LION PRECISION

TechNote

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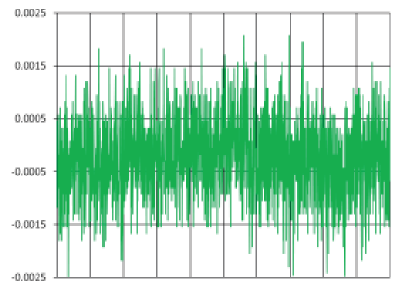
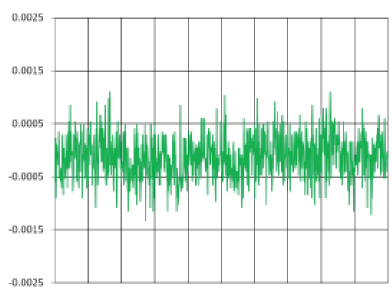
Understanding Sensor Resolution Specifications and Performance





Applicable Equipment:

All noncontact displacement sensors

Applications:

All noncontact displacement sensor applicaitons

Summary:

The TechNote describes in detail the resolution specification found in most sensor datasheets and indicates important factors in the interpretation of this specification.

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Introduction

Resolution is an important specification because without sufficient resolution you may not be able to reliably make the needed measurement, and an over performing sensor will burden your budget.

As a machine designer or engineer, you must continually specify sensors for use in your designs. During your search, you are confronted by an array of product specifications you must rely upon to select the sensor with the right cost-performance ratio. Unfortunately, not all displacement sensor specifications are presented in a way that allows direct comparison. Resolution represents one of the most frequently misunderstood and poorly defined descriptions of performance. Resolution is an important specification because without sufficient resolution you may not be able to reliably make the needed measurement, and an over performing sensor will burden your budget. Resolution is only meaningful within the context of the system bandwidth, the application, and the measurement method and unit of measure used by the sensor manufacturer. A simple "resolution spec" in a datasheet rarely provides enough information for a fully informed sensor selection. Understanding this important specification will empower you to more confidently make the right displacement sensor choice.

The Basics

Resolution is not accuracy. A very inaccurate sensor could have very high resolution, and a low resolution sensor may be sufficiently accurate in some applications.

Essentially, resolution is the smallest measurement a sensor can reliably indicate. Before discussing this in any detail, it is important to understand what resolution is not; it is not accuracy. A very inaccurate sensor could have very high resolution, and a low resolution sensor may be very accurate in some applications. Resolution is not the least significant digit in a display or the least significant bit in a conversion between the digital and analog worlds. Digital devices have a resolution specification based on the least significant digit/bit, and if insufficient, may further degrade the overall sensor resolution, but the fundamental limit of a sensor's resolution is determined in the analog world; the battle for higher resolutions in sensor design is primarily a fight against electrical noise.

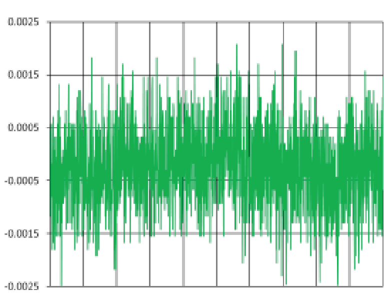

Figure 1

Electrical noise in a sensor output

The electrical noise in a sensor's output is the primary factor limiting its smallest possible measurement. All electronic components produce small random changes in voltage potentials that combine throughout the circuitry and appear as a band of noise when viewed with an oscilloscope (Fig. 1). Electrical noise is a factor in any electronic system trying to sense very small changes in voltage. For example, electrical noise causes image graininess in telescopes using CCD detectors. Users can't see small distant objects if the objects are the same size as the noise-induced grains. Some high-tech telescopes use supercooled CCDs because extremely low temperatures nearly eliminate the random movement of charges in the CCD thereby reducing electrical noise to near zero. With very little noise, the small objects are now visible . For you, the engineer specifying a displacement/position sensor, the essential problem is this: your measurement of a 1µm displacement will be lost if the sensor has 10µm of noise in the output. It is critical that the resolution of your selected sensor be considerably lower than the smallest measurement you are trying to achieve, but sensor resolution specifications can be misleading. Bandwidth, unit of measure, and other information must be included in the resolution specification in order to predict the smallest measurement you will be able to make in your specific application.

