Understanding manufacturers' performance specifications is a necessary step in choosing the right transducer for the job.

What Transducer Performance Specs Really Mean

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Performance is the word commonly used to describe how well something works under actual operating conditions. In selecting a pressure transducer, expectations regarding performance are typically influenced to a significant extent by the manufacturer's specifications as they relate to the three largest components of transducer error: reference accuracy, thermal error, and long-term drift.

The prudent transducer user will take the time to understand precisely what is being described by each of these specifications, which is particularly important when making comparisons because there may be differences from one manufacturer to another in the methods used to establish specs. Further, some manufacturers' figures may represent "typical error," while others may be stating worst-case error potential. In some transducer applications, the variations in how specification figures are calculated and presented—and the small differences in absolute values themselves—may have relatively little significance. In some situations, however, confidence in performance, especially in terms of initially tighter accuracy and less drift, becomes particularly desirable, as in the case, for example, of sensing probes that may be difficult to access or replace. The need for the greatest possible accuracy is also critical when transducers are used in equipment that is held as the standard for test and measurement procedures. In certain applications such as process control, of course, compromises of any sort are typically unacceptable.

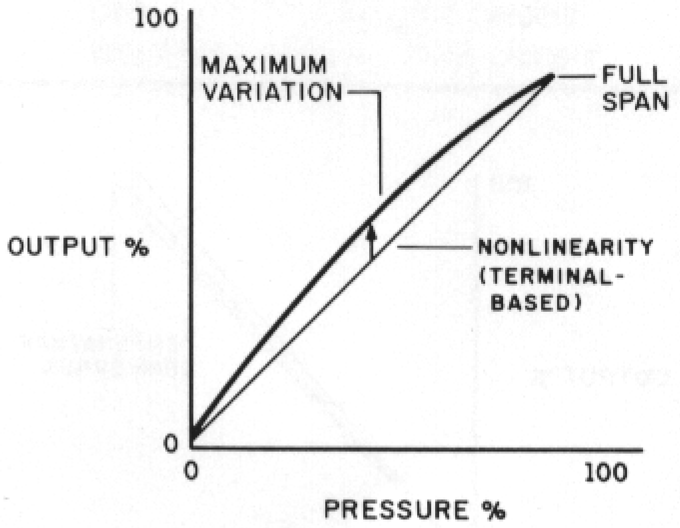

Figure 1. *The linear response curve of silicon overlayed over a straight line representing the theoretical linearity ideal indicates a direct correlation between pressure and output.*

With these points in mind, an examination of the major components of transducer error—reference accuracy, thermal error, and long-term drift—is in order.

► Reference Accuracy. Reference accuracy can be defined as the combination of errors resulting from nonlinearity, hysteresis, and nonrepeatability.

Nonlinearity, the greatest deviation of transducer output from a specified straight line, is the most significant contributor to inaccuracy. It is also an area with special potential for confusion about the real meaning of the specifications. In essence, only two methods are used to specify nonlinearity. By far the method most commonly used by manufacturers is called "best-fit-straight-line" (BFSL) specification. The other method, "terminal-based" (TB) specification, is more stringent and is used by manufacturers of high-performance sensors.

Figure 1 shows the linear response curve

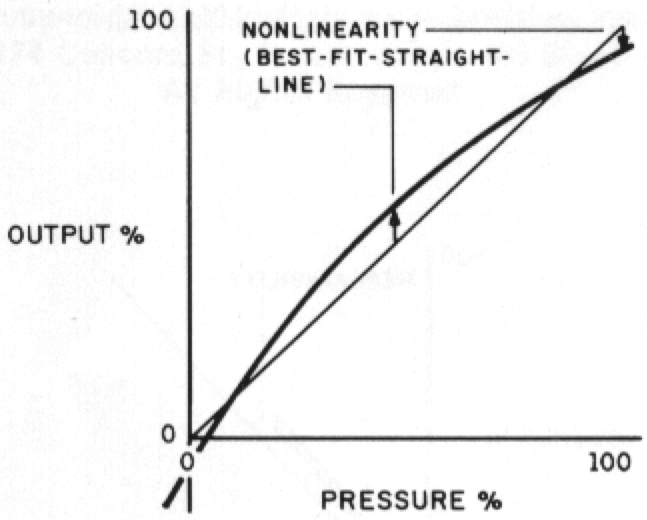

Figure 2. *To specify linearity using the best-fit-straight-line calculation, the curve representing the actual performance of the transducer is "fitted" to the ideal linearity line in such a way as to minimize the sum of the root-mean-square errors occurring at any point between the two. The error percentage is a plus or minus percentage approximated by dividing x by 2.*

