WHITEPAPER

HOW TO SELECT DIFFERENTIAL PRESSURE TRANSDUCERS
For Low Differential, Critical Pressure Applications Part 1

What's Inside

System manufacturers are providing the highest quality, most reliable and most energy efficient automobiles, airplanes, turbine and gas engines and associated components ever produced. This is due to the manufacturers' ever increasing demand for rigorous test and measurement of these products. Differential pressure transducers (DPTs) are an integral part of that process for applications that demand reliability, repeatability and high accuracy.

The performance of today's differential pressure transducers has improved to provide solutions to demanding applications. This paper discusses how differential pressure transducers are used in critical pressure applications, two performance characteristics of a differential pressure transducer, and why they are important to consider when selecting a pressure transducer for low differential, critical pressure applications.

DPTs measure the difference in pressure between two points, typically using a reference pressure other than atmospheric pressure (See Figure1). To do this, the sensor has two ports that allow pressure to be applied to both sides of the sensing element. One port is for the test piece (process port), the other for reference (reference port). The difference in the pressure detected by the DPT produces a highly accurate reading that is proportional to the measured differential pressure.

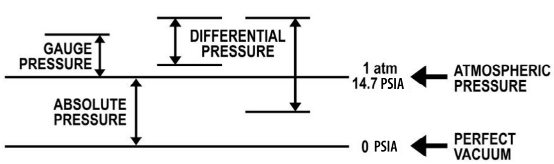

Figure 1: Different Types of Pressure Measurements

1. Low Differential Pressure Transducer Applications

DPTs are typically used in test stands, wind tunnels, leak detection systems and other applications. Engineers for each application look for transducer improvements critical to their industry. For example, engineers who design and use test stands want measuring instruments with very high accuracy because precise airflow measurements are required to calculate system performance. A test stand might use a low pressure transducer to measure gas flow into a diesel engine to determine performance, or it could measure the efficiency of an off-road vehicle engine.

Wind tunnel engineers, on the other hand, are interested in transducers with high accuracy and fast response times. Low-speed wind tunnel applications require measurements of changing air velocities. Therefore, a transducer may be calculating an aircraft's air speed, or it may measure how air flows over an automobile. It even might help determine the optimal curvature and pitch of a wind turbine blade. These applications rely on DPTs for accurate and reliable local air velocity measurements when used in conjunction with a pitot-static probe (See Figure 2).

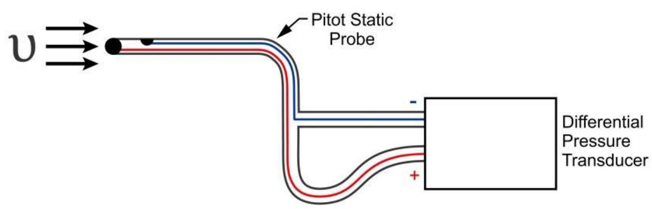

Figure 2: DPT Used to Calculate Air Velocity in a Wind Tunnel

$$\upsilon = \sqrt{\frac{2 * \Delta P}{\rho}}$$

υ = air velocity
ΔP = differential pressure
ρ = air density

Conversely, designers of leak detection systems based on differential pressure decay measurements put a premium on overpressure protection because an accidental overload can easily occur with the high pressures that are applied. These leak detection systems use DPTs to calculate leak rates, based on pressure decay, to determine the sealing integrity of small volume components.

A gas engine may be tested to determine if the seals are leak tight, or process-piping running at high pressures might be monitored to detect leaks. Each channel of a machined casting might be independently sealed and checked to a test specification of 3 scc/m at 90 PSIG. The higher the applied static line pressure, combined with the smaller differential pressures that can be resolved, results in the smaller the leak rate that can be detected (See Figure 3).

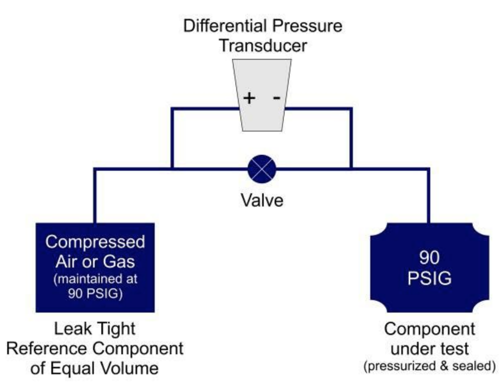

Figure 3: Leak Detection with a DPT

$$Q_{Leak\ Rate} = \frac{V * \Delta P}{\Delta t * P_S}$$

ΔP= differential pressure decay
P_S= static line pressure
Δt= measurement time duration for ΔP
V= component volume

2. Accuracy

Output readings are extremely accurate, down or below ±0.07% FS RSS (Full scale, Root Sum Squared method), as capacitance transducer suppliers reduce noise influence and utilize digital linearization processes. These sensors use a frequency signal output from the sensor instead of an analog signal, which at the 20-40 MHz range reduce the conducted noise entering the circuit. These high frequency signals are easily and precisely measured and "digital ready" for conditioning through digital signal processing.

