Designation: D 6027 – 96$^{\epsilon 1}$

# Standard Practice for Calibrating Linear Displacement Transducers for Geotechnical Purposes[1]

This standard is issued under the fixed designation D 6027; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

$\epsilon^1$ NOTE—This standard was corrected editorially in January 2000.

## 1. Scope

1.1 This practice outlines the procedure for calibrating linear displacement transducers (LDTs) and their readout systems for geotechnical purposes. It covers any transducer used to measure displacement which gives an electrical output that is linearly proportional to displacement. This includes linear variable displacement transducers (LVDTs), linear displacement transducers (LDTs) and linear strain transducers (LSTs).

1.2 This calibration procedure is used to determine the relationship between output of the transducer and its readout system and change in length. This relationship is used to convert readings from the transducer readout system into engineering units.

1.3 This calibration procedure also is used to determine the accuracy of the transducer and its readout system over the range of its use to compare with the manufacturer's specifications for the instrument and the suitability of the instrument for a specific application.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

## 2. Referenced Documents

2.1 *ASTM Standards:*

D 653 Terminology Relating to Soil, Rock, and Contained Fluids[2]

## 3. Terminology

3.1 *Definitions*—Definitions of terms used in this practice are in accordance with Terminology D 653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *calibrated range*, *n*—distance for which the transducer is calibrated.

3.2.2 *core*, *n*—central rod that moves in and out of the transducer body.

3.2.3 *linear displacement transducer (LDT) or linear variable displacement transducer (LVDT)*, *n*—an electrical transducer which converts linear displacement to electrical output. A LVDT consists of a LVDT body and a LVDT core which can be removed. A LDT holds the core within the sensor body.

3.2.4 *null position*, *n*—the core position within the sensor body at which the transducer voltage output is zero (some transducers may not have a null position).

3.2.5 *percent error*, *n*—the difference between a measurement of a reference standard and the actual length of the reference standard divided by the reference standard and the result converted to percent.

3.2.6 *power supply*, *n*—a voltage source with output equal to that required by the sensor.

3.2.6.1 *Discussion*—Some LVDTs use ac voltage while others use dc. The LVDTs and LDTs may be damaged if connected to the incorrect power supply.

3.2.7 *readout system*, *n*—electronic equipment that accepts output from the signal conditioner for the transducer and provides a visual display or digital record of the transducer output.

3.2.8 *repeatability voltage error*, *n*—the difference in voltage output for successive measurements of the same reference standard.

3.2.9 *signal conditioner*, *n*—electronic equipment that makes the output of the transducer compatible with the readout system. The signal conditioner may also filter the transducer output to remove noise.

3.2.10 *total linear range (TLR)*, *n*—total distance that the core may move from the position of maximum voltage output through the null position to the position of minimum voltage output with a linear relationship between displacement and voltage.

3.2.11 *traceability certificate*, *n*—a certificate of inspection certifying that the transducer meets indicated specifications for its particular grade or model and whose accuracy is traceable to

[1] This practice is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.95 on Information Retrieval and Data Automation.

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[2] *Annual Book of ASTM Standards*, Vol 04.08.

the National Institute of Standards and Technology or to another international standard.

## 4. Summary of Practice

4.1 A displacement transducer is mounted in a manner to permit it to be subjected to a precise, known displacement.

4.2 Displacement is applied in steps over the full range of the transducer and readings taken from the readout device.

4.3 The slope of the best-fit straight line relating sensor readout data to displacement is determined by linear regression.

4.4 The percent error of the transducer readout system is calculated and compared with the requirements for the specific use of the sensor.

## 5. Significance and Use

5.1 The LDTs play an important role in geotechnical applications to measure change in dimensions of specimens.

5.2 The LDTs must be calibrated for use in the laboratory to ensure reliable conversions of the sensor's electrical output to engineering units.

5.3 The LDTs should be calibrated before initial use, at least annually thereafter, after any change in the electronic configuration that employs the sensor, after any significant change in test conditions using the transducer that differ from conditions during the last calibration, and after any physical action on the transducer that might affect its response.

5.4 LDTs generally have a working range within which voltage output is linearly proportional to displacement of the transducer. This procedure is applicable to the linear range of the transducer. Recommended practice is to use the LDT only within its linear working range.

## 6. Apparatus

6.1 *Linear Displacement Transducer*, to be calibrated.

6.2 *Power Supply with Output*, equal to that required by the sensor.

NOTE 1—Some LVDTs use ac voltage while others use dc. The LVDTs and LDTs may be damaged if connected to the incorrect power supply.

6.3 *Signal Conditioning, Readout Equipment, and Related Cables and Fittings*.

