Displacement Transducers and Accuracy Classification per ASTM E2309

Driving test machine variability out of the material testing equation is critical to success. With the potential for as many as thirty parameters affecting measurement uncertainty, it is important to identify sources of possible error and then work to minimize them. And in this pursuit, confidence in displacement measurements becomes increasingly important. In some cases, displacement measurement accuracy requirements can approach accuracy requirements similar to those for force (ASTM E4/ISO7500) or strain (ASTM E83/ISO9513) measurements.

DISPLACEMENT MEASUREMENT STANDARDS

First published in 2005, ASTM E2309 applies to linear variable displacement transformers (LVDTs) and any other transducer measuring displacement. Stated more broadly, ASTM E2309 is used to verify displacement measuring systems and devices used in material testing machines.

ASTM E2309 provides greater confidence in measurement repeatability by requiring two runs of data to capture variance. ASTM E2309 also has multiple accuracy classifications similar to ASTM E83 for the verification of extensometers. Each classification has a relative error criteria in % of reading plus a fixed error.

With ASTM E2309, measurement performance may be classified for various portions of the physical range as well as for the entire range.
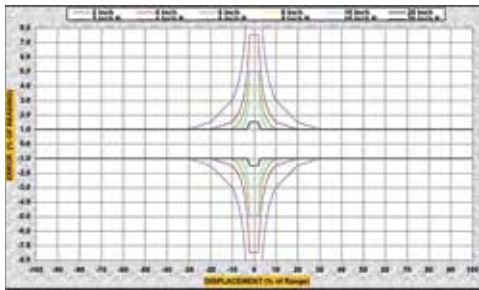
ASTM E2309 ACCURACY CLASSIFICATION

ASTM E2309 has four levels of accuracy classification. Within each classification are two primary accuracy specifications called Relative Error (% of reading) and Fixed Error (essentially a static floor specification). A third specification associated with measurement resolution also exists but is rather insignificant at this point in the discussion.

Classification *Relative Error *Fixed Error (*whichever is greater)

» **Class A** ± 0.5% of Reading or ± 0.001 Inch (0.025 mm)
» **Class B** ± 1.0% of Reading or ± 0.003 Inch (0.075 mm)
» **Class C** ± 2.0% of Reading or ± 0.005 Inch (0.125 mm)
» **Class D** ± 3.0% of Reading or ± 0.010 Inch (0.250 mm)

ASTM E2309 Class B Accuracy Tolerance Summary
ASTM E2309 Class B accuracy tolerance (±1% of reading or ±0.003 inch) converted to % of Reading

Tightly grouped repetitive test data from identical test articles is always preferred over loosely grouped data.

The accompanying graph helps illustrate the Class B tolerance bands for 2, 4, 6, 8, 10, and 20-inch full-length LVDTs or equivalent displacement transducers.

Important to note, as shown in this graph, ASTM E2309 places greater rigor on low-end measurement as the full range of the displacement device increases. The standard effectively establishes a measurement floor proportional to the full scale of the measurement device. The purposeful intent illustrates the axiom: "do not use a yardstick to do the work of a micrometer!"

The four levels of accuracy classification within ASTM E2309 provide a consistent reference for displacement measurement and the means to establish specific accuracy classification requirements.
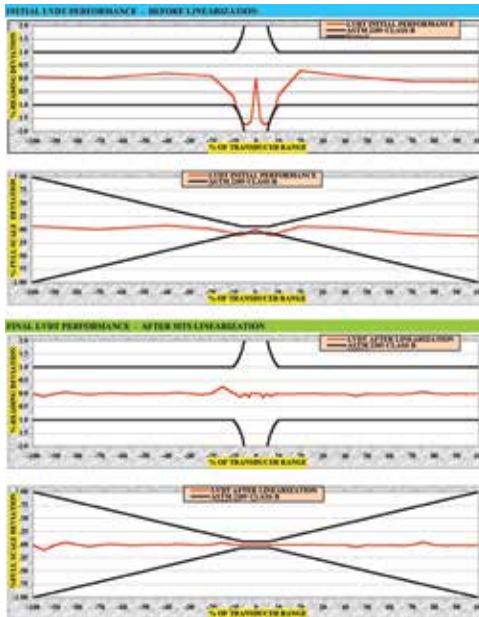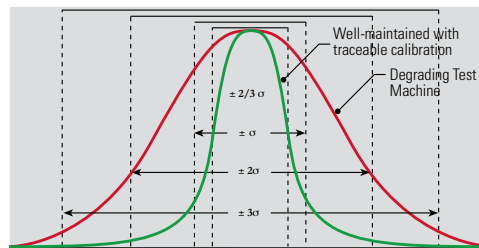
CHALLENGES TO MAINTAINING LVDT ACCURACY

