TECHNICAL ESSAY

Displacement Sensing the Baumer Electric Way

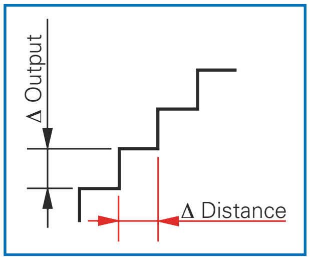
Brian Duval, Publicity & Corp.Com.

In the beginning, non-contact sensors were largely an on-off affair. They, like their switch predecessors either "saw" something or didn't. They passed this information on to a transistor or relay output, that is, an on or off signal. That worked pretty well. And, in most cases, it still works.

But, advances in automated equipment lead to advances in sensors. Design engineers began to need information beyond simple presence and absence. Specifically, they needed to measure thickness, coplanarity, stack height and other qualitative values while retaining the benefits of non-contact sensing. In response, some sensor manufacturers developed sensors capable of providing a distance proportional analog output. In short, they developed distance sensors. Known collectively as displacement sensors, analog output sensors, linear sensors or distance sensors; they allow a user the benefit of gaining more than simple presence/absence while enjoying the simplicity of sensor integration.

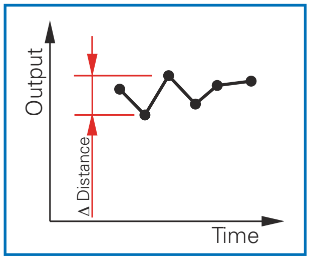
Before we break into the various technologies available for displacement sensors, there are some specific definitions pertaining to sensor performance that must be clarified.

Resolution



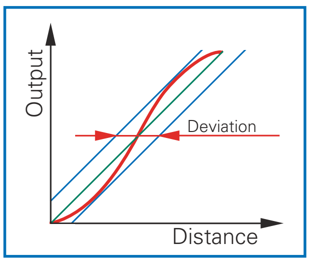
Resolution corresponds to the smallest possible distance change which causes a detectable change in the output signal.

Repeat accuracy (R)



Repeat accuracy is defined as the difference of measured values in successive measurements within a period of 8 hours at an ambient temperature of 23°C +/- 5°C.

Linearity



Linearity is the deviation from a proportional linear function (straight line). It is given as a percentage of the upper limit of the measuring range (full scale)

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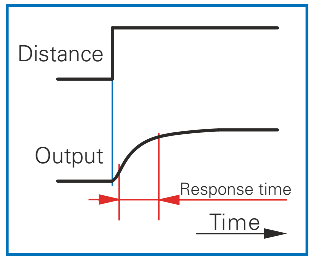
Reaction time



Reaction time is defined as the time required by the sensor's signal output to rise from 10% to 90% of the maximum signal level. For sensors with digital signal processing it is the time required for calculation of a stable measured value.

Temperature drift

Ambient temperature changes result in defined drifts of the measured values. Mostly the temperature drift is proportional to the temperature change. For example: 0.08%/K (DT).

Outline of measuring principles

The technologies outlined in diagram 1 are able to provide an analog output signal that is proportional to the distance between sensor and target object. The chart shows typical Baumer Electric sensor parameters for the respective sensing principle.

diagram 1

	inductive	optical	ultrasonic
measuring distance	0-10 mm	15-1000 mm	20-2500 mm
resolution	0.1 µm	2 µm	0.3 mm
repeat accuracy	1 µm	2 µm	0.5 mm
linearity	0.4 - 5%	0.06 – 1.2%	0.5%
reaction time	0.35 ms	0.9 ms	30 ms
teach-in	Yes	Yes	Yes

Inductive sensors

Inductive displacement sensors are most appropriate for displacement/distance measurement on targets of electrically conductive metals such as steel, aluminium or metallic alloys. The measuring principle is based on the evaluation of inductive eddy currents. As a consequence, this physical principle is very resistant against all kinds of no-nmetallic pollution.

Common measuring ranges run from 0 to over 20 mm, with both current and voltage analog outputs available. Thanks to innovative technologies, Baumer Electric produces inductive displacement sensors as small as 6.5 mm x 40 mm while maintaining ranges up to 2 mm.

Inductive sensors are perfect for applications with requirements for high resolution and repeat accuracy. Presently, resolutions as low as >0.1 µm (about 1/500th of a human hair) are possible while repeatability figures can dip below 1 µm.