6.4 *Test Method A—Precision Gage Block Calibration*:

6.4.1 *Precision Gage Blocks*, a set of precision reference blocks traceable to the National Institute for Standards and Technology. A gage block set should contain sizes necessary to perform satisfactorily the calibration procedures as outlined in Section 9 over the total linear range of the transducer.

6.4.2 *Comparator Stand*, consisting of a base of warp-free stability and ground to a guaranteed flatness, a support column, and an adjustable arm onto which the sensor mounting block can be securely attached. Alternatively, mount the sensor in the configuration it will be used in such a way that gage blocks can be inserted to displace the core for calibration purposes.

6.4.3 *Sensor Mounting Block*, a device used to attach the sensor to the comparator stand. Alternatively, mount the sensor to the test equipment in which the transducer is to be used.

6.5 *Test Method B—Micrometer Fixture Calibration*:

6.5.1 *Micrometer Fixture*, a precision instrument for linear measurement capable of obtaining readings over the total linear range of the LDT. The spindle must be nonrotating and spring loaded. The micrometer fixture is to be calibrated annually by the manufacturer or other qualified personnel.

## 7. Hazards

7.1 **Safety Hazards:**

7.1.1 This practice involves electrical equipment. Verify that all electrical wiring is connected properly and that the power supply and signal conditioner are grounded properly to prevent electrical shock to the operator. Take necessary precautions to avoid exposure to power signals.

7.2 **Safety Precautions:**

7.2.1 Examine the sensor body for burrs or sharp edges, or both. Remove any protrusions that might cause harm.

7.2.2 The transducer can be permanently damaged if incorrectly connected to the power supply or if connected to a power supply with the wrong excitation level.

7.2.3 Follow the manufacturer's recommendations with regard to safety.

7.3 **Technical Precautions:**

7.3.1 The core and body of the LDT are a matched set. For best performance, do not interchange cores with other LDT bodies.

7.3.2 Replace the core and body if either shows any signs of dents, bending, or other defects that may affect performance of the device.

7.3.3 Store the body and core in a protective case when not in use.

7.3.4 Do not exceed the allowable input voltage of the sensor as specified by the manufacturer.

7.3.5 Do not connect a voltage source to the output leads of the sensor.

7.3.6 Do not over tighten the sensor within the mounting block.

7.3.7 The behavior of some transducers may be affected by metallic holders. If possible, the working holder should be used during calibration.

## 8. Calibration and Standardization

8.1 If using Test Method A, verify that the gage blocks are of sufficient precision and bias and in a clean, unscratched condition.

8.2 If using Test Method B, verify that the micrometer fixture is in good working order and of sufficient precision and bias.

## 9. Procedure

9.1 Perform this calibration in an environment as close to that in which the sensor will be used as possible. The LDT, calibration gage blocks, micrometer fixture, and comparator stand should be in the environment in which they are to be calibrated for at least 1 h prior to calibration to stabilize temperature effects.

9.2 Verify that the power supply is adjusted to supply the recommended voltage to the sensor.

9.3 With equipment turned off, connect all power supply, signal conditioning, and recording equipment exactly as it will be used in service. Allow all electronics to warm up for at least 30 min before beginning any readings.

9.4 Record type and serial number of the sensor to be calibrated. If it has no serial number, record the model number and other identifying markings.

9.5 Record the maximum allowable input voltage specified by the manufacturer and the input voltage used for this calibration.

9.6 Record the total linear range of the sensor and the range over which the transducer will be calibrated.

9.7 Record the type and serial number of the reference standard used.

9.8 *Test Method A—Precision Gage Block Calibration*:

9.8.1 Attach the sensor mounting block to the adjustable arm of the comparator stand or mount into test equipment as it will be used in service.

9.8.2 Slide the LDT core and core extension rod assembly into the LDT body.

NOTE 2—Some LDTs require the core to be in place before powering the LDT.

9.8.3 Place the sensor body into the sensor mounting block and tighten the appropriate screw on the mounting block. Do not over tighten the screw on the mounting block. This can damage the sensor body.

9.8.4 Place a gage block (or series of blocks) that has a height equal to the total linear range of the sensor under the core.

9.8.5 Adjust the sensor body up or down on the comparator stand support column as necessary to obtain a reading on the readout equipment that is approximately equal to the reading for the transducer with the core pushed into the transducer body to the end of the linear operating range as indicated by the manufacturer's calibration data.

9.8.6 Secure the adjustable arm on the support column of the comparator stand in this position by tightening the screw of the adjustable arm.

9.8.7 Remove the gage block (or series of blocks) from beneath the core rod and allow the core rod to rest on the comparator base. Note the transducer reading with the core now extended from the transducer body. It should equal approximately the voltage reading for the transducer with the core pulled from the transducer body to the end of the linear operating range as indicated by the manufacturer's calibration data.

9.8.8 Record the value of sensor output as sensor reading for zero displacement.

9.8.9 Select appropriate gage blocks to displace the core through its total linear range in steps. It is recommended that a minimum of five readings equally spaced throughout the sensor total linear range be used.