Table 1
Comparison of TB and BFSL Calibration

Terminal-based		**Best-fit-straight-line**
≤0.5 percent (The error will never exceed 0.5 percent.)	=	±0.25 percent (The error will be within ±0.25 percent.)

of silicon overlayed over a straight line representing the theoretical linearity ideal—a direct correlation between pressure and output. Because the curve is smooth and parabolic, it is possible to fix maximum variation between the curve and the theoretical ideal at about midway between the base point (zero pressure) and 100 percent output.

To specify linearity using the BFSL calculation, the curve representing the transducer's actual performance is "fitted" to the ideal linearity line in such a way as to minimize errors relative to the ideal. This method produces a result similar to that depicted in Figure 2; however, the error percentage is actually a plus or minus percentage relative to the ideal.

In contrast, with terminal-based specs, the zero pressure (zero output) point and 100 percent pressure (100 percent output) point are "terminals" to which the actual performance of the transducer is fixed, as shown in Figure 1. In this case, variation at its greatest point, midspan, is specified as nonlinearity and is always expressed as equal to or less than the ideal, not as a plus or minus percentage. This will always define the worst-case condition. For a given transducer, the stated TB specification will be double that defined by the BFSL technique.

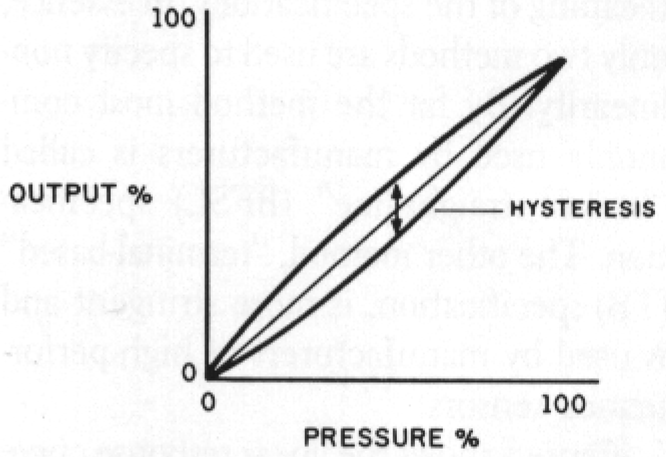

Figure 3. *Hysteresis is the difference in output reading at a given pressure point when the pressure point is approached first with increasing pressure from zero, and then with decreasing pressure from full scale.*

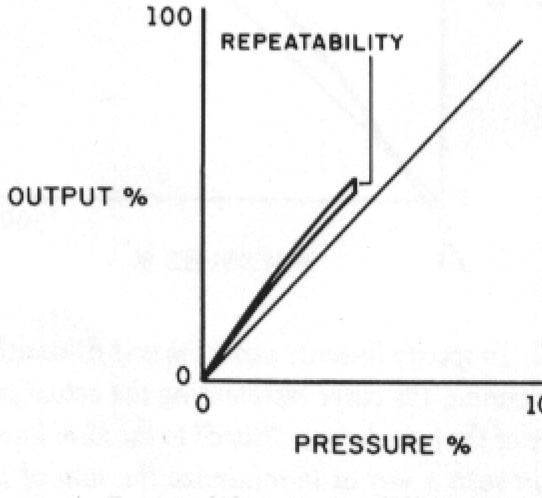

Figure 4. *Repeatability is the difference in output reading at a given pressure point when the pressure is applied consecutively from the same direction.*

The real sensor error for a given transducer is fixed regardless of which method is used. The difference between the two specifications becomes important, however, when attempting to achieve maximum accuracy. Technically, it is more difficult to calibrate a transducer because of the multiple points required to determine true BFSL performance. Therefore, transducers are usually calibrated using TB techniques (zero, full-scale, and mid-range), but are specified using BFSL terminology. The result is that a user following these methods will note that the real, terminal-based, maximum error is expressed as a number twice that specified by BFSL. For example, see Table 1.

