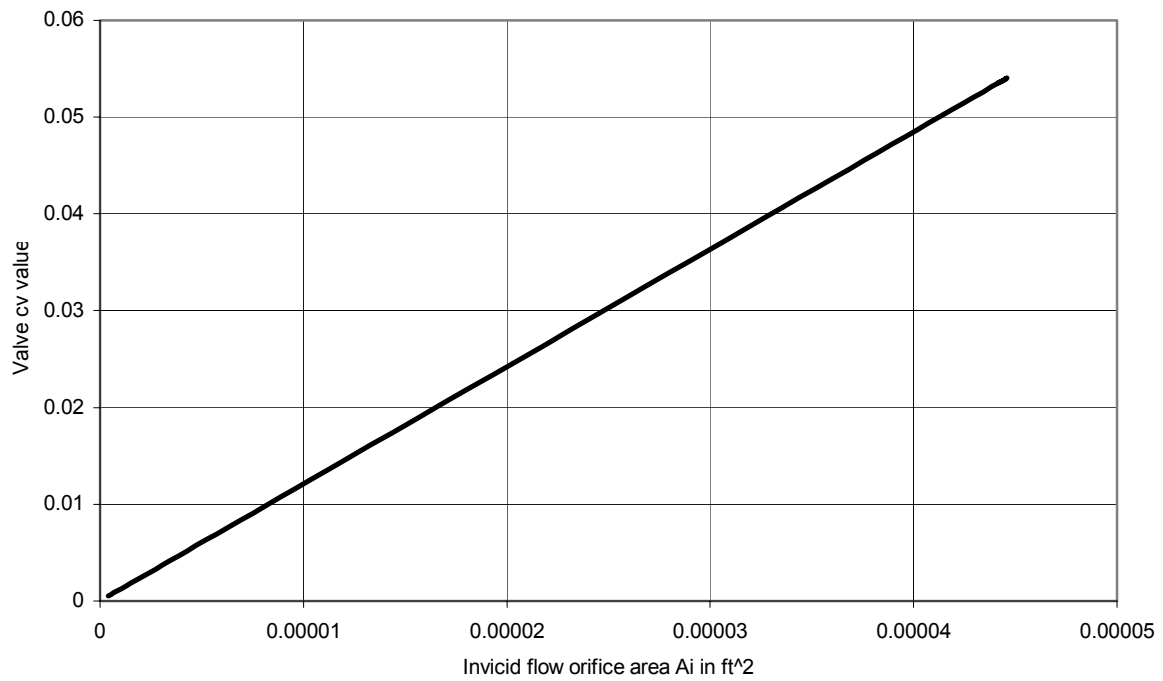


Figure 9 - Inviscid flow of natural gas through orifice A_i at $p_o = 300$ psia

Needle valve SFP10SSB value of cv versus turns open

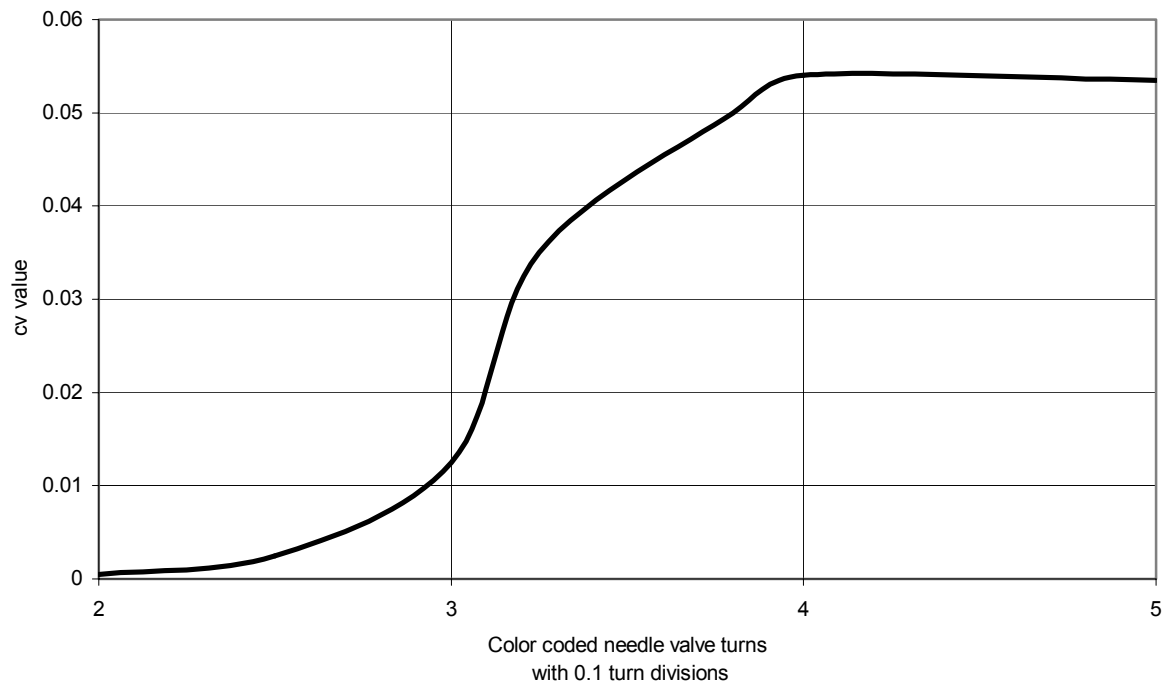


Figure 10 - Needle valve SFP10SSB value of cv versus turns open

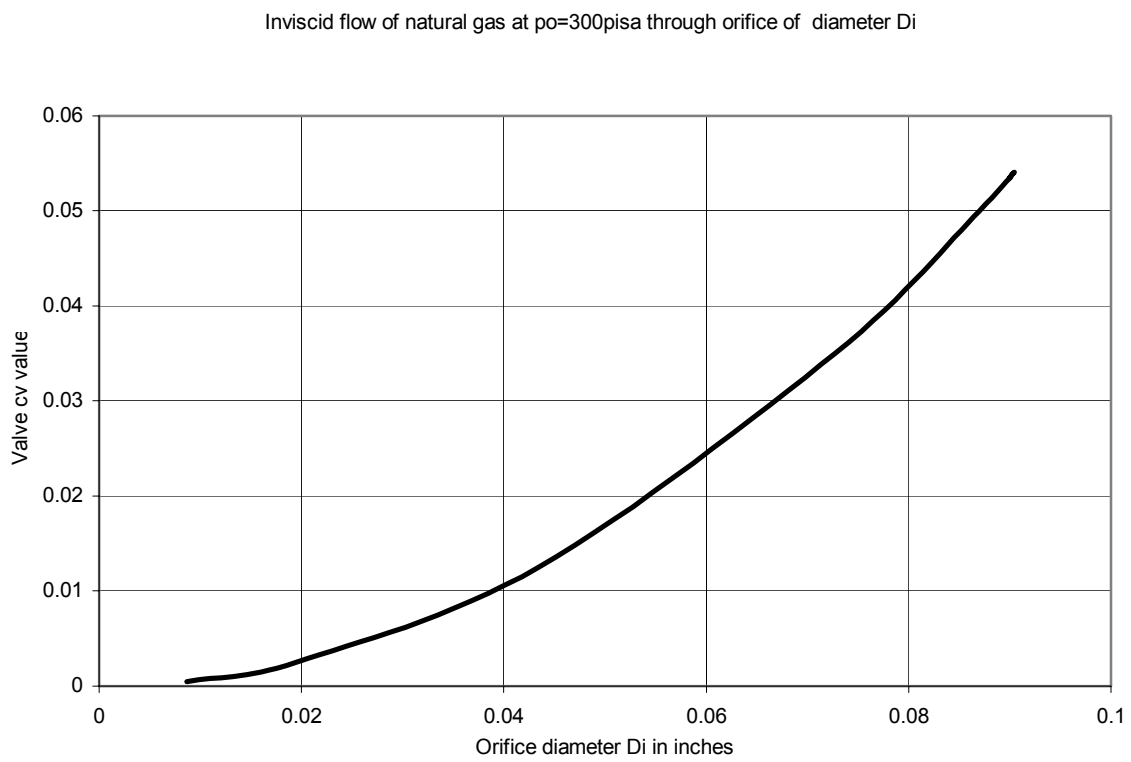


Figure 11 - Inviscid flow of natural gas at $p_o=300$ psia through orifice of diameter D_i

V. Conclusions

Background Noise and Proposed Testing Plan

There is very little documentation in current published literature on the actual acoustic characteristics of the signals generated by various sources in natural gas transmission line systems. To identify damage or leaks in a gas line the various possible background noises must be documented and characterized by their frequency and amplitude content. Through the participation of Dominion Transmission in this project, the WVU team has the opportunity to catalog and characterize a wide variety of transmission line noise sources.

