Optex FA website full of sensor information

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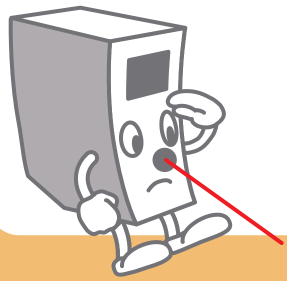
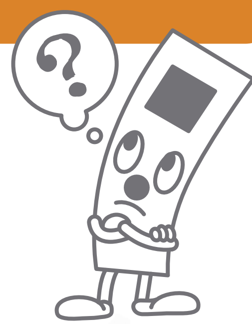
Displacement Sensor Handbook

OPTEX FA CO., LTD.

Contents



1. What is a Displacement Sensor?



- Displacement sensors measure the height and thickness of workpieces and distances in units of micrometers.
- Photoelectric sensors detect the presence of workpieces, but displacement sensors can accurately measure the distance to workpieces in millimeters.

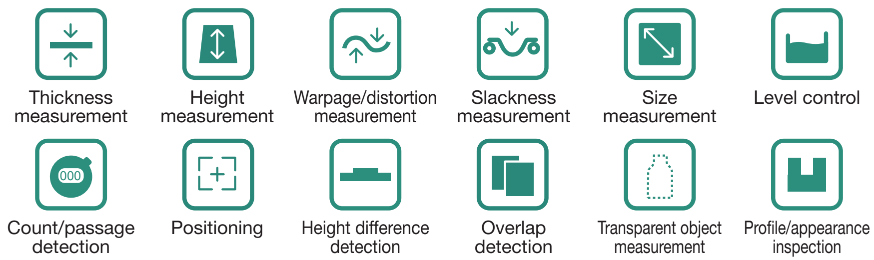
* There are various types of displacement sensors including contact types, ultrasonic types, capacitive types, and inductive types, but this handbook explains **laser displacement sensors**, which are an optical type that uses a laser as its light source.

Laser displacement sensor features

○
- **Non-contact measurements.**
- **Long-distance measurements.**
- **Small object measurements.**
- **High-speed and highly accurate measurements.**
- **Suitable for almost of all objects.**

×
- **Weak to optical system contamination such as oil and dust.**

Laser displacement sensor abilities



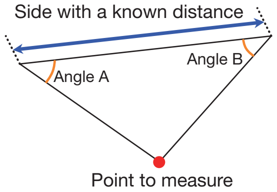
2. Measurement Methods

The key points for using a laser displacement sensor to accurately measure distance are the measurement principle and the measurement methods.

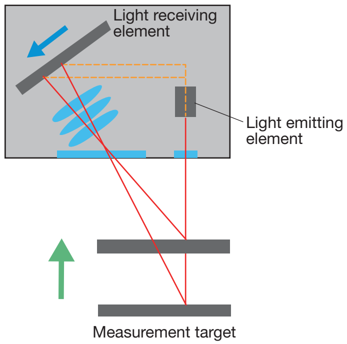
2-1. Measurement Principle

Laser displacement sensors use the principle of **triangulation**. This is a method that uses the principles of triangles to measure the distance to a separate point.

- As shown in the diagram on the right, if the accurate distance between two points is known, the distance to a position separate from these two points (the red circle, ●) can be found so long as the angles from these two points are known.

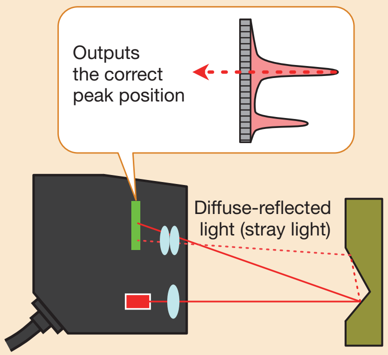


- With a laser displacement sensor, a triangle is created between the light emitting element, light receiving element, and measurement target. Then, the distance to the measurement target is found (see the diagram on the right).
- If the distance to the target changes (green ⬆), the position of the light on the light receiving element changes (blue ⬅). In other words, the distance to the target is measured from the position of the light on the light receiving element.



