UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 1008-89

PROCEDURE FOR

CALIBRATING LINEAR VARIABLE DIFFERENTIAL TRANSFORMERS

INTRODUCTION

This procedure is under the jurisdiction of the Geotechnical Services Branch, code D-3760, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 1008. The number immediately following the designation indicates the year of acceptance or the year of last revision.

1. Scope

1.1 This designation outlines the procedure for calibrating LVDTs (linear variable differential transformers).

1.2 Method A outlines the calibration procedure using precision gauge blocks; method B outlines the calibration procedure incorporating a micrometer fixture.

2. Applicable Documents

2.1 *USBR Procedure*:

USBR 1000 Standards for Linear Measurement Devices

USBR 3900 Standard Definitions of Terms and Symbols Relating to Soil Mechanics

2.2. *Federal Specification*:

GGG-G-15C Gage Blocks and Accessories

3. Summary of Method

3.1 Readings from an LVDT and from either the precision gauge blocks (method A) or the micrometer fixture (method B) are compared to determine the linearity and repeatability of the LVDT. The results are used to determine the acceptability of the LVDT for laboratory use.

4. Significance and Use

4.1 LVDTs must be calibrated for use in the laboratory to ensure reliable linear measurements.

4.2 Calibrate LVDTs before initial use and at least annually thereafter.

5. Terminology (see fig.1)

5.1 Definitions are in accordance with USBR 3900.

5.2 Terms not included in USBR 3900 specific to this designation are:

5.2.1 *Null Position.*-The LVDT core position within the LVDT body that voltage output is zero.

5.2.2 *TLR* (total linear range).-Total distance that may be traveled by the LVDT core in moving from the position of maximum voltage output at one end of the body—through the null position—to the position of maximum voltage output at the opposite end of the body.

5.2.3 *Full-Scale Displacement.*-Total distance traveled by the core in moving from the null position to one end of the total linear range; i.e., one-half of the total linear range.

5.2.4 *Range.*-Total distance traveled by the core expressed in terms of percent plus or minus full-scale displacement.

5.2.5 *Repeatability.*-The degree of LVDT measurement variation for successive measurements of the same reference standard.

5.2.6 *Linearity.*-The variation of LVDT measurements from a straight line. The measurements are obtained using a series of reference standards applied over the total linear range of the LVDT.

5.2.7 *Percent Error.*-The ratio (expressed as a percent) of (1) the difference between an LVDT measurement of a reference standard and the actual length of the reference standard to (2) the total linear range of the LVDT. Percent error also may be determined over a fraction of the total linear range.

5.2.8 *Voltage Error.*-The difference in LVDT voltage output for successive measurements of the same reference standard.