LVDTs are prone to greater non-linearity performance over different portions of their travel than the typical strain-gage transducer. LVDTs by design are variable AC transformers where cable capacitance, impedance, demodulator phase variation, and slight variability in the physical winding of the transformer and its matched core are all sources of non-linearity which contribute to measurement errors. The worst-case non-linear portion of the LVDT working range typically defines its accuracy. This is most often seen when approaching the null crossing region of the physical range. A variety of linearization techniques can be applied to address this non-linearity across the working range. The plots to the left illustrate how a typical 10-inch stroke LVDT performs as compared to the E2309 Class B tolerance bands before and after linearization.

The "seagull" effect within the top plots is attributed primarily to variance in windings through the null region. MTS has a full complement of advanced normalizing and linearization algorithms as reflected in plots 3 and 4.

ASTM E2309 provides the means to classify different portions of the displacement range. Independently classifying accuracy performance in the <10% region and the >10% region provides definitive information of the entire range. This is far better than simply not taking traceable measurements in the <10% region during sensor calibration. Again, it is far better to know the performance classification than to assume performance in an undefined sensor region.

LVDT WEAR AND DEGRADATION OVER TIME

Other challenges to maintaining LVDT measurement accuracy are normal wear and degradation. LVDTs are subject to wear over time often related to how well the transformer and its core stay in concentric and angular alignment to one another over the full length of travel. External contamination in the form of dirt over long-term use also contributes to accelerated wear. Over time, both can contribute to changes in linearity and accuracy prior to ultimate sensor failure. Trends derived via performing periodic calibration can provide an indication of these changes over time.
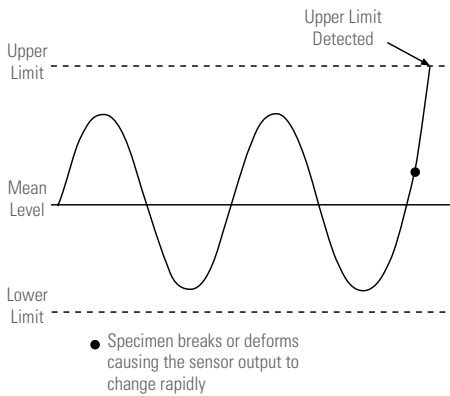
IMPORTANCE OF DISPLACEMENT CALIBRATION

Periodic calibration establishes a historical relationship between the value indicated by a measuring instrument or measuring system and the corresponding calibration standard.

MTS recommends and performs annual displacement calibration using traceable standards. The calibration process determines if the performance of the device is within acceptable tolerances as defined by specifications and the requirements the test application has for the particular displacement device.

Upper Limit
Detected

Upper
Limit

Mean
Level

Lower
Limit

● Specimen breaks or deforms
causing the sensor output to
change rapidly

Limit Detection

UNDERSTANDING ACCURACY REQUIREMENTS

Test applications are diverse and different applications place different requirements for accuracy on the primary displacement device. For example, a displacement device used for limit detection will have a different accuracy requirement than if it is used for direct measure of specimen deformation.

*Example 1: Limit Detection*

To illustrate limit detection, suppose a test is to cycle ±10KN applied force and the resulting displacement approximates ±1 centimeter about the mean level. Setting the displacement limits slightly beyond the expected operating range detects unexpected changes. Primarily, this state change detection has a repeatability requirement.