The accuracy of a pressure transducer is traditionally quantified by the RSS method:

$$\%\ Accuracy_{RSS} = \sqrt{(Non - Linearity)^2 + (Non - Repeatability)^2 + (Hysteresis)^2}$$

Better accuracy, a lower % FS, is achieved when each of the three values are as small as possible. The three characteristics of the accuracy calculation are show in Figures 4-6. Non-repeatability and hysteresis are inherent in the design of the sensing element and are difficult to compensate for during the manufacturing process. Often these values are indicators of the basic quality and stability of the sensor. What is compensated for during the calibration process is non-linearity. The best fit straight line (BFSL or BSL) method of calculating non-linearity fits a straight line through the actual curve in order to minimize the relative error between the actual curve and the straight line. In this case, the end points of the curve have no meaningful relationship to the BFSL.

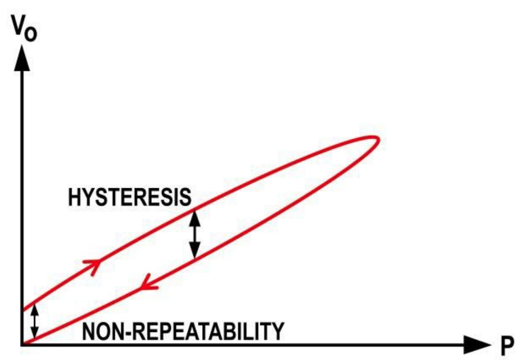

Figure 4: Effects of Non-Repeatability and Hysteresis on a Pressure Transducer Output

The BFSL method of calculating non-linearity fits a straight line through the actual curve in order to minimize the relative error between the actual curve and the straight line. In this case, the end points of the curve have no meaningful relationship to the best fit straight line.

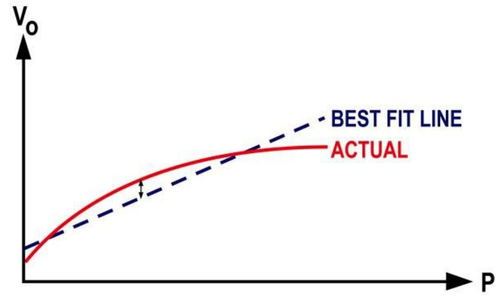

Figure 5: How Non-Linearity is Measured With Best Fit Straight Line Method

A more accurate and stringent method of calculating non-linearity is the end point method (Figure 6), which measures the non-linearity when a straight line is drawn connecting the end points from P0 (zero differential pressure) to PFS (full scale). In this case, the end-point accuracy is preserved when calibration adjustments are made to zero offset or span. The different methods of measuring non-linearity have an effect on how RSS sensor accuracy is reported. For example, a sensor with a ±0.03% non-linearity with the endpoint method could have a ±0.015% non-linearity with the BFSL method. The lower non-linearity number for the BSFL method does not result in improved accuracy.

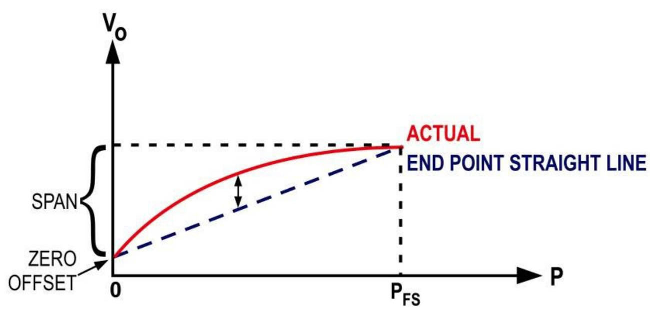

Figure 6: How Non-Linearity is Measured With Stricter Endpoint Method

During the manufacturing process, the transducer performs all digital processing to linearize the output signal. Digital signal linearization accomplishes this more accurately than analog signal linearization. The result is real-time, accurate and reliable data about the state of the monitored process. In addition, digital processing provides a higher degree of immunity from electrical noise than analog processing can offer.

3. Total Error Band

Another significant transducer improvement is total error band (TEB). Since newer transducers are thermally characterized, they are better thermally compensated, which improves TEB. The TEB typically includes maximum uncertainty errors for zero and span offset, zero and span shift, hysteresis, non-linearity and non-repeatability (See Figure 8).