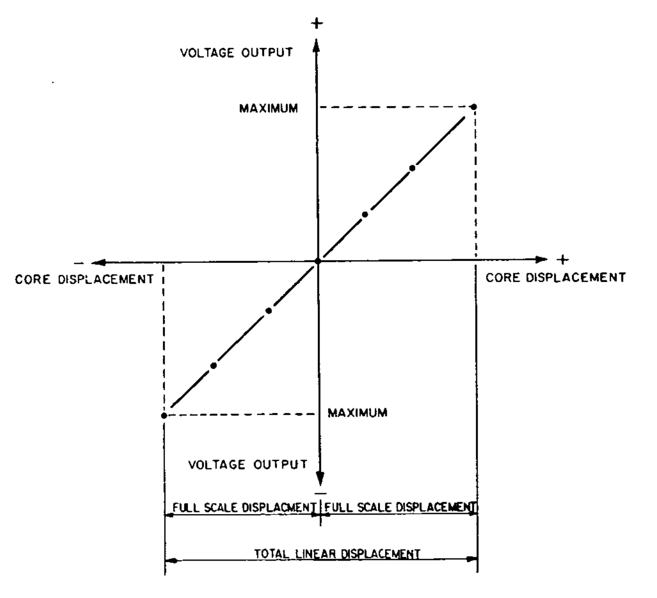
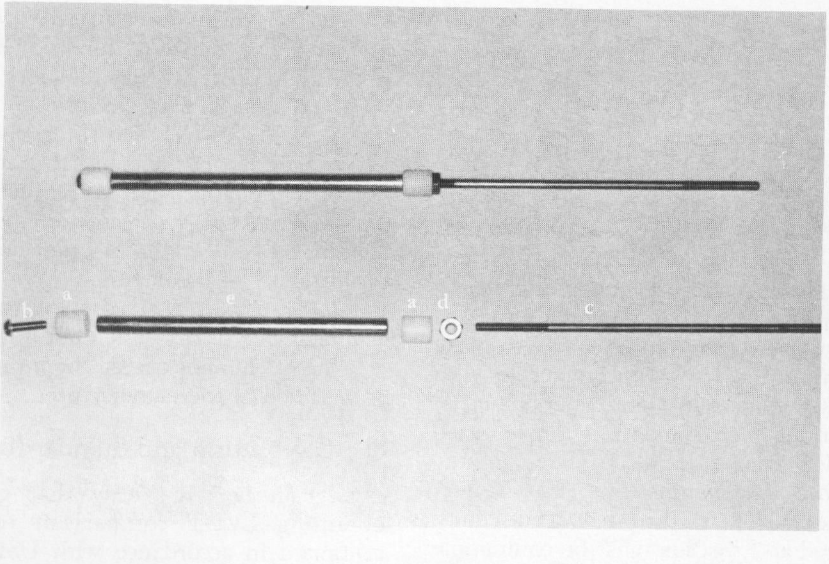
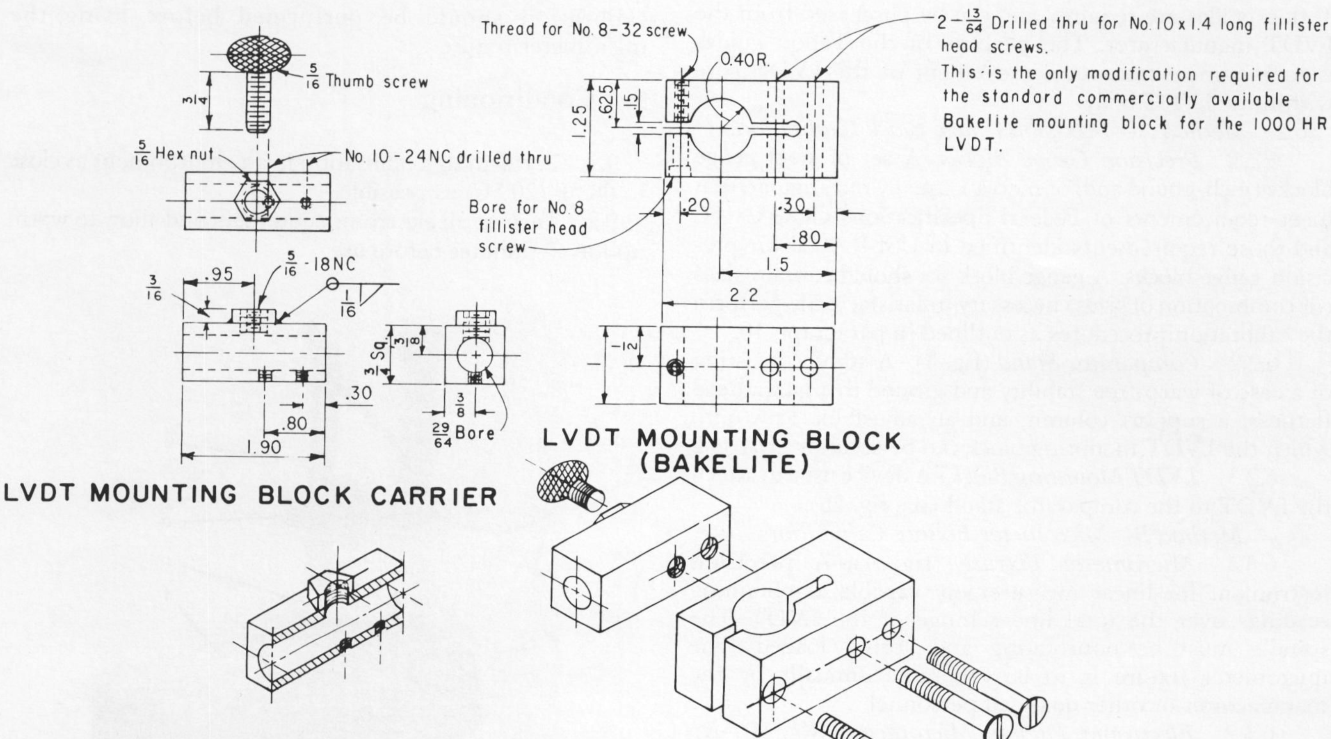