Light receiving element CMOS sensor

Generally, laser displacement sensors use CMOS sensors, which are used in devices such as digital cameras, for their light receiving elements. This makes it possible to identify the true peak position, which is not affected by ambient light or diffuse-reflected light (stray light), thereby enabling stable measurements even of complicated shapes.

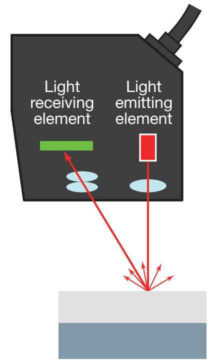


2-2. Measurement Methods

There are two types of light reflections: specular reflection in which light is reflected at the same angle as the light struck the surface (the angle of incidence) and diffuse reflection in which light is reflected at a variety of angles. One of these types of reflected light is used to measure distance.

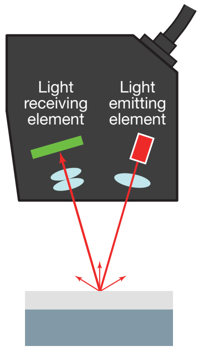
■ Diffuse reflection

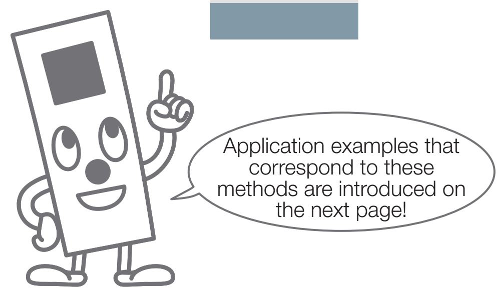
In this method, the beam is emitted perpendicular to the measurement surface and, among all the reflected light, the diffusely reflected light is received. This makes it possible to **obtain a wide measurement range**. However, this method is not suited to transparent objects and specular objects, which generate almost no diffuse reflections.



■ Specular reflection

In this method, an optical system is arranged so that the light emitting angle and the light receiving angle are the same and the specularly reflected components of the reflected light are received. This is mainly used in the **measurement of transparent objects and specular objects**. A disadvantage is that the measurement range is shorter than that of the diffuse reflection method, but the accuracy increases by the same amount that the measurement range decreases.



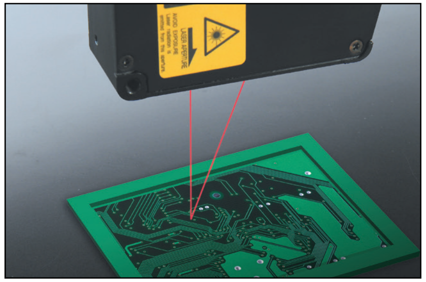


3. Applications

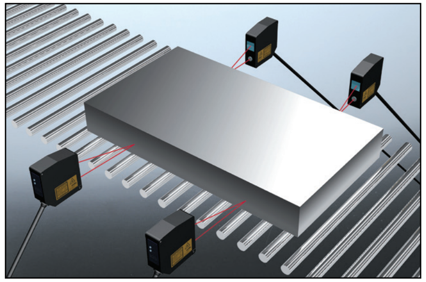
Laser displacement sensors are used in quality management, measurement, and control applications in a wide variety of industries. Specular reflection types are frequently used in industries such as the FPD, PV, semiconductor, and film industries.

