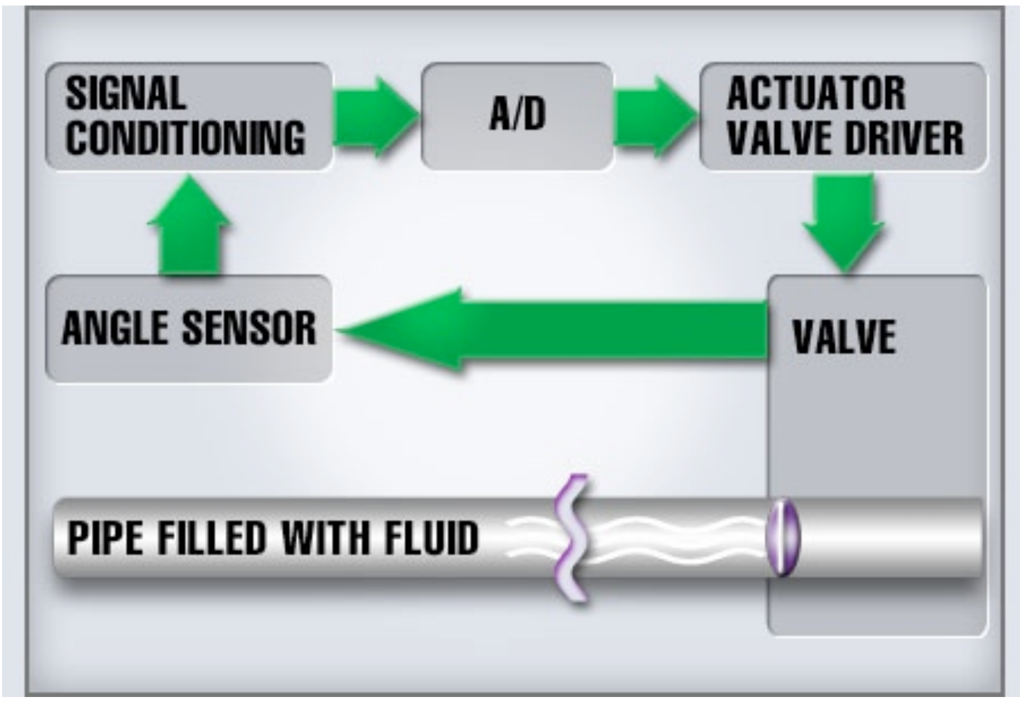
Tech Tip: Determining Sensor Accuracy For Your Application

We need to start with an application, then determine the accuracy and precision that application requires as it relates to an angle/rotary-position sensor. Let's consider an hydraulic valve operation for an actuator and say the valve moving up to 90° needs to be controlled within ±1.0°.

We need to create an error budget and assign maximum error amounts to each part that affects the accuracy of moving the valve. The components involved are represented by the block diagram below.



Each component in the application contributes to the error total including the fluid the valve is in contact with through its bulk modulus elasticity. However, closed-loop control can compensate for latent valve movement caused by fluid compression so, except for a small delay, we are left with adding up the tolerances of the angle sensor, signal conditioning circuitry, A/D converter, valve driver circuitry and hydraulic valve.

While we can add up the maximum tolerances of the components just mentioned, it will give a result that is a worst possible case. The worst case is unlikely, as all the errors from all the components would have to be operating at maximum error levels at the same time and in the same direction (positive versus negative error values). A more accurate way to calculate an error-budget is using the square root of the sum of the squares for each component, then add up the resulting errors.

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Specifications for hysteresis, temperature coefficient, linearity and reproducibility have to be taken into account for each analog component in the signal path. For A/D converters the quantization error, which looks like noise, is inherent in the process of converting an analog signal to digital values and needs to be counted. Offset, full-scale (referred to as gain) error, differential and integral nonlinearity also need to be considered.

Each block shown in the diagram can have an error-budget calculated. This article will detail the calculation of the angle sensor's error-budget and similar calculations can be made for the other blocks with allowances for the types of errors the components are subject to as described in the A/D section above. Terms such as repeatability and reproducibility are defined on Novotechik's website – here.

If we suppose that an angle sensor is needed with no more than 33 % of the total tolerance ±1.0 degrees for the system, we need to make sure our angle sensor has a maximum error budget of ±0.33° (1.0/.333) or an absolute error of 2 • 0.33° = 0.66°.