Figure 1. - Terminology of the LVDT.



(a) LVDT core/core extension rod assembly. a) teflon guide, b) No. 6-40 UNF threaded screw, c) LVDT core extension rod, d) lock nut, and e) LVDT core.



(b) Schematic of LVDT mounting block.

Figure 2. – LVDT mounting block and rod assembly.

6. Apparatus

6.1 *General Apparatus*:

6.1.1 *LVDT*.–An electrical transducer which converts linear displacement to electrical output. An LVDT (linear variable differential transformer) consists of a stationary LVDT body and a movable LVDT core. The LVDT core is threaded on both ends so the LVDT core extension rods can be attached.

6.1.2 *Signal Conditioner and Readout Equipment*.–A signal conditioner provides excitation voltage for the LVDT, as well as appropriate electronic circuitry to make the output of the transducer (LVDT) compatible with readout equipment. Readout equipment accepts output from the signal conditioner and converts it into a visual display of transducer displacement.

6.1.3 *LVDT Core Extension Rod* (fig. 2a).–A nonmagnetic rod (preferably brass), threaded on both ends. The diameter of the rod and threads must be compatibie with the diameter of the hole in the LVDT core. The rod should be threaded a minimum of 1 inch (25 mm) at each end with an approximate total length of 2-1/2 inches (65 mm).

6.1.4 *LVDT Teflon Guides* (fig. 2a).–Two LVDT Teflon guides are required and can be purchased from the LVDT manufacturer. The purpose of the Teflon guides is to minimize transverse movement of the LVDT core within the LVDT body.

6.2 *Method A—Precision Gauge Block Calibration*:

6.2.1 *Precision Gauge Blocks*.–A set of steel gauge blocks (inch-pound and/or metric), usually rectangular, that meet requirements of Federal Specifications GGG-G-15C and those requirements identified in USBR 1000 for precision gauge blocks. A gauge block set should contain sizes (or combination of sizes) necessary to satisfactorily perform the calibration procedures as outlined in paragraph 10.

6.2.2 *Comparator Stand* (fig. 3).–A 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 LVDT mounting block can be securely attached.

6.2.3 *LVDT Mounting Block*.–A device used to attach the LVDT to the comparator stand (see fig. 2b).

6.3 *Method B—Micrometer Fixture Calibration*:

6.3.1 *Micrometer Fixture* (fig. 4).–A precision instrument for linear measurement capable of obtaining readings over the total linear range of the LVDT. The spindle must be nonrotating and spring loaded. The micrometer fixture is to be calibrated annually by the manufacturer or other qualified personnel.

6.3.2 *Electronic Digital Micrometer* (fig. 4).–An electronic micrometer used to convert displacement of the spindle of the micrometer fixture to visual numeric display.

7. Precautions

7.1 *Safety Precautions*:

7.1.1 The LVDT body should be examined for burrs and/or sharp edges.

7.1.2 Verify all electrical wiring is connected properly, and that the signal conditioner (if used) is grounded properly to prevent electrical shock to the operator.