Recent activities have focused on validation of the various sensor and piping combinations with the WVU supersonic wind tunnel and lab apparatus. This focus is now expanding to include field-testing of the most recent configuration. In July 2003 personnel from Dominion Transmission inspected the PAMP. Minor modifications were recommended to make the electronics suitable for hazardous locations. These modifications are currently being carried out. In July, the PAMP was also installed on a line near the Dominion Transmission's North Summit, Pennsylvania storage station to determine the units functionality on an actual transmission line and to record pipe wall signals generated by two 3200 Hp 8 cylinder Cooper V-250 reciprocating compressors at that location. A short time interval recorded by the Model 3031 microphone can be seen in Figure 13.

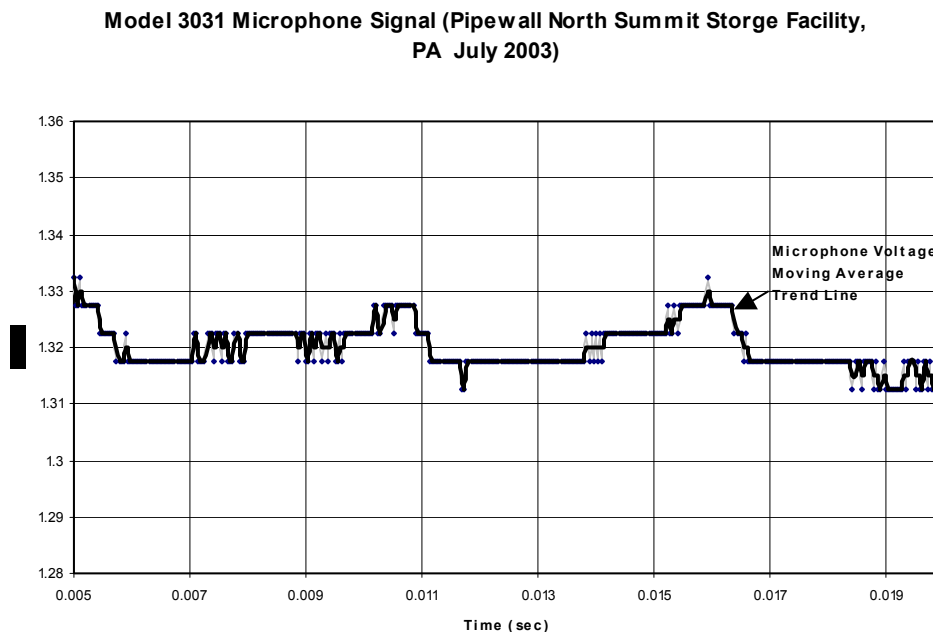


Figure 13 – Snap shot of pipe wall signal recorded at a compressor station near Uniontown, Pa.

Future activities will include the cataloging and characterizing of the most common noise sources associated with transmission line activities. Dominion Transmission has suggested two transmission line systems, which may be suitable for background noise cataloging due to accessibility and line pressures. One system is between Bridgeport, West Virginia and Morgantown, West Virginia. This system has a number of access ports and a line pressures between 200 and 350 psi. The other system is in the vicinity of New Cambridge Ohio. The

system near New Cambridge has a fairly constant line pressure of approximately 850 psi. A unique feature of the Ohio system is that there is one main transmission line, which was installed in a straight line for at least 30 miles. The 30-mile line segment has 2 or 3 access points where the PAMP could be installed. This unique combination of a straight line, a fairly constant line pressure, easy access and a known noise source (Gilmer reciprocating compressor station) will allow noise attenuation effects in an active transmission line to be observed. Table 6 shows the initial plan to catalog background noise.

Noise Source	Location	Line Pressure	Special Considerations
Reciprocation Compressor	North Summit Storage Facility, PA	> 3000 psi	Due to excessive pressures only pipewall and airborne signals will be recorded.
Reciprocation Compressor	Salt Well Road Compressor Station, WV	~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 pipewall 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 pipewall airborne signals will be recorded.
Acoustic Flow Meter	Salt Well Road Compressor Station, WV	~200-350 psi	To characterize flow noise
Rotary Flow Meter	Salt Well Road Compressor Station, WV	~200-350 psi	To characterize flow noise
90 degree turn in Line	Salt Well Road Compressor Station, WV	~200-350 psi	To characterize flow noise
Tee in line	Salt Well Road Compressor Station, WV	~200-350 psi	To characterize flow noise
Gate Valve	Salt Well Road Compressor Station, WV	~200-350 psi	To characterize flow noise
Gate Valve	Salt Well Road Compressor Station, WV	~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 Compressor Station, WV	~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 pipewall 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 6 – West Virginia University proposed testing plan to catalog gas transmission line common noise sources using the July 2003 PAMP



Figure 14 – PAMP installed on transmission line at Dominion Transmissions North Summit storage facility

VI. References

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