Even with such excellent repeat accuracy and resolution, the common 3-4% linearity exhibited by these sensors occasionally presents problems. To combat this, Baumer electric specifies the measured value even further

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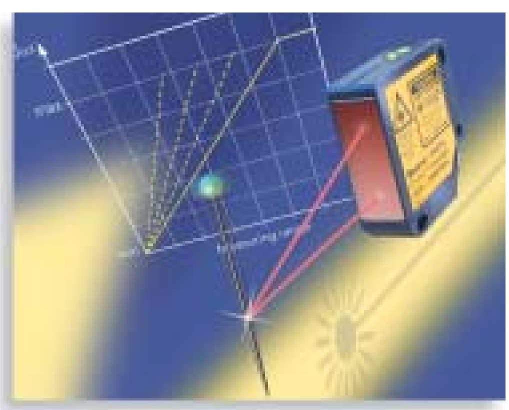

OADM 12 Laser Displacement Sensor

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by providing polynomial functions (mathematical description of the sensor's characteristic curve). These polynomial functions enable programming of common control units with very precise measuring and regular algorithms.

Typical polynomial function (based upon measuring characteristics of a Baumer Electric 12 mm tubular displacement measuring inductive sensor)
Distance = a + b (Iout) + c (Iout)2 + d (Iout)3 + e (Iout)4
measuring range 0 to 2 mm, 0-20 m (Iout)
Following coefficients are available:
a = - 0.144334; c = - 0.00782
e = -7.27311 * 10 -6
b = 0.151453; d = 0.00040
This equals a distance of 0.4638 mm with a measured value of for example 5 mA (Iout).

Another alternative available to solve linearity issues are sensors with integrated microprocessor. This digital signal processing method enables a considerable linearization of the characteristic output curve, significantly decreasing linearity error. This becomes especially evident in absolute distance measurement. For example, a linearized M12 sensorwith a measuring range from 0 to 4 mm achieves a maximum linearity error of less than +/- 0.4% (an improvement by factor of 10).

The most important characteristics of inductive sensors:

- suitable for electrically conductive material (steel, aluminium, brass etc.)
- high resolution
- short reaction time
- resistant against pollution
- small size
- relatively low cost

Laser Sensors

Unlike inductive and ultrasonic technologies, there are many ways of optically sensing distance, including laser interferometers, diffuse sensors with and without fiber optics, as well as time of flight sensors. Each has it's own strengths and weaknesses.

Interferometers offer resolution into the nanometers and long sensing ranges, but are expensive and require complex peripherals and optically efficient targets.

There are analog output diffuse sensors and fiber optic amplifiers which can be programmed to offer rough displacement measuring. They operate on intensity of received light, which, in ideal conditions and with consis-

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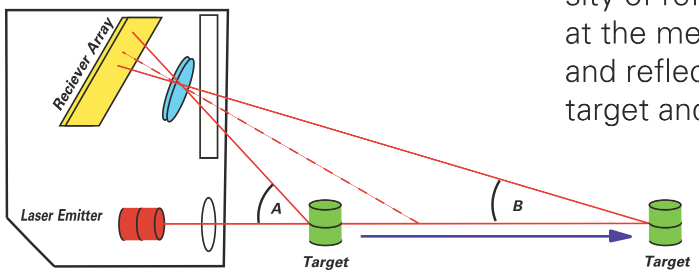

Triangulation Principle

tent targets, can be converted to a distance proportional analog output. However, by relying on the intensity of reflected light, they are at the mercy of target color and reflectivity: a matte black target and a white target, held at the same distance, will offer very different readings.

Time of flight sensors, most often lasers, offer long ranges and self contained packages. However, by relying on propagation time, they are somewhat limited in resolution, offering 3-5 mm over their measuring range.

Most machine applications require specifications somewhere between nanometer resolution and long ranges. They also often deal with less than ideal target properties: small target size, varying color, surface properties and speed.

In the real word of industrial machinery, triangulation based laser displacement sensors are the standard.

The major benefit of laser-based triangulation displacement sensors is the combination of high resolution and comparatively long ranges. While many sensor manufacturers offer versions with <10 μm resolution and ranges to 1 m, the highest resolution specs usually are possible over relatively small windows and at shorter ranges. So, a 1 μm resolution and a 1 m sensing distance will not happen simultaneously.

Triangulation technology utilizes a laser light source to project a well-collimated beam, which reflects off the target, back to the sensor. The light reflected by the object passes through a lens that focuses the reflected beam onto a receiver. Any change in the distance between sensor and target will immediately change the angle of the returning light thereby changing the position of the beam on the receiving array. The CCD line as receiving element and the microcontroller combine to output the measured values as analog signals.