Example 2: Cascade Control

Cascade Control provides another example of how displacement feedback can be used for control stability rather than data collection. This control mode is used for specimen testing that requires a high degree of stability under dynamic conditions. This mode uses two sensor feedback signals as illustrated in the diagram. In this configuration, force feedback accuracy is the prime interest for specimen data collection. The displacement channel provides the stability required to ensure a highly repetitive applied force through the test article.

In the examples of limit detection and cascade control, stability and repeatability are most critical while accuracy of the displacement device remains important yet to a lesser degree in the overall application perspective.
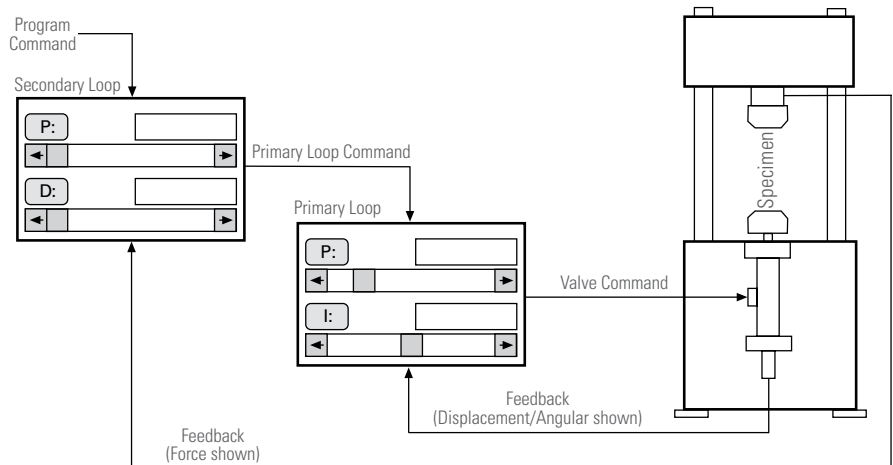
Cascade Control Diagram

MAGNETOSTRICTIVE POSITION SENSORS – AN LVDT ALTERNATIVE

Magnetostrictive linear displacement transducers measure the position of an external permanent magnet that can be attached to an actuator piston rod or any moving machine part. Within the sensing element, a sonic strain pulse is induced in a specially-designed magnetostrictive waveguide by the momentary interaction of two magnetic fields. One field comes from a movable permanent magnet that passes along the outside of the sensor. The other field comes from an "interrogation" current pulse applied along

the waveguide. The resulting strain pulse travels along the waveguide and is detected at the head of the sensing element. The position of the magnet is determined by measuring the elapsed time between the application of the interrogation pulse and the arrival of the resulting strain pulse with a high speed counter. Using the elapsed time to determine position of the permanent magnet provides an absolute position reading that never needs re-homing after a power loss. Non-contact sensing eliminates wear, and provides durability and output repeatability.

These sensors typically provide E2309 Class A performance over an entire physical range >100cm where an LVDT can struggle to achieve Class C over the physical range at the >25cm lengths using typical linearization algorithms.

Magnetostrictive position sensors offer extraordinary high linearity over very long stroke lengths (>100cm) and are capable of performing in close loop control @ 50Hz dynamic with velocities of up to 50cm/sec.

SUPERIOR SYSTEM ANALYSIS WITH ASTM E2309 CALIBRATION

Classifying the measurement performance of the test system's displacement sensor per ASTM E2309 will increase confidence in test results.

Additionally, MTS Field Service Engineers employ the principles and philosophy of end-to-end calibration. Essentially this means that the system-level field calibration practice involves all the elements involved in the measurement process, including the transducer, cables, conditioners and controllers. By examining a system this way, MTS provides you with a higher quality calibration with a reduced risk of error. The elements of the system are evaluated as a unit, eliminating considerable uncertainty.

Periodic MTS calibration and routine maintenance solutions are designed to help ensure that your test machines are consistently delivering accurate and repeatable data. Integral to this solution is the ability to periodically validate the integrity of your measuring devices.