Diffuse-reflective type

PCB warpage measurement

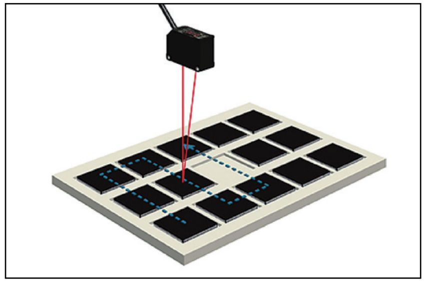


Steel plate tilt measurement

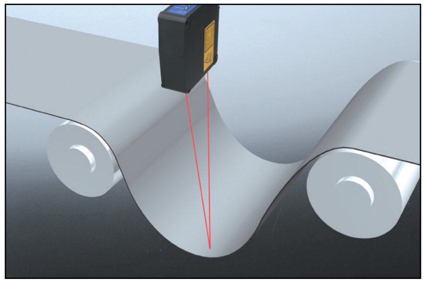


Measurement of sealant amount

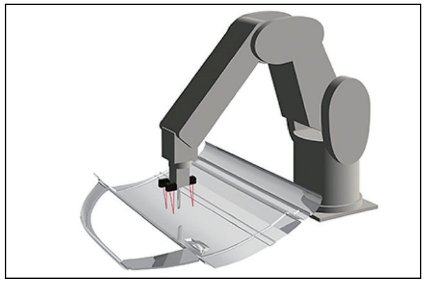
Presence of chips in trays



Slackness control of sheet materials

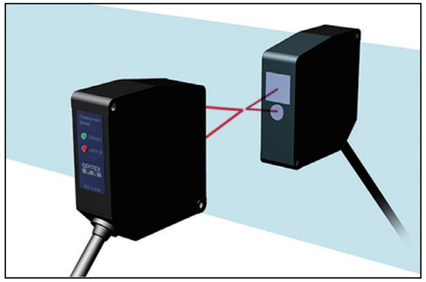


Robot arm positioning

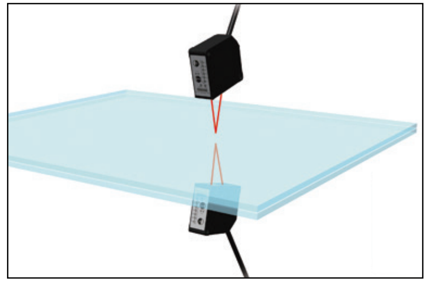


Specular reflection type

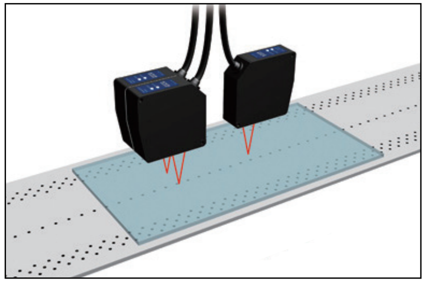
Thickness of transparent films



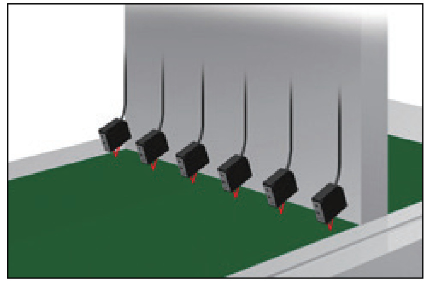
Glass substrate double-feeding



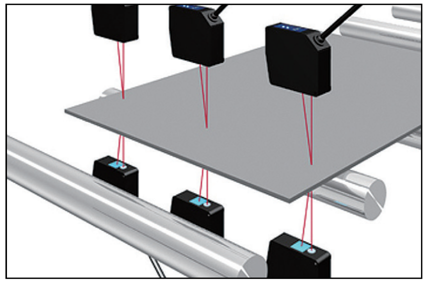
Liquid crystal glass distortion



Exposure head Z-axis control



Solar cell substrate thickness

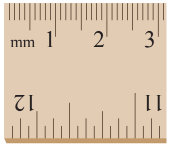


4. Terminology

It is important to know how detailed and how accurately a laser displacement sensor can measure distance.
Accuracy and functions related to accuracy are explained below.

4-1. Resolution

- This indicates **how detailed the sensor's scale is**. That is, how detailed a unit the sensor can use to perform measurements. Take a ruler for example. Its scale is at gradations of 1 mm, so the resolution is 1 mm.



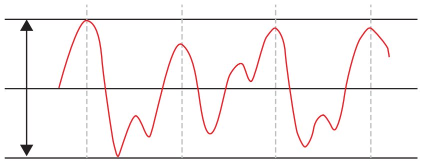
4-2. Repeat Accuracy

- The measured values obtained by a laser displacement sensor vary even when the workpiece is stationary. The repeat accuracy is the **amount of variation** between values obtained from repeated measurements of the same position on a stationary workpiece.

e.g.: CD5-85 (diffuse mode)

Repeat accuracy: 1 μm

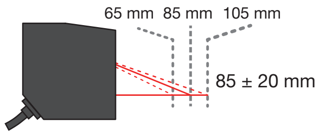
* Typical example with an average count of 4096 (The average count must be written in the measurement conditions.)