In order to limit the effects of signal noise, all laser measurement sensors perform an internal sampling, sometimes called integration or averaging. During sampling, sensors take multiple readings and average them, resulting in

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smoother, more accurate outputs. In order to achieve higher resolutions, more samples must be integrated. This increase in samples often increases response time proportionally with any improvement in resolution. While 1 µm resolution is possible, it typically comes with a response time as slow as 100 ms - rarely usable in a dynamic application.

By contrast, Baumer Electric OADM Laser displacement sensor family's <900 µs response time is an absolute high, regardless of resolution and target color. The OADMs will offer up to 2 µm resolution at <900 µs on even matte black targets. In fact, on an ideal target like matte white ceramic, response times can be as fast as 250 µs with no decrease in resolution! An advanced receiving element, capable of sub-pixel resolution, combined with intelligent microprocessors allow the OADM sensors to offer consistent response times at all resolutions independently of target color and reflectivity.

Most versions of triangulation displacement lasers project a laser point, which work extremely well for small parts and point measurements on fairly smooth textures, but rough textures can increase the potential for false readings.

To limit the potential for false readings on irregular surfaces such as concrete, or the "orange peel" texture of some painted media, Baumer Electric offers triangulation based displacement sensors that project a laser line, in addition to the point (dot) versions. By averaging the reflection across this line, irregularities on the target surface are effectively "tuned out", resulting in extremely accurate readings.

For time-synchronous tasks, for example measuring the object's thickness, there is an additional synchronizing input. By an external signal measurements from several sensors can be started at the same time.

Laser displacement sensors are also undergoing a process of miniaturization. Where the industry standard has for years been a multiple-component system consisting of a sensing head and external control unit, new products such as the Baumer Electric OADM 12 offer completely self contained body sizes as small as 12 x

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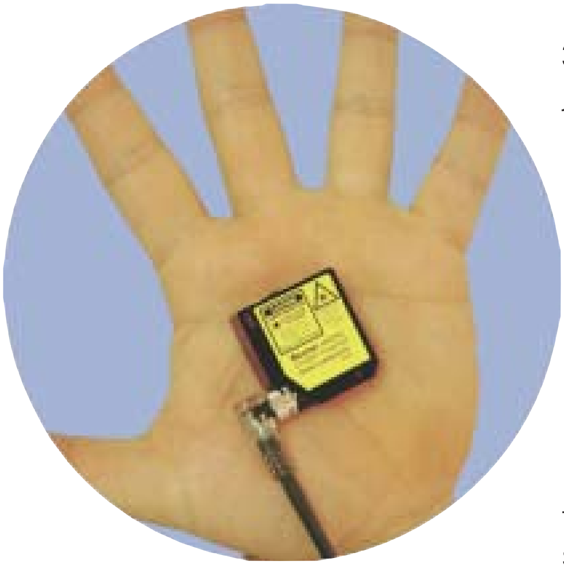

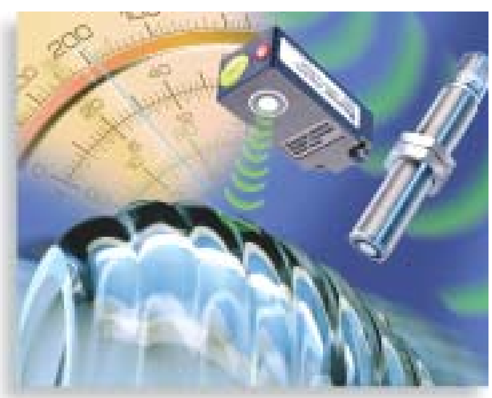

Ultrasonic Sensors

37 x 34 mm and weighing just 37 grams. These one-piece sensors are considerably smaller than the sensing head of previous multiple-component versions, require no external controller, and offer 2 μm resolution and 250-900 μs response times.

Most important characteristics of Baumer Electric optical sensors:

- suitable for very different kinds of material
- for small or rapidly moving objects
- high resolution
- high linearity
- short reaction time

Ultrasonic Sensors

In addition to optical and inductive technologies, some manufacturers also offer products that offer distance measurement via ultrasonic transmission.

The central principle revolves around sound propagation time. Based on the speed of sound through air, and calculating the time required for the sound to return to the sensor, distance can be measured with resolutions down to <0.3 mm.

By applying converters based on the reversible piezoelectric effect, it is possible to realize one-head systems with the converter serving both as transmitter and receiver.