Error Budget Calculation

Let's choose a Vert-X 51(MH-C option) Series angle sensor model to use in our example. Let's also state that the ambient temperature varies from 15°F to +105°F, and that we are selecting the 4 to 20 mA current output version. The Vert-X 51 Series data sheet includes these relevant specifications:

Measurement range:	0 to 90° (based on application, out of possible 0 to 360°)
Independent linearity:	≤ ± 0.3 % of measurement range
Repeatability:	0.1°
Hysteresis:	0.1°
Temperature coefficient:	100 ppm/K
Resolution:	12 bit (0.09° for 360° measurement range)

1) Convert temperature to degrees Kelvin, since values are in °F, and calculate the temperature coefficient (tempco) error.

Temperature drift error calculation

Temperature conversion formulas are: $°C = (°F - 32) \cdot \frac{5}{9}$ and $K = °C + 273.15$

so replace °C in the second formula with the equivalent for °C from the first one.

$$T_K = \left\{ \left(T_{°F} - 32 \right) \bullet \frac{5}{9} \right\} + 273.15$$

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Then substituting in the actual values for maximum and minimum ambient temperature, we get:

$$T1_K = \left\{(105-32)\bullet\frac{5}{9}\right\} + 273.15$$

$$T1_K = 313.71$$

$$T2_K = \left\{(15-32)\bullet\frac{5}{9}\right\} + 273.15$$

$$T2_K = 263.71$$

$$\Delta T = T_1 - T_2$$

$$\Delta T = 313.71\ K - 263.71\ K$$

$$\Delta T = 50\ K$$

From our specifications for temperature coefficient, maximum ambient temperature induced error for this application is,

$$50K \bullet 100\ ppm/K = 5{,}000\ ppm$$

2) Convert all other tolerances to ppm, first adding the percent of full scale range used, linearity, then converting linearity error specified from percentage to ppm.

<u>Linearity error calculation</u>

Repeatability is specified, but not used in the error budget calculation as reproducibility is calculated and used as it includes hysteresis. Repeatability value is converted to ppm for comparative purposes showing reproducibility error to be a little higher:

$$0.3\%\bullet\left\{\frac{10{,}000\ ppm}{1\%}\right\} = 3{,}000\ ppm$$

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Reproducibility error calculation

First calculate resolution for range selected for application: measurement range programmed to use divided by total range, times resolution specified for total range of sensor

Note: $\frac{1}{2^{12}} \cdot 360° = 0.09°$ (resolution conversion from bits to degrees)

Calculate as percentage of range used in application, then covert to ppm,

$$\text{resolution} = \left\{\frac{90°}{360°}\right\} \bullet 0.09°$$

$$\text{resolution} = 0.0225°$$

$$\begin{aligned} \text{reproducibility} &= (2 \bullet \text{resolution}) + \text{hysteresis} \\ &= (2 \bullet 0.0225°) + 0.1° \\ &= 0.1225° \end{aligned}$$

$$\left\{\frac{0.1225°}{90°}\right\} \bullet \{100\%\} = 0.1361\%$$

$$0.1361\% \bullet \left\{\frac{10{,}000 \text{ ppm}}{1\%}\right\} = 1{,}361 \text{ ppm}$$

3) Restate the error amounts and take the square root of the sum of the squares of the values,

tempco	5,000.0 ppm
linearity	3,000.0 ppm
reproducibility	1,361.0 ppm

first, square, then add each error,

$(5{,}000)^2 + (3000)^2 + (1{,}361)^2 =$

$25{,}000{,}000 + 9{,}000{,}000 + 1{,}852{,}321 =$

$35{,}852{,}321 \text{ ppm}^2 =$

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next take the square root,

$$\sqrt{35{,}852{,}321\ \text{ppm}^2} =$$

$$5{,}987.68\ \text{ppm} =$$

4) Convert from ppm back to percent,

$$5{,}987.68\ \text{ppm} \bullet \left\{ \frac{1\%}{10{,}000\ \text{ppm}} \right\} =$$

$$0.5988\% =$$

5) Convert percentage to degrees of full scale range for accuracy result in degrees

Full scale, as programmed into sensor, for this application: 90° - 0° = 90°

$$0.5988\% \bullet \left\{ \frac{90^\circ}{100\%} \right\} =$$

0.54° =

Since 0.54° is less than the tolerance of 0.66°, the Vert-X 51 Series sensor is a good choice for an angle sensor in this application.

This article is for wiper-based angle sensors as well as magnetic angle sensors with no hysteresis compensation programmed in. For magnetic based sensors, hysteresis can also be programmed in or out and the calculations would have to be altered accordingly.

Since the Vert-X 51 sensor is a magnetic sensor with an internal D/A converter and associated circuitry, other errors are present in the internal D/A and circuitry. However, these are comparatively trivial and not included in the calculation.