With repeat accuracy, the peak-to-peak distance of the measured values is calculated.

4-3. Full Scale (F.S.)

- This indicates the **range that the sensor can measure**.
- The height difference and moving range of the measurement target must be less than or equal to this value. This is an important item when selecting a model.



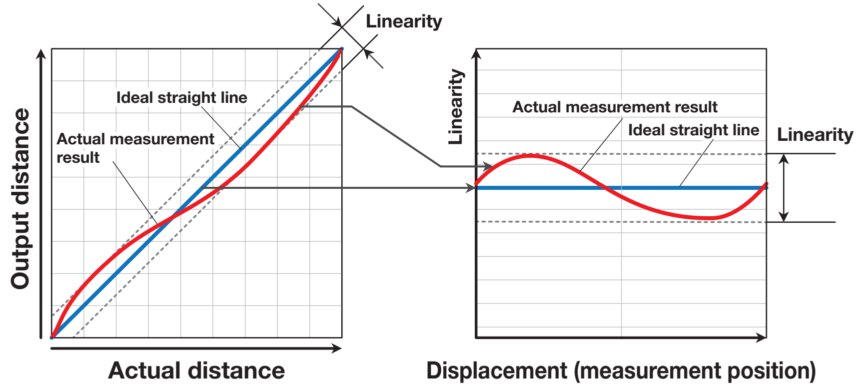
e.g.: CD5-85 (diffuse mode)

Measurement range: 85 ± 20 mm
(= 65 mm to 105 mm)

→ Full scale: ±20 mm = 40 mm

4-4. Linearity

- Linearity is the **offset between the measured value and the value of the actual displacement (distance)**.
  In the following diagram, the actual distance measured by a laser displacement sensor is mapped to the horizontal axis and the output distance is mapped to the vertical axis.

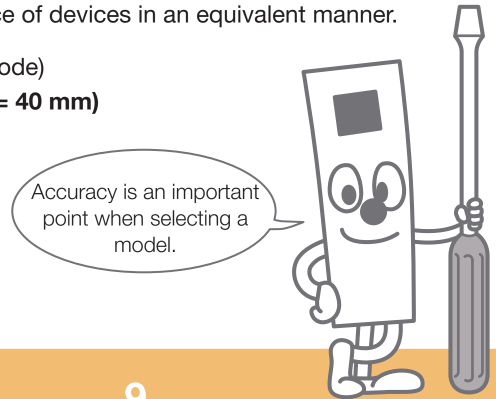


If a sensor is free of errors, the relationship between the actual distance and the output distance is a clear straight line. This is the ideal straight line. However, just like the actual measurement result indicates here, values that are offset from the ideal straight line are output in actuality. This offset is called linearity.

- Linearity is expressed as a percentage of the full scale. The longer the full scale, the more difficult it becomes to maintain accuracy. Therefore, expressing the linearity as a percentage of the full scale makes it easy to evaluate the performance of devices in an equivalent manner.

e.g.: CD5-85 (diffuse mode)

±0.05% F.S. (F.S. = 40 mm)



4-5. Sampling Frequency/Sampling Period

- The sampling frequency (unit: Hz) is the number of **measurements per second**. The larger this value, the shorter the time required for a single measurement (sample). The shorter the measurement time, the better the sensor can support high-speed lines. However, the receiving light level becomes small, so caution is required for workpieces (such as black rubber) with low reflectance.
- Because laser displacement sensors perform feedback control on the light receiving time, even if the measurement time is too long, the receiving light level does not become saturated.