TEB is the difference between the most positive and most negative deviation from the true pressure. It is determined by examining the combination of all possible errors within the constraints of the unit's pressure measurement and operating temperature range. The TEB value is used to define the worst-case performance of a transducer over its compensated temperature range.

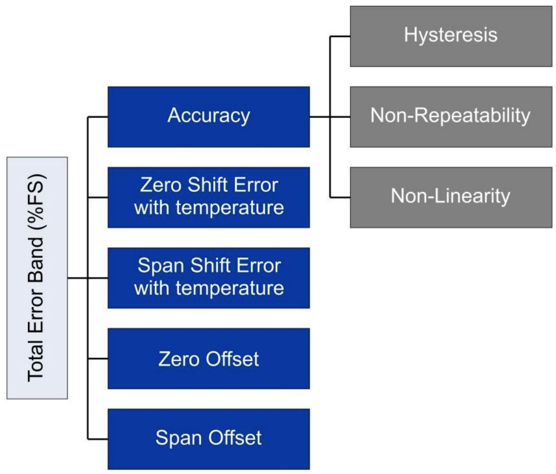

Figure 7: Total Error Band (TEB)

A sensor is characterized over its calibrated temperature range, for example -20° to 60°C. In this process, data are collected in the manufacturing process by recording the zero offset and span at different temperatures through an automated manufacturing process. A non-linear curve-fitting algorithm is performed to characterize unique sensor behavior. Through this process, compensation data are permanently loaded in each transducer to actively compensate for thermal environmental effects. The result is a TEB of <0.5% FS over the wide compensated temperature range.

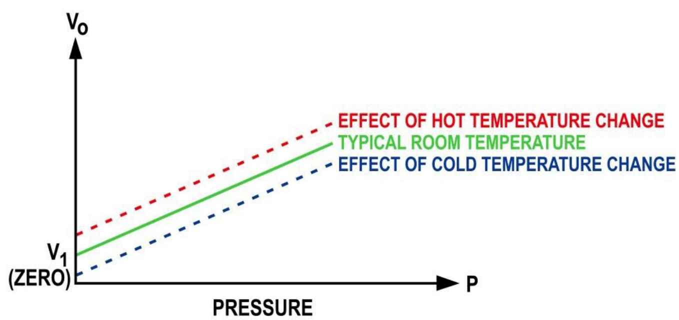

Figure 8: Example of Temperature Effect on Zero

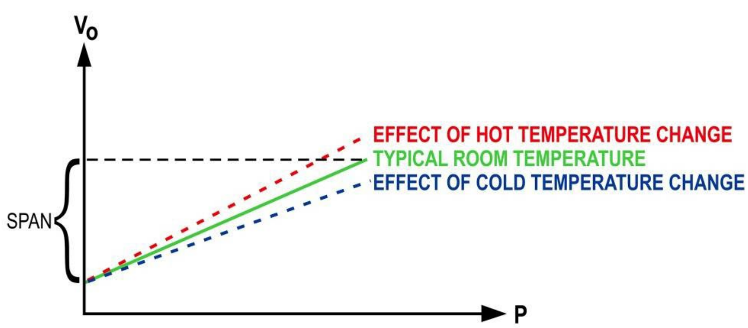

Figure 9: Example of Temperature Effect on Span

Of all environmental factors, temperature influences signal output the most. Try to avoid overlooking the importance of selecting a sensor with low thermal error to achieve the best performance over the operating temperature range.

Author Bio:
Gino Pinto is the Manager of R&D Engineering at Setra Systems Inc. where he has worked for over 17 years with primary responsibilities in research, design and new Product Development. With over 28 years of industry experience, Gino had also worked at successful start-up companies having since been acquired by Motorola, Goodrich Corp., and Gefran Inc. Gino received his Masters of Science in Mechanical Engineering and BSME from UMass Lowell and holds 9 US patents related to sensing devices.

About Setra:
Founded by former professors of Engineering at Massachusetts Institute of Technology (M.I.T.), Setra has been designing and manufacturing sensor products since 1967. Our specialty is in the pressure and sensing in a wide range of markets including HVAC/R building automation, pharmaceutical, energy, medical sterilization, industrial OEM, test & measurement, meteorology and semiconductor.

Setra Creates Solutions:
- Over 40 years of expertise in sensing and sensing applications
- R&D and Design Engineerings focused providing application solutions
- Sensors cover a wide range of pressure rages with unique expertise in low pressures
- Sales and manufacturing in the U.S., Europe, and Asia for fast solutions and products