Resolution and Bandwidth

Bandwidth (frequency response) indicates how sensors respond at different frequencies. Higher bandwidth sensors can measure higher frequency motion and vibration. Electrical noise is generally broadband, which means it contains a wide spectrum of frequencies. A low-pass filter will reduce or eliminate high frequency noise, while reducing the sensor's bandwidth. Low-pass filtered signals have less noise and therefore better resolution but at the expense of usable bandwidth. Figure 2 shows the noise of a sensor with a 15kHz bandwidth, and Figure 3 shows the same sensor output with a 100Hz low-pass filter. Because of the lower noise level, you would be able to see smaller displacements with the low-pass filtering, but you would not be able to accurately detect displacements occurring at frequencies at 100Hz or higher. This is why a resolution specification apart from a bandwidth specification is not entirely useful. You must know if the resolution specification will hold at the frequency at which you need to make your measurement. Even though a sensor may have a general bandwidth specification of 1kHz or higher, the resolution may have been specified at 100Hz or lower, but the datasheet may not clearly indicate that. Do not assume that a sensor's general bandwidth specification and resolution specification can be achieved simultaneously.

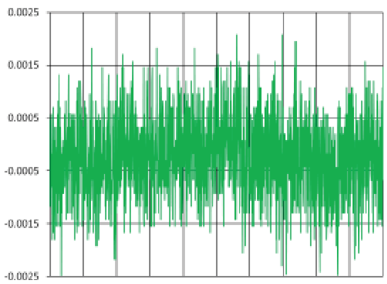

Figure 2

Noise from a sensor with 15kHz bandwidth

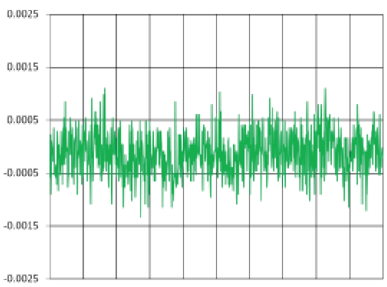

Figure 3

Noise from a sensor with 100Hz bandwidth

Do not assume that a sensor's general bandwidth specification and resolution specification can be achieved simulta-neously.

Some manufacturers provide two resolution specifications: Static and Dynamic. The Static specification only applies when the sensor output is low-pass filtered for very low bandwidth, sometimes as low as 10Hz. This is useful if you will be using the sensor with an equivalent bandwidth filter to measure slow moving systems. The Dynamic specification is usually for an unfiltered sensor; this is the resolution you can expect when using the sensor at full bandwidth in high-speed dynamic applications. If the data sheet uses Static and Dynamic terms, search for a note that defines exactly what frequencies are represented by Static and Dynamic. Until you have actual frequencies, you will not know if the sensor is a good choice for your application. Lion Precision lists resolution at specific bandwidths, removing any guess work.

Where is the Filter?

Commercially-available low-pass filter designs are dependent on many parameters in addition to the cutoff frequency. As a result, two different 1kHz filters may produce different results when used with your sensor. When sensor resolution is reported for lower bandwidths, it is critical that you know if the filter used in the resolution measurement is integral to the sensor. If the bandwidth filter is integral to the sensor, you can be confident that you will achieve the specified resolution. If the manufacturer used an external filter to generate the

If the sensor does not include an integral bandwidth filter, you will have to provide your own filtering for lower bandiwidth resoluiton, and the results may not match the listed specification.

specification, such as a bandwidth limit option on a data acquisition system or oscilloscope, then you would have to acquire an identical filter to be assured of the same results. Lion Precision sensors include integral bandwidth filters assuring that actual performance will match the specifications.

Units of Measure

A dimensional unit specification, such as nanometers, will clearly indicate the smallest displacement measurement you can reliably expect to make with the sensor.