7.2 *Technical Precautions*:

7.2.1 The LVDT core and body are a matched set as purchased from the manufacturer; for best performance, do not interchange cores with other LVDT bodies.

7.2.2 Replace the core and body if either shows any sign of dents, bending, or other defects which may affect performance of the device.

7.2.3 The LVDT core and body should be stored in a suitable box or case when not in use.

7.2.4 Do not exceed the input voltage of the LVDT as specified by the manufacturer.

8. Calibration and Standardization

8.1 *Method A*.–Verify that gauge blocks used for obtaining LVDT comparison readings are currently calibrated in accordance with USBR 1000. If the gauge block calibration is not current, the calibration procedure should be performed before using the gauge blocks.

8.2 *Method B*.–Verify that the micrometer fixture has been currently calibrated by the manufacturer or other qualified personnel. If the calibration is not current, the calibration should be performed before using the micrometer fixture.

9. Conditioning

9.1 Perform this calibration in an environment as close to 68 °F (20 °C) as possible.

9.2 Turn on all electronic equipment and allow to warm up for 30 minutes before use.

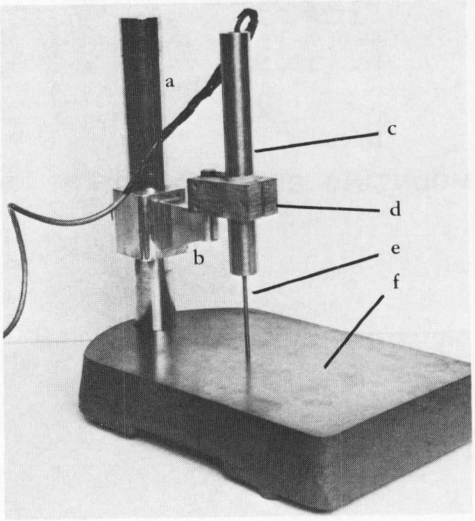


Figure 3. – LVDT Comparator stand and LVDT mounting block (method A). a) support column, b) adjustable arm, c) LVDT body, d) LVDT mounting block, e) LVDT core extension rod, and f) base.

