PURPOSE: The main purpose is to measure the wave speed for a water pipe and to compare the measured speed with theoretical speeds. Another purpose is to measure the pressure rise generated by a sudden valve closure and to compare this rise with a theoretical pressure rise.

SETUP: The setup consists of a pump which draws water through one long pipe from a tank and sends it back to the same tank through another long pipe. A high speed manual valve is installed just upstream of the pump inlet. A high speed pressure sensor is installed just upstream of the valve. It is used to measure the pressure transients that are generated by a sudden valve closure. The sensor is connected to an oscilloscope.

PROCEDURE: Use a sudden valve closure to determine the pipe period. Use the period to calculate the wave speed of the pipe. Compare the measured wave speed with the speed for a rigid pipe and the speed for a flexible pipe. Calculate the pressure rise for a number of flow rates and in each case compare with the theoretical pressure rise.
WAVE PROPAGATION IN PIPES

The pressure change caused by a flow speed change is

$$\Delta P = -\rho a \Delta S$$

For a wave travelling up a rigid pipe wave speed is

$$a = \sqrt{K/\rho}$$

where $K$ is the bulk modulus of the fluid and $\rho$ is its density. For a flexible pipe wave speed is

$$a = \sqrt{K/\rho}$$

where $K$ is the effective bulk modulus of the pipe

$$K = K / (1 + DK/Ee)$$

where $D$ is its diameter, $e$ is its wall thickness and $E$ is the Elastic Modulus of the pipe wall material. It takes 4 wave transits of a pipe to complete a cycle. This implies

$$T = 4 \ L / a \quad a = 4 \ L / T$$
<table>
<thead>
<tr>
<th>RUN</th>
<th>Q</th>
<th>U</th>
<th>ΔP</th>
<th>ΔP_T</th>
<th>ΔP_E</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LPM</td>
<td>M/S</td>
<td>VOLTS</td>
<td>BAR</td>
<td>BAR</td>
</tr>
</tbody>
</table>
SAMPLE CALCULATIONS

EXPERIMENTAL WAVE SPEED

\[ a_E = \frac{4L}{T} \]

THEORETICAL WAVE SPEEDS

\[ a_R = \sqrt{\frac{K}{\rho}} \]

\[ K = \frac{K}{1 + D K / E e} \]

\[ a_F = \sqrt{K / \rho} \]

PRESSURE RISE

\[ S = M \varphi \]

\[ \Delta P_T = \rho a_E S \]

\[ \Delta P_E = N \Delta P \]
ABS PIPE DATA

L = 13.41 m
D = 40 mm
e = 4 mm
E = 2.2 GPa

WATER DATA

K = 2.2 GPa
\( \rho = 1000 \text{ kg/m}^3 \)

CALIBRATION FACTORS

M = 0.013 [m/s] / [lpm]
N = 1.7 [bar] / [volt]
MINIATURE VOLTAGE OUTPUT PRESSURE SENSORS
FULLY TEMPERATURE COMPENSATED

PX40 Series
0.5 to 4 Vdc Output

PX40-15G5Y, $65, shown much larger than actual size.

All Ranges $65

✓ Smallest Amplified Package
✓ Small Lightweight Package
✓ Fully Signal Conditioned
✓ Temperature Compensated
✓ Port Designed for O-Ring Interface
✓ Excellent Media Compatibility
✓ Wet or Dry Industrial Applications

Typical Applications
✓ Laboratory Equipment
✓ Electronic Brake Systems
✓ Engine Oil Level
✓ Transmission Fluid Level
✓ Air Conditioning Systems
✓ Industrial Fluid Level

SPECIFICATIONS
Excitation: 5 Vdc @ 10 mA
Output Source Current: 0.5 mA max
Output Sink Current: 1.0 mA max
Hysteresis and Repeatability: 0.15% FS
Span: ±0 Vdc Output: Linearity:
±50 mmHg 4.00 Vdc typical 0.90%
0 to 15 psi ±0.11 Vdc 0.20%
0 to 30 psi ±0.08 Vdc 0.30%
0 to 100 psi ±0.09 Vdc 0.10%
0 to 150 psi ±0.07 Vdc 0.10%

Electrical Connection

Dimensions: mm (in)

Null:
±50 mmHg 2.50 ±0.05 Vdc
0 to 15 psi ±0.11 Vdc
0 to 30 psi ±0.04 Vdc
0 to 100 psi ±0.04 Vdc
0 to 150 psi ±0.04 Vdc

Operating Temp:
-45 to 125°C (-49 to 257°F)
Compensated Temp:
-45 to 125°C (-49 to 257°F)

Overpressure:
±50 mmHg ±170 mmHg
0 to 15 psi 45 psi
0 to 30 psi 80 psi
0 to 100 psi 200 psi
0 to 150 psi 300 psi

Response Time: 1 ms
Gage Type: Silicon
Media Compatibility: Limited to media that will not attack inert, copper, silicon, stainless steel, glass and solder (i.e., air, water, refrigerants, engine fuel)
Vent: Dry gases only
Weight: 5 g (0.18 oz)

Recommended Reference Book:
What Every Engineer Should Know About Project Management,
GE-0511, $76
See Section Y
For Additional Books

MOST POPULAR MODELS HIGHLIGHTED!

To Order (Specify Model Number)

<table>
<thead>
<tr>
<th>RANGE</th>
<th>MODEL NO.</th>
<th>PRICE</th>
<th>COMPATIBLE METERS*</th>
</tr>
</thead>
<tbody>
<tr>
<td>±50 mmHg</td>
<td>6.7 kPa</td>
<td>PX40-50BHG5Y</td>
<td>$65</td>
</tr>
<tr>
<td>0 to 15 psi</td>
<td>0 to 1 bar</td>
<td>PX40-15G5V</td>
<td>65</td>
</tr>
<tr>
<td>0 to 30 psi</td>
<td>0 to 2.1 bar</td>
<td>PX40-03G5V</td>
<td>65</td>
</tr>
<tr>
<td>0 to 100 psi</td>
<td>0 to 6.9 bar</td>
<td>PX40-100G5V</td>
<td>65</td>
</tr>
<tr>
<td>0 to 150 psi</td>
<td>0 to 10.3 bar</td>
<td>PX40-150G5V</td>
<td>65</td>
</tr>
</tbody>
</table>

* See section D for compatible meters.

Ordering Example: PX40-15G5Y, 0 to 15 psi transducer with 0.5 to 4.5 Vdc output, $65.