9.8.10 Raise the core rod and place the appropriate gage block(s) on the comparator stand base beneath the core rod in a manner to raise incrementally the core step-by-step into the transducer body.

9.8.11 Record the gage block height in Column 1 and the corresponding output of the sensor readout equipment in Column 2 as shown in Fig. 1.

9.8.12 Continue to add gage blocks at the selected displacement increments and record readings in Fig. 1 until the core has been displaced through its total linear range.

9.8.13 Remove the gage blocks in reverse order and record readings in Fig. 1 until the core again rests on the comparator base.

9.8.14 Repeat these steps for a minimum of two times to obtain data on reproducibility.

9.8.15 Calculate the calibration factor, linearity and voltage error as described in Section 10.

9.9 *Test Method B— Micrometer Fixture Calibration:*

9.9.1 Secure the sensor body into the chuck of the micrometer fixture. Do not over tighten the chuck around the sensor body.

9.9.2 Slide the core into the body.

9.9.3 Attach the core to the spindle of the micrometer head carrier using an appropriate attachment assembly.

9.9.4 Rotate the micrometer head until it is near its starting position of travel.

9.9.5 Move the micrometer head carrier along the bed of the micrometer fixture until the output of the sensor is approximately the lowest value indicated by the manufacturer for the working range of the transducer. Tighten the micrometer head carrier to the bed of the micrometer fixture.

9.9.6 Record the sensor readout as Sensor Reading 1 for zero displacement.

9.9.7 Rotate the micrometer head to displace the core through a fraction of its total linear range. It is recommended that a minimum of five readings equally spaced throughout the sensor total linear range be used.

9.9.8 Record the micrometer displacement in Column 1 and the corresponding output of the sensor readout equipment in Column 2 as shown in Table 1.

9.9.9 Continue to rotate the micrometer head to the selected displacement increments and record readings on Table 1 until the core has been displaced through its total linear range.

9.9.10 Rotate the micrometer head in reverse order and record readings in Table 1 until the core again rests on the comparator base.

9.9.11 Repeat these steps for a minimum of two times to obtain reproducibility data.

9.9.12 Calculate the calibration factor, linearity, and voltage error as described in Section 10.

## 10. Calculation

10.1 The calibration factor is determined using linear regression techniques. With the following definitions for readings in one direction:

$R_i$ = reading of LDT at I displacement,
$R_m$ = mean value of readings,
$D^i$ = measured I displacement of LDT, in. (mm),
$D_m$ = mean value of displacements,
$n$ = number of readings, and
$K$ = calibration factor of transducer and readout system.

$$K = \frac{n \times \Sigma R_i D_i - \Sigma R_i \times \Sigma Di}{n \times \Sigma {R_i}^2 - \Sigma R_i \times \Sigma R_i} \quad (1)$$

It is recommended that the data together with the best-fit line from regression be plotted as shown in Fig. 2 to determine that all measurements lie close to the best-fitted line.

10.2 Determine the transducer error for each displacement

**Table 1: Linear Differential Transducer Calibration**

Transducer Serial Number: AB 0778
Model Number: TT 1430
Manufacturer LVDTs, Ltd
Total Linear Range: 10 mm
Allowable Excitation: ≤ 12 volts

Date: 12/20/93
Calibrated by: gtt
Checked by: wam

Power Supply Serial Number: ps43
Voltage Output Setting for Power Supply 10.02
Units for Displacement mm
Calibration Reference xx Gage blocks __micrometer fixture

Sensor Readout Device digital volt meter
Units for Readout volts
Temperature 22°C

| Displacement mm | Sensor Reading volts | Computed Displacement, mm | Percent Error | Comments |
|---|---|---|---|---|
| 0 | -5.000 | -0.001 | -0.014 | core moving in |
| 2.5 | -2.510 | 2.498 | -0.022 | " |
| 5.0 | -0.016 | 5.001 | 0.011 | " |
| 7.5 | 2.478 | 7.504 | 0.044 | " |
| 10.0 | 4.957 | 9.993 | -0.074 | " |
| 7.5 | 2.479 | 7.505 | 0.054 | core moving out |
| 5.0 | -0.011 | 5.006 | 0.062 | " |
| 2.5 | -2.504 | 2.504 | 0.039 | " |
| 0 | -4.999 | 0.000 | -0.004 | " |
| 2.5 | -2.505 | 2.503 | 0.029 | core moving in |
| 5.0 | -0.016 | 5.001 | 0.011 | " |
| 7.5 | 2.479 | 7.505 | 0.054 | " |
| 10.0 | 4.958 | 9.994 | -0.064 | " |
| 7.5 | 2.479 | 7.505 | 0.054 | core moving out |
| 5.0 | -0.012 | 5.005 | 0.051 | " |
| 2.5 | -2.503 | 2.505 | 0.049 | " |
| 0 | -4.998 | 0.001 | 0.006 | " |