A resolution specification may be given in volts, percent of full scale, or dimensional units. Perhaps the most meaningful to the engineer trying to measure position/displacement is dimensional units. A dimensional unit specification, such as nanometers, will clearly indicate the smallest displacement measurement you can reliably make with the sensor. If the specification is given as a percent, that value must be multiplied by the sensor's range to determine the smallest possible displacement measurement. If the specification is given as a voltage, then the value will have to be multiplied by the sensor's sensitivity (displacement units/voltage change) to determine the smallest possible displacement measurement. Once you know the sensor's resolution in dimensional units, it is critical that you determine if the specification represents an RMS or Peak-to-Peak value.

The distinction between RMS (root mean square) and Peak-to-Peak (sometimes called by the equivalent name Peak-to-Valley) is critically important to understanding the absolute sensor performance. Analog methods of measuring these values include special meters and visual interpretation of an oscilloscope display. In the digitized world, these values are calculated by capturing a large number of samples of the output voltage and analyzing the data statistically.

RMS measurements of dynamic electrical signals indicate the equivalent power from a DC source. It is similar to, but not the same as, an average value. RMS values may be determined by analog meters which measure the signal power and equating it to a DC voltage that would produce the same power. When digitized and analyzed statistically, the RMS value is equal to the standard deviation of the captured samples. RMS is the most relevant specification when measuring broadband vibration.

Most datasheets list resolution in RMS. Peak-to-Peak resolution is usually 10 times higher. Search datasheets for P-P values or a RMS to P-P multiplier.

Peak-to-Peak (P-P) is the difference between the maximum and minimum peaks of the noise over some period of time. Figure 3 shows a P-P noise level of 2.4mV over one second. If the signal is captured digitally, the samples can be analyzed to find the maximum and minimum peaks. If the samples create a perfectly normal (Gaussian) distribution, the P-P value can be estimated as six times the standard deviation, but in practice, this is rarely the case. Noise signals are rarely so well behaved and usually contain spurious peaks that create an actual P-P value much higher than six times the standard deviation. This means that resolution values specified by their P-P range must be at least six times greater than RMS values and are usually considerably higher than that. The 2.4mV P-P value in Figure 3 translates to 0.29mV RMS; the P-P value is more than eight times higher than the RMS value in this case.

P-P resolution value is the most appropriate specification if you are trying to continuously determine the instantaneous position of your target.

The P-P value is the most appropriate specification if you are trying to continuously determine the instantaneous position of your target. At any moment in time, the sensor output can vary by an amount equal to the P-P resolution specification; therefore, your position measurement can vary by that same amount.

Reading Datasheets

To fully understand the resolution of the sensor you are considering, you must conclusively identify these parameters in the specification:

- A resolution specification(s)
- Bandwidth at which the stated resolution is obtained
- If any bandwidth filters are integral to the sensor
- Unit and type (P-P or RMS) of measure of the resolution specification

Most sensor datasheets list a resolution specification, but they may not provide all of the information required to fully understand the actual resolution you will have in your application. Resolution may be listed as a single specification that applies to all ranges for a particular model, or there may be separate resolution specifications for each probe/range combination. The datasheet will likely include a bandwidth specification for the sensor, but it may or may not clearly list the bandwidth at which the resolution was specified; the resolution bandwidth may have to be searched for in footnotes or other small print. If the bandwidth is not listed, you will need to verify with the manufacturer that the resolution specification applies at the full bandwidth of the system. If resolution information is available at multiple bandwidths, it may be difficult to determine if the bandwidth filters are integral to the sensor. If the sensor is listed as being available in multiple bandwidth configurations, the filters are likely to be integral and the resolution specification will apply to the sensor you will receive. If no mention is made of the sensor's capacity to be configured at different bandwidths, you will need to ask the manufacturer how the other bandwidths were achieved when the resolution was specified.

Because RMS resolution specifications are always significantly lower than P-P, most datasheets will list resolution as an RMS value. If you are measuring continuous instantaneous position, you will need to know the P-P resolution. The datasheet may list both RMS and P-P values, or a multiplier for converting the RMS value to P-P. If no P-P value or multiplier is listed, you will have to contact the manufacturer; in the meantime, you can assume that the P-P value is at least six times higher and usually closer to ten times higher.

As an engineer, you have experienced the pain of discovering in mid-process that some component of your system doesn't perform as you expected. By understanding sensor resolution, its relationship to bandwidth, and the different units of measure, you can now make confident decisions about your displacement sensors.

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