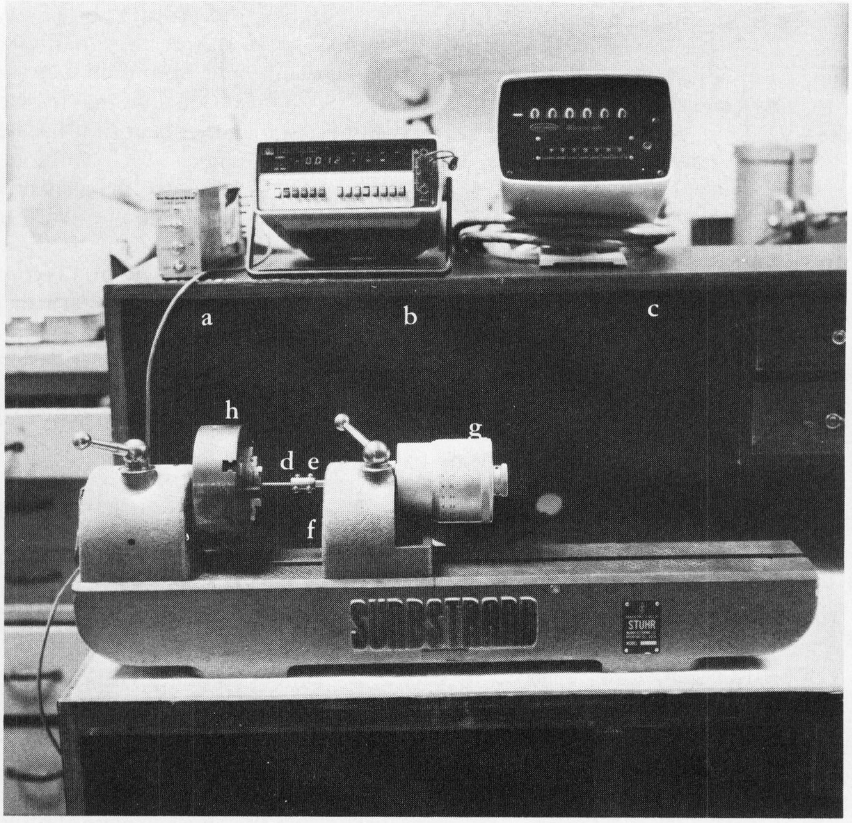


Figure 4. - LVDT Calibration assembly—micrometer fixture (method B). a) signal conditioner, b) readout equipment, c) electronic digital micrometer, d) LVDT core extension rod, e) spindle, f) micrometer head carrier, g) micrometer head, and h) chuck.

9.3 The LVDT, calibration gauge blocks, micrometer fixture, and comparator stand should be in the environment in which they are to be calibrated for at least 24 hours prior to calibration.

10. Procedure

10.1 All data are to be recorded on the "Linear Variable Differential Transformer Calibration" form as shown on figure 5.

10.2 Record type and serial number of the LVDT to be calibrated; if it has no serial number, record the model number and any other identifying markings.

10.3 Record the total linear range of the LVDT.

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

10.5 Attach the cable from the LVDT to the signal conditioner; and attach the cable from the signal conditioner output to the readout equipment. Plug in the readout equipment to a power source and allow a minimum 30-minute warmup.

10.6 Slide an LVDT Teflon guide onto each end of the LVDT core as shown on figure 2a.

10.7 Attach the LVDT core extension rod to the end of the LVDT core by screwing the LVDT core extension rod into the threaded LVDT core.

10.8 *Method A—Precision Gauge Block Calibration*:

10.8.1 *Null Position of LVDT*:

10.8.1.1 Attach the LVDT mounting block to the adjustable arm of the comparator stand as shown on figure 3.

10.8.1.2 Slide the LVDT core and core extension rod assembly into the LVDT body.

10.8.1.3 Place the LVDT body into the LVDT mounting block and tighten the appropriate screw on the mounting block. (DO NOT overtighten the screw on the mounting block; this can deform the LVDT body.)

10.8.1.4 Apply voltage to the LVDT. Ensure that the line voltage is compatible with the power requirements of the signal conditioner. Refer to the manufacturer's operating instructions for voltage requirements.

10.8.1.5 Place a gauge block (or series of blocks) which has a height equal to one-half the total linear range of the LVDT under the LVDT core extension rod; i.e. for an LVDT having a 2-inch (50.8-mm) total linear range, a 1-inch (25.4-mm) gauge block is used.

10.8.1.6 Using the adjustable arm, adjust the LVDT body up or down on the comparator stand support column as necessary so the output of the readout equipment is approximately equal to 0 volt.

10.8.1.7 Secure the adjustable arm on the support column of the comparator stand in the position described in subparagraph 10.8.1.6, by tightening the screw of the adjustable arm.

10.8.1.8 Use the ZERO adjustment on the signal conditioner to obtain a reading of exactly 0.000 volt. This is the null position of the LVDT.

NOTE 1.–Adjustment of the signal conditioner may vary slightly depending on the type of signal conditioner used. Refer to the manufacturer's operating instructions for adjustment of the specific signal conditioner used.

10.8.2 *Signal Conditioner Span Setting* (LVDT factor determination):

10.8.2.1 Remove the gauge block (or series of blocks) from beneath the LVDT core extension rod.

10.8.2.2 Place a gauge block (or series of blocks) which has a height equal to the total linear range of the LVDT (as recorded in subpar. 10.3) under the core extension rod; i.e., for an LVDT with a 2-inch (50.8-mm) total linear range, a 2-inch gauge block is used.

10.8.2.3 Adjust the signal conditioner, using the GAIN control screw, so that the output of the LVDT is equal to ±10.000 volts d.c. (Polarity depends on the wiring of the LVDT.)