On the other hand, because the TB specification is based on absolute accuracy at zero and F.S., the worst possible case, usually at mid-range, will never exceed the unit's specified nonlinearity. Further, if the user so desires, a transducer specified at ≤5 percent using TB specs can be calibrated and tweaked to BFSL techniques by using at least five points to find the theoretical straight line.

Hysteresis is the difference in output reading at a given pressure point when the pressure point is approached first with increasing pressure from zero, and then with decreasing pressure from F.S., as shown in Figure 3.

Repeatability, on the other hand, is the difference in output reading at a given pressure point when the pressure is applied consecutively from the same direction, as shown in Figure 4.

Fortunately, today's solid-state sensors use silicon, which has nearly perfect elasticity; therefore, no work-hardening or creep occurs over time. Consequently, the significance of hysteresis and repeatability errors is extremely small—which allows standard high-performance sensors to achieve up to 99.95 percent linearity (BFSL).

► **Thermal Error.** Thermal or temperature performance is specified over a compensated temperature range (typically 100°F) and, within this range, temperature performance will virtually always be within specifications. It is distinct from the transducer's full potential temperature operating range (which could exceed 200°F), and is the range within which the transducer is typically temperature compensated and can be used without damage or permanent changes in performance characteristics.

Thermal error is determined by two components: temperature zero error and temperature span error. The former, shown in Figure 5, is simply the change at zero output that results from variations in temperature with no pressure applied to the transducer.

Temperature span error, shown in

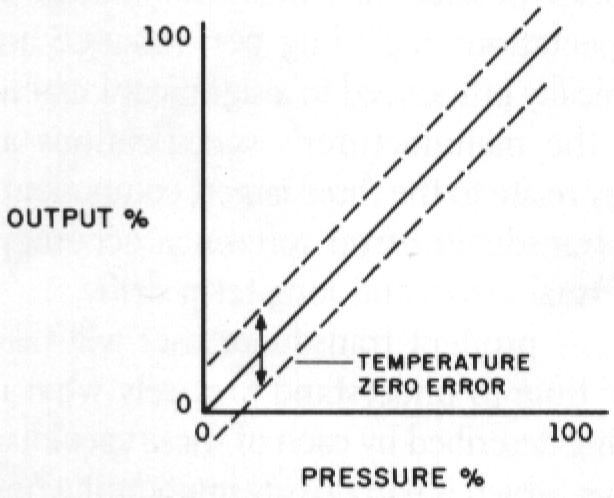

Figure 5. *Temperature zero error is the change at zero output that results from variations in temperature with no pressure being applied to the transducer.*

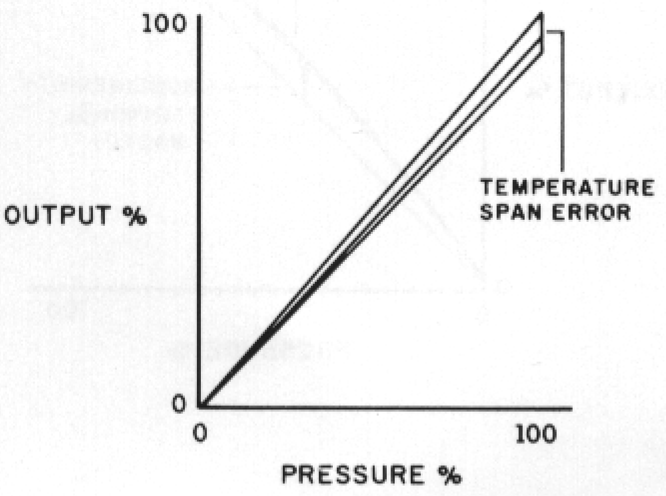

Figure 6. *Temperature span error is the change in output that results from temperature changes while the transducer is under full-scale pressure, assuming no zero shift.*