Slope of best fit line 1.004 mm/volt
Maximum Percent Error 0.074%
Allowable Percent Error 0.1%

Accept xx Reject___

**FIG. 1 Linear Differential Transducer Calibration**

reading using the following expressions:

$$\text{Computed Displacement} = (R_i - R_0) \times K, \tag{2}$$

where:

$R_0$ = the computed best-fit reading for zero displacement determined from the linear regression analysis on the calibration data.
Error = computed displacement − applied displacement = *Er*.
*Percent Error* = 100 × error/calibrated range.

where computed displacement is calculated using the computed calibration factor for the transducer readout system and the output for each calibration step.

## 11. Interpretation of Results

11.1 Each transducer is supplied with a specified maximum error. Compare the measured maximum percent error from calibration with that given by the manufacturer. If the measured error exceeds that specified by the manufacturer, either the readout system is inadequate or the transducer is defective. The transducer should not be used until the source of the discrepancy is identified and resolved. Some applications may permit use of a transducer with a measured error larger than given by the manufacturer.

11.2 Each application for a displacement transducer has its own requirement for allowable error. Compare the percent error determined for each step during calibration with the maximum allowable percent error for the application. If the measured percent error exceeds the allowable percent error, this transducer cannot be used for the intended application.

11.3 Maximum allowable error can be determined from the accuracy requirements for the particular test for which the transducer is to be used. Some geotechnical tests require displacements to be measured to the nearest 0.001 in. (0.025 mm). A transducer for this test with a total linear range of 1 in. (25.4 mm) has a maximum allowable error of 0.1 %. A consolidation test requires displacements be read to 0.0001 in.

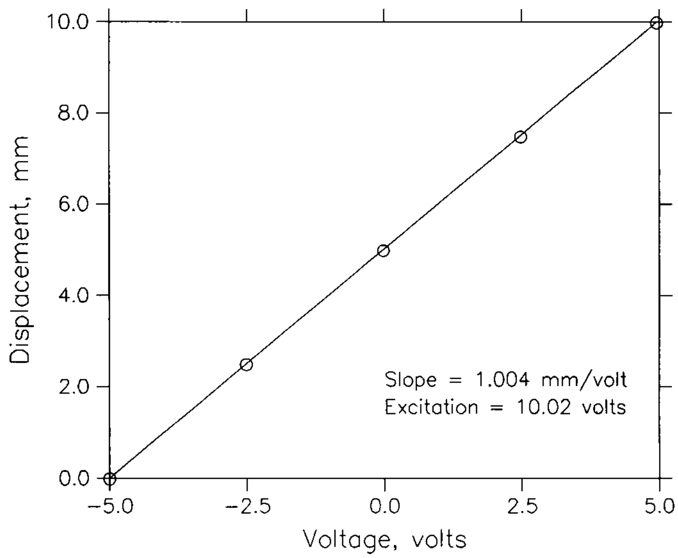


**FIG. 2 LVDT Calibration**

(0.0025 mm). A transducer for this test with a total linear range of 0.5 in. (12.7 mm) has a maximum allowable error of 0.02 %.

11.4 The steps described in 11.1-11.3 may be performed on each load and each unload step of the calibration, or they may be performed on the entire set of calibration data.

11.5 Several factors besides the transducer can cause the calibration to produce errors in excess of the maximum allowable error. These include:

11.5.1 Fluctuations in the output of the power supply,

11.5.2 Insufficient precision or accuracy of readout system,

11.5.3 Flexibility in the transducer mounting system,

11.5.4 Electrical noise in the transducer or readout system, and

11.5.5 Temperature changes during calibration.

11.5.6 If the transducer calibration gives too much error, a systematic procedure must be followed to isolate and correct the cause.

11.6 The calibration factor determined by this practice is specific to the electronic settings used during calibration. Altering any of these settings, such as changing the input power supply, will change the calibration factor and necessitate a new calibration.

11.7 The resulting calibration factor, *K*, is used to calculate displacement as:

$$\text{Change in displacement} = (\text{change in reading}) \times K \tag{3}$$

## 12. Report

12.1 The calibration report consists of a completed and checked linear differential transducer (LDT) Calibration form, Fig. 1.

12.2 All calculations should be checked.

12.3 It is recommended that a graph of data like that shown in Fig. 2 be prepared to visually check the linearity and accuracy of each data point used in the calibration and the linearity over the entire range of the transducer. Plot each data point and the line giving the best fit to the data. The graph should be of sufficient size to show any significant differences between measured data and the calibration.

## 13. Keywords

13.1 calibration; displacement; instrumentation; strain; transducer