NOTE 2.–For convenience, subparagraph 10.8.2.3 specifies a setting of ±10.000 volts d.c. for the LVDT output at full-scale displacement. Other values of output at full LVDT displacement may be used, if desired.

10.8.2.4 Remove the gauge block (or series of gauge blocks) from beneath the core extension rod and replace it with a gauge block (or series of gauge blocks) having a height equal to one-half the total linear range of the LVDT. The readout should indicate 0.000 volt; if it does not, reset by adjusting the ZERO adjustment.

10.8.2.5 Repeat subparagraphs 10.8.2.2 through 10.8.2.4 until values of 0.000 and ±10.000 (see note 2) volts are obtained.

10.8.2.6 Record the value of LVDT output at full-scale displacement ±10.000 volts (see note 2) as "LVDT output 1" as shown on figure 5.

10.8.2.7 Remove the gauge block (or series of gauge blocks) from beneath the LVDT core extension rod and allow the LVDT core extension rod to rest on the comparator stand base.

10.8.2.8 Record the LVDT output obtained as "LVDT output 2" as shown on figure 5.

10.8.2.9 Calculate and record the LVDT output change and the "LVDT factor" as shown on figure 5.

10.8.3 *Linearity of the LVDT*:

10.8.3.1 Select appropriate displacement increments (gauge blocks) to displace the LVDT core through its total linear range. It is recommended that the gauge blocks be selected such that a minimum of four readings—equally spaced throughout the LVDT total linear range—are used.

10.8.3.2 Raise the LVDT core extension rod, and place the appropriate gauge block(s) on the comparator stand base beneath the LVDT core extension rod.

10.8.3.3 Record the gauge block(s) height in column 1 and the corresponding output of the LVDT readout equipment in column 2 as shown on figure 5.

10.8.3.4 Continue to displace the LVDT core at the selected increments until it has been displaced through its total linear range.

10.8.3.5 Record the gauge block(s) height and the corresponding output of the LVDT readout equipment at each displacement increment as shown on figure 5.

10.8.3.6 Calculate and record values of percent of TLR and percent error for each displacement increment as shown on figure 5.

10.8.3.7 Check the linearity of the LVDT in accordance with provisions in subparagraph 12.1.

10.8.4 *Repeatability of the LVDT*:

10.8.4.1 Remove the gauge block(s) from beneath the LVDT core extension rod.

10.8.4.2 Repeat subparagraphs 10.8.3.2 through 10.8.3.5 using the same displacement increments (gauge blocks) selected in subparagraph 10.8.3.1.

10.8.4.3 Calculate and record the voltage error at each corresponding displacement increment as shown on figure 5.

10.8.4.4 Check repeatability of the LVDT in accordance with provisions in subparagraph 12.2.

10.9 *Method B—Micrometer Fixture Calibration*:

10.9.1 Secure the LVDT body into the chuck of the micrometer fixture as shown on figure 4. (DO NOT overtighten the chuck around the LVDT body.)

10.9.2 Slide the LVDT core with the Teflon guides and core extension rod assembly into the LVDT body.

10.9.3 Attach the LVDT core extension rod to the spindle of the micrometer head carrier using an appropriate attachment assembly as shown on figure 4.

10.9.4 Apply voltage to the LVDT. Ensure that the line voltage is compatible with the power requirements of the signal conditioner. Refer to the manufacturer's operating instructions for voltage requirements.

10.9.5 Ensure that the signal conditioner has had a minimum 30-minute warmup time.

10.9.6 *Null Position of LVDT*:

10.9.6.1 Turn the GAIN control of the signal conditioner (see note 1) to the minimum gain setting.

10.9.6.2 Adjust the ZERO control of the signal conditioner to achieve an output of zero volt.

10.9.6.3 Turn GAIN control to approximately the midpoint position.

10.9.6.4 Remove the LVDT core by sliding the micrometer head carrier along the bed of the micrometer fixture until the output is approximately 0 volt. Tighten the micrometer head carrier to the bed of the micrometer fixture.

