MicroStrain Sensing Technical Note

All LVDT Displacement Transducers

Displacement Temperature Coefficient

Date
March 5, 2021

Summary
Parker LORD displacement sensors are calibrated at room temperature (~22°C) and the voltage displacement correlations provided in the calibration records are intended to be applied at the same temperature. Variations in sensor and signal conditioner temperature will result in differences in the voltage output for the same position. This discussion looks at correcting for voltage output changes due to uniform[1] temperature changes across a Parker LORD displacement sensor.

Discussion
Temperature variation on a Parker LORD sensor lead to changes in output voltage for several reasons. The largest typical influence is the temperature dependence of the permeability of the ferrous core target material. The voltage change is dependent on the magnetic linkage between the core and the differential sensing coils. As the temperature impacts the permeability of the core, the magnitude of the magnetic linkage changes. Because core effects impact the coils differently depending on the sensor's position, this effect manifests as a "gain" error, meaning it is proportional to the distance from the null (balanced, center) position.

Temperature also impacts the resistance of the magnet wire that construct the sensing coils. Although the coils ideally contain same length of wire, resulting in the cancellation of any lead wire resistance effect changes through the differential measurement, in reality there is some finite difference that appears in the form of an "offset" error or a constant error, proportional to temperature but independent of the core's position.

Other effects are also present and depending on the stroke and resolution of the sensor, may or may not be on a scale that is relevant to the measurement in question. Such impacts are the material expansion of the core carrier itself as it undergoes thermal changes. The same effect applies to the outer shell of the sensor and the material expansion relative to the mounting location. Should effects on these levels be of concern for a specific application the user should contact Parker LORD technical support and discuss the 1application in detail as the generalized temperature coefficients provided in the datasheets material may not be accurate enough to provide the desired resolution.

Parker LORD publishes "typical" temperature coefficients in our displacement data sheets. These values provide an approximate means to correct for the voltage change that occurs when the sensor is subjected to a temperature different than the one at which it was calibrated.

1. Temperature fluctuations at the signal conditioner require a different correction as do temperature gradients across a sensor.

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Specifications

Electrical Specifications

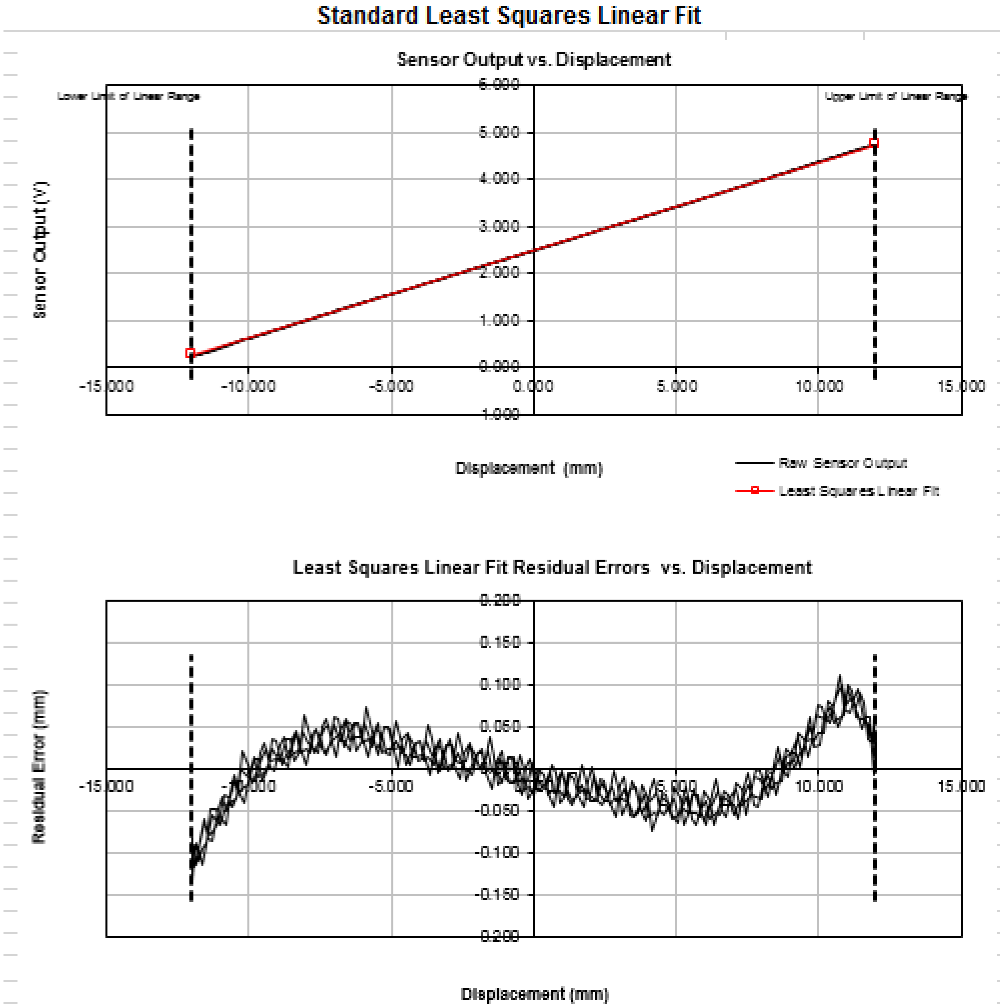
Obtained using DEMOD-DVRT® and DVRT® with 800 Hz lowpass filter at constant temperature