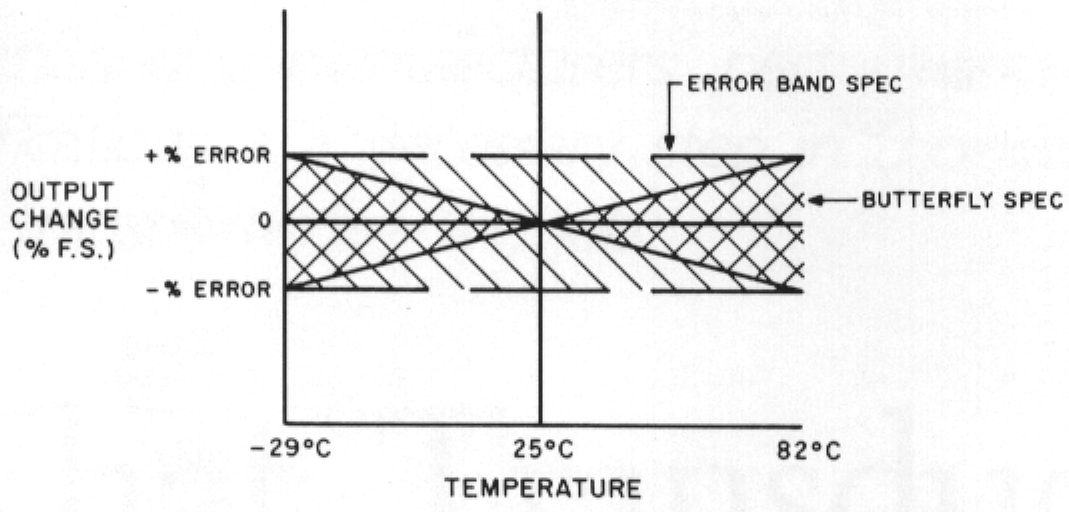

Figure 7. *Temperature zero error and temperature span error can be expressed as a butterfly specification (shown) or in terms of the percent of full-scale span per degree of temperature change from 25°C (room temperature).*

Figure 6, is the change in output that results from temperature changes while the transducer is under F.S. pressure, assuming no zero shift.

To enable transducer users to determine the thermal error that can be expected for their actual temperature conditions, both temperature zero error and temperature span error are expressed, either as a butterfly specification (see Figure 7) or in terms of the percent of F.S. span per degree of temperature change (percent F.S./°C) from 25°C (room temperature).

Temperature performance may also be specified as an error band (percent of F.S. error over a given temperature range). Specification by this method, which is less stringent, means that transducer error could be any value within the error band at any point within the compensated range of the device.

► **Long-Term Drift.** Drift is expressed as the percentage change in calibrated output over a specified period, usually 6 or 12 months, under normal operating conditions; it is usually given as a typical value because testing each transducer for drift is impractical.

One major cause of long-term drift, work-hardening of the sensing element, can be minimized either by using transducers with silicon sensing elements, or by using a sensor package design without mechanical linkages to transmit the pressure to the silicon sensor. One especially satisfactory package uses a thin SS diaphragm and a fluid coupling to the sensor; the coupling does not affect the measurement. The diaphragm should be large enough to have a minimal effect on the sensor and to provide excellent protection (isolation) from the media.

CALCULATING OVERALL PERFORMANCE

Users interested in determining overall performance can use one of two methods.

Table 2
Worst-Case Error Calculation

Accuracy = ±0.25 percent
Drift = ±0.2 percent
Worst-case error = 1.45 percent
Thermal zero error = ±0.5 percent
Thermal span error = ±0.5 percent.

The first method requires determining the algebraic sum of the performance errors (worst-case error). Worst-case error assumes that all errors add in the same direction, which is unlikely (see Table 2).

The other method, which is well accepted and offers a good representation of typical transducer performance, uses the root-mean-square of all the error components, as in:

0.25 + 0.2 + 0.5 + 0.5 = ±0.78 percent worst-case error.

RMS does not assume all errors are in one direction.

In summary, today's transducer purchasers are fortunate in having a large selection of reputable suppliers and quality products from which to choose. By doing their homework on the way performance factors are defined, calculated, and presented, users can make confident decisions geared to acquiring pressure sensing products that precisely match cost and performance needs.

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