10.9.6.5 Rotate the micrometer head to achieve a reading of exactly 0.000 volt. This is the null position of the LVDT.

10.9.7 *Signal Conditioner Span Setting* (LVDT factor determination):

10.9.7.1 Reset the electronic digital micrometer to read 0.000.

10.9.7.2 Rotate the micrometer head until the LVDT core has been displaced a distance equal to one-half the total linear range of the LVDT; i.e. for an LVDT having a 2-inch (50.8-mm) total linear range, the digital micrometer should read ±1.000 inch (25.4 mm). Record the value of LVDT output achieved as "LVDT output 1."

10.9.7.3 Adjust the signal conditioner, using the GAIN control screw, so the output of the LVDT readout equipment is equal to ±10.000 volts d.c. (see note 2). Polarity depends on the wiring of the LVDT.

10.9.7.4 Rotate the micrometer head in the opposite direction until the electronic digital micrometer reads 0.000 volt. The readout equipment should indicate 0.000 volt; if it does not, reset by adjusting the ZERO adjustment.

10.9.7.5 Repeat subparagraphs 10.9.7.2 through 10.9.7.4 until values of 0.000 and ±10.000 volts (see note 2) are obtained.

10.9.7.6 Rotate the micrometer head until the electronic digital micrometer indicates the LVDT has been displaced a distance equal to one-half the total linear range of the LVDT. (This is to be equal displacement but opposite direction as that achieved in subpar. 10.9.7.2.)

10.9.7.7 Record the LVDT output obtained as "LVDT output 2."

10.9.7.8 Calculate and record the LVDT output change and the "LVDT factor."

10.9.8 *Linearity of the LVDT*:

10.9.8.1 Select appropriate displacement increments to displace the LVDT core through its total linear range. It is recommended that the displacement increments be selected such that a minimum of four readings—equally spaced throughout the LVDT range—are used.

10.9.8.2 Rotate the micrometer head until the electronic digital micrometer output corresponds to the desired displacement increment.

10.9.8.3 Read and record the digital micrometer output and corresponding LVDT output voltage.

10.9.8.4 Continue to displace the LVDT by rotating the micrometer head to the selected increments until the LVDT core has been displaced through its total linear range.

10.9.8.5 Record the LVDT displacement as indicated by the digital micrometer and the corresponding voltage output at each displacement increment.

10.9.8.6 Calculate and record values of percent of TLR and percent error for each displacement increment.

10.9.8.7 Check the linearity of the LVDT in accordance with provisions of subparagraph 12.1.

10.9.9 *Repeatability of the LVDT*:

10.9.9.1 Rotate the micrometer head until the digital micrometer reads 0.000 volt.

10.9.9.2 Repeat subparagraphs 10.9.8.2 through 10.9.8.5 using the same displacement increments selected in subparagraph 10.9.8.1.

10.9.9.3 Calculate and record the voltage error at each corresponding displacement increment as shown on figure 5.

10.9.9.4 Check repeatability of the LVDT in accordance with provisions in subparagraph 12.2.

11. Calculations

11.1 Calculations are as shown on the "Linear Variable Differential Transformer Calibration" form. (fig. 5).

12. Interpretation of Results

12.1 *Linearity.*-Table 1 is to be used for evaluation of LVDT linearity.

12.1.2 If percent error, at the listed percent of total linear range, exceeds the amount listed in table 1 the LVDT should be rejected.

12.2 Repeatability.-The voltage error should not exceed ±0.05 volt at any displacement. If the voltage error (col. 8, fig. 5) exceeds ±0.05 volt, the LVDT should be rejected.

13. Report

13.1 The report is to consist of a completed and checked "Linear Variable Differential Transformer Calibration" form (fig. 5).

13.2 All calculations are to show a checkmark.

14. Background Reference

"Handbook of Measurement and Control," *Handbook HB-76*, copyright 1976 by Schaevitz Engineering, Pennsauken, NJ, Library of Congress Catalog No. 76-24971.