A short-burst ultrasonic "packet" is transmitted. At the same time, an internal clock is started, measuring propagation time. The sound packet is reflected by the object back to the sensor, at which time the clock stops. The time elapsed between transmitting the packet and receiving the echo back is the basis for calculation of the distance to be measured. The complete control of the process is realized by an integrated microcontroller.

The major benefit of ultrasonic displacement sensing is their ability to measure difficult targets. Solids, liquids, granulates and powders can all be detected with similarly high resolutions. Even transparent and highly reflective items, those that cause optical sensors such difficulty, can be reliably recognized by ultrasonic sensors. Additionally, analog output ultrasonics offer comparatively long ranges, in many cases exceeding 3 m.

Now as good as ultrasonics can be, they do have some limitations. Surfaces such as

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foam may absorb the majority of the sound, significantly decreasing measuring range. Similarly, extremely rough surfaces may diffuse the sound excessively, also decreasing range and resolution. However, an optimal resolution is guaranteed up to a surface roughness of 0.2 mm.

Another traditional limitation of ultrasonics are their propensity for emitting a wide sonic cone, limiting their usefulness in small target measurement as well as increasing the chance of receiving false feedback from interfering objects.

With this limitation in mind Baumer Electric developed M12 ultrasonics with sonic cone angles as narrow as 6 degrees. These sensors allow for the detection of much smaller objects, as well as sensing targets through narrow objects such as bottle necks, pipes and ampoules.

Most important characteristics of ultrasonic sensors
- alternative to optical sensors
- high linearity
- constant resolution
- high measuring distance
- resistant against pollution

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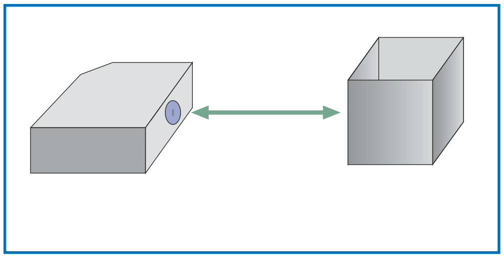
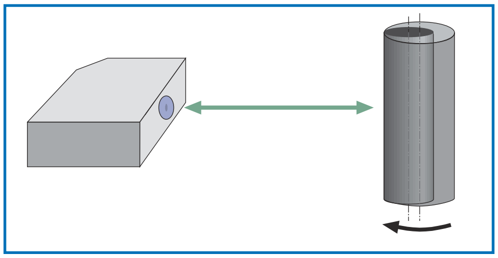
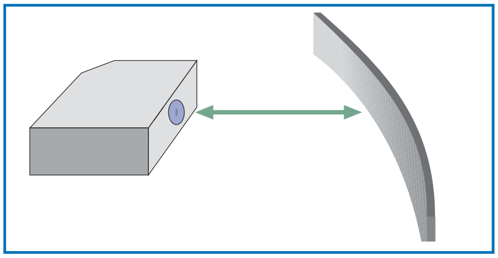
Travel / position / displacement



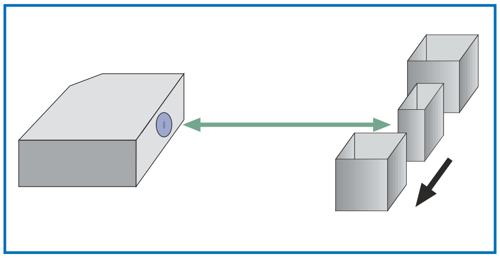
Diameter / eccentricity



Deflection / deformation



Size comparison / measurement tolerance



Versatile applications

The increasing variety of products and high requirements on quality call more and more for reliable product and process control. Many tasks in positioning and measurement that so far had been up to expensive sensor systems or even were not feasible in practice are now solved by the help of the varied Baumer product program.

Typical applications for measuring sensors:

- absolute displacement measurement
- measuring thickness
- slope and deformation control
- linear distance measurement
- position control
- profile logging
- product assortment
- centering control (diameter and eccentricity measurement)

Here are the 9 questions to answer before deciding on a distance sensor:

1. What is your target material?

2. What is your range to target?

3. What resolution is required?

4. What are your physical mounting needs? How much space can you allocate to the sensor?

5. What output signal is required? (0-10 VDC, 4-20 mA, RS 485)

6. How fast is the target moving? What is the necessary response time?

7. What degree of environmental protection is required?

8. What are the connection requirements? (cable, quick disconnect)

9. Who is my local Baumer Electric representative? Call 800.937.9336.

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