Linear Stroke Lengths	4, 8, 24, 38 mm (standard resolution) 6 mm (high resolution) 500 µm or less (nano resolution)
Accuracy	± 1.0 % using straight line ± 0.1 % using polynomial
Sensitivity	DEMOD® output / sensor range
Signal to noise	4200 to 1 (with filter 3 dB down at 800 Hz, standard resolution), 466 to 1 (unfiltered)
Resolution	1.0 µm for 4 mm stroke 2.0 µm for 8 mm stroke 6.0 µm for 24 mm stroke 9.5 µm for 38 mm stroke 0.6 µm for high resolution version 125 nm for nano resolution version (up to 10 nm resolution is possible with customized sensor range and electronics)
Frequency response	800 Hz standard, 20 KHz optional
Temperature coefficient	offset 0.002% / °C (typical) span 0.030% / °C (typical)

Figure 1: Excerpt from Parker LORD displacement sensor datasheet

As the data in Figure 1 shows, Parker LORD's typical temperature coefficients are 0.002%/°C for offset and 0.030%/°C for span (gain). That all sounds good, and those numbers seem small but how does one actually calculate those correction factors and determine if the thermal errors are on a scale that should be corrected for? The section below shows how one applies the temperature coefficients for a given sensor in a specific application.

A hypothetical customer is using a Parker LORD S-LVDT-24 (24mm full stroke, PN: 6105-0200) free sliding sensor with a DEMOD-DC (0-5VDC output, PN: 6130-0010) signal conditioner to measure cam shaft deflection in an engine. When operating, the cam shaft environment typically warms to 64°C. The user plans on applying the linear calibrations, assuming a +/-1% accuracy and a resolution of +/-0.1%. As the calibration sheet (Figure 2) shows, this sensor provides ~+/-0.1mm in accuracy (~+/-0.5% worst case) and ~+/-0.025mm resolution (~0.1%).



	Least Squares Linear Fit Model	Least Squares Linear Fit Results	
	D = M*x + B	Slope (mm/V)	Offset (mm)
		5.33592	-13.34307
where	D = Displacement (mm)		
	M = Slope (mm/V)	Residual Errors (within linear range)	
	x = Sensor Output (V)	Max (%F.S.)	Min (%F.S.)
	B = Offset (V)	0.46431	-0.54803

Figure 2: Linear Calibration Sheet for example sensor

The customer connects her sensor and signal conditioner and begins collecting data. She notices her sensor output ranges from 1.326 volts to 4.210 volts but is aware that these measurements are taken with the sensor uniformly heated to 64°C and wants to know how much of an impact the temperature shift has in the sensor output.

First, she calculates the nominal displacement values to see what the uncorrected displacement would be, max to min. From the calibration sheet:

$D = M * x + B$; M (slope) = 5.33592 mm/V; B (offset) = -13.34307 mm (Eq. 1)

Plugging the maximum and minimum sensor outputs into the above equation, the customer determines her uncorrected displacement values are:

D_{min} = -6.268 mm

D_{max} = 9.121 mm

The customer then calculates her approximate gain (span) error using the following formula:

$$Er_G = \frac{(V_{out} - V_{null})}{V_{null}} * (T_c - T_s) * CF_G * V_{FS} \qquad \text{(Eq. 2)}$$

Where V_{out} is the sensor output voltage that she's looking to correct, V_{null} is the sensor output at the null position (2.5 VDC for Demod-DC, 5 VDC for Demod-DVRT2), T_c is the temperature at calibration (typically 22°C), T_s is the sensor temperature that she is correcting for, CF_G is the gain (span) correction factor published as 0.03% in the data sheet and V_{FS} is the full scale voltage output for the signal conditioner (5 VDC for Demod-DC, 10 VDC for Demod-DVRT2).

Plugging in her values the user calculates her adjustment for gain error for each measurement as:

$$Er_{G(\min)} = \frac{(1.326 - 2.5)}{2.5} * (22 - 64) * \frac{0.03\%}{100} * 5 = 0.02958\ volts$$

$$Er_{G(\max)} = \frac{(4.210 - 2.5)}{2.5} * (22 - 64) * \frac{0.03\%}{100} * 5 = -0.04309\ volts$$

The user now also needs to consider the offset correction for each measurement:

$$Er_O = (T_c - T_s) * CF_O * V_{FS} \qquad \text{(Eq. 3)}$$

where CF_O is the offset correction factor published as 0.002% in the data sheet and the other variables are as defined in the paragraph above.

Plugging in her values the user calculates her adjustment for offset error for each measurement. Since offset error is independent of sensor position and is only dependent on temperature and other fixed coefficients, she only needs to calculate offset error once as:

$$Er_O = (22 - 64) * \frac{0.002\%}{100} * 5 = -0.0042\ volts$$

The user now sums the voltage errors and adds those to the actual sensor output value to obtain the corrected voltage output.

$$Vc_{min} = V_{out} + Er_{G(\min)} + Er_O = 1.3513\ volts \qquad \text{(Eq. 4)}$$

$$Vc_{max} = V_{out} + Er_{G(\max)} + Er_O = 4.1627 volts \qquad \text{(Eq. 5)}$$

Again, using the linear correlation provided in the calibration sheet (Eq. 1) the user determines her new temperature-corrected max/min displacement values:

$$D'_{min} = 5.33592 * Vc_{min} - 13.34307 = \text{-6.132 mm} \quad \text{(Eq. 6)}$$

$$D'_{max} = 5.33592 * Vc_{max} - 13.34307 = \text{8.869 mm} \quad \text{(Eq. 7)}$$

The user's correction resulted in an adjustment of -0.1354 (-2.2%) mm to her minimum displacement and of -0.2523 mm (-2.8%) to her maximum displacement recording. The customer can now determine, based on her end requirements, whether she needs to continue to apply temperature corrections to her measurements throughout the use of the displacement system or if the added error can be ignored in her results.

Support

MicroStrain Sensing support engineers are always available by phone, email, chat, and Teams to support you in any way we can.