Table 1. - LVDT percent error tolerances.

Total linear range		Range, plus or minus		Allowable percent error over indicated percent of total linear range, %		
in	mm	in	mm	50	75	100
0.10	2.5	0.050	1.25	0.10	0.25	2.00
0.20	5	0.100	2.5	.10	.25	2.00
0.40	10	0.200	5.0	.10	.25	2.00
0.60	15	0.300	7.5	.10	.25	2.00
0.80	20	0.400	10	.15	.25	2.00
1.00	25	0.500	12.5	.15	.25	2.00
2.00	50	1.000	25	.25	.25	2.00
4.00	100	2.000	50	.25	.25	2.00
6.00	150	3.000	75	.15	.25	2.00
8.00	200	4.000	100	.15	.25	2.00
10.00	250	5.000	125	.15	.25	2.00
20.00	500	10.000	250	.15	.25	2.00

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LINEAR VARIABLE DIFFERENTIAL TRANSFORMER CALIBRATION

Designation USBR 1008-89

LVDT TYPE HR 1000 MANUFACTURER Example SERIAL NO. 15

REFERENCE STANDARD USED: ☒ GAUGE BLOCKS SERIAL NO. GB112
☐ MICROMETER FIXTURE SERIAL NO. ______

CALIBRATION PERFORMED BY ______ DATE ______

CALIBRATION CHECKED BY ______ DATE ______

LVDT FACTOR DETERMINATION

(a) LVDT TOTAL LINEAR RANGE (TLR)	2.000	☒ in ☐ mm
(b) LVDT OUTPUT 1	10.000	V
(c) LVDT OUTPUT 2	-9.978	V
(d) LVDT OUTPUT CHANGE (b) - (c)	19.978	V
(e) LVDT FACTOR (a)/(d)	0.100	☒ in/V ☐ mm/V

LINEARITY

TRIAL NO.	REFERENCE STANDARD LENGTH ☒ in ☐ mm (1)	PERCENT OF TLR (%)	LVDT OUTPUT (VOLTS) (2)	CHANGE IN LVDT OUTPUT (3) = (2) - (c) (VOLTS) (3)	LVDT MEASUREMENT (4) = (3) x (e) ☒ in ☐ mm (4)	PERCENT ERROR (5) = $\frac{(1) - (4)}{(a)}$ x 100 (5)
1	0	0	-9.978	0	0	0
2	0.250	12.5	-7.480	2.498	0.2498	0.010
3	0.500	25	-4.982	4.996	0.4996	0.020
4	0.750	37.5	-2.483	7.495	0.7495	0.025
5	1.000	50	0.000	9.978	0.9978	0.110
6	1.250	62.5	2.525	12.503	1.2503	-0.015
7	1.500	75	5.037	15.015	1.5015	-0.075
8	1.750	87.5	7.533	17.511	1.7511	-0.055
9	2.000	100	10.000	19.978	1.9978	0.110

REPEATABILITY

TRIAL NO.	REFERENCE STANDARD LENGTH ☒ in ☐ mm (6)	PERCENT OF TLR (%)	LVDT OUTPUT (VOLTS) (7)	VOLTAGE ERROR (8) = (7) - (2) (VOLTS) (8)
1	0	0	-9.976	0.002
2	0.250	12.5	-7.519	-0.039
3	0.500	25	-5.003	-0.021
4	0.750	37.5	-2.522	0.039
5	1.000	50	0.000	0.000
6	1.250	62.5	2.532	0.007
7	1.500	75	5.040	0.003
8	1.750	87.5	7.531	-0.002
9	2.000	100	10.000	0.000

LINEARITY ☒ ACCEPT ☐ REJECT

REPEATABILITY ☒ ACCEPT ☐ REJECT

REMARKS ______

GPO 850 - 945

Figure 5. - Linear variable differential transformer calibration — example.