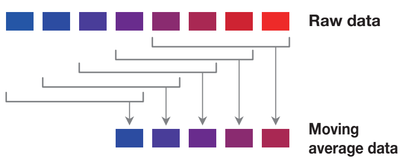
Sampling frequency (Hz) = 1/sampling period (ms/μs)

4-6. Averaging (Moving Average)

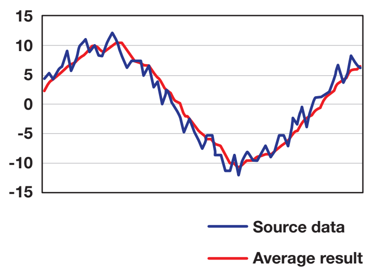
- Even when the target is stopped, measurement values vary from one measurement to another. Therefore, perform a **moving average** on the measurement data from multiple measurements in order to stabilize this data.
During the moving average, the measurement locations are shifted sequentially in order to calculate the average over the ranges indicated with brackets (⎵) as shown in the diagram on the right.
- Setting a large moving average count reduces variations, but the response becomes slow and it becomes impossible to measure subtle changes.

Moving average calculation method

e.g.: Average count: 4



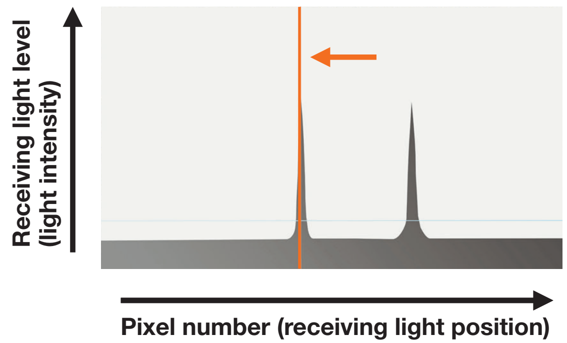
Moving average processing graph



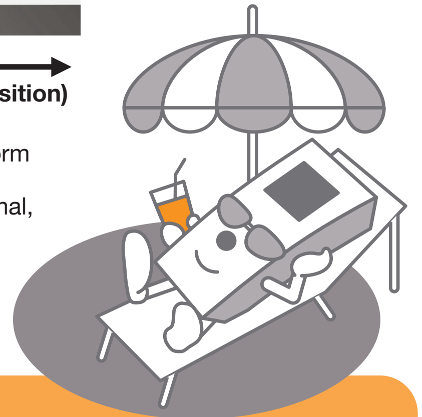
4-7. Receiving Light Waveform

- With some sensors, it is possible to display the position and intensity of the receiving light as a waveform.
This graph is called a receiving light waveform. In the receiving light waveform, the **peak position is the measured value**.

If a peak forms like that shown in the following diagram, it is possible to perform accurate measurements.



- Because laser displacement sensors perform feedback control automatically in order to ensure that the receiving light level is optimal, normally there is no need to be concerned with the received light waveform.



Displacement sensor types and features

There are many types of displacement sensors. Each one has its own advantages and disadvantages, but the optical laser displacement sensors that we have introduced here excel in many categories.

Type	Accuracy	Distance	Speed	Target
Contact	Very good	Poor	Bad	Good
Optical (laser)	Very good	Very good	Very good	Very good
Ultrasonic	Bad	Very good	Bad	Very good
Capacitive	Very good	Bad	Very good	Poor
Inductive	Good	Bad	Very good	Bad (metal only)

5. Measurements with Calculations

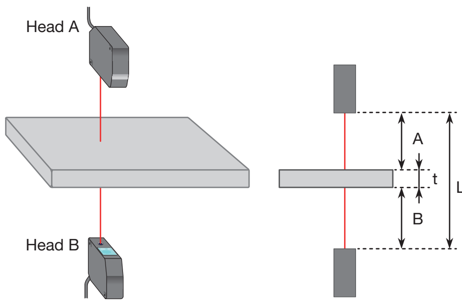
By using multiple laser displacement sensors and performing calculations on their measured values, measurements that are not possible with a single sensor become possible.

5-1. Thickness Measurement

By performing a calculation with the measured values from the front surface (head A) and back surface (head B) of the workpiece, it is possible to measure the thickness.

Thickness t = L - (A + B)

- Because the actual "L" is not accurately known, use a workpiece whose thickness is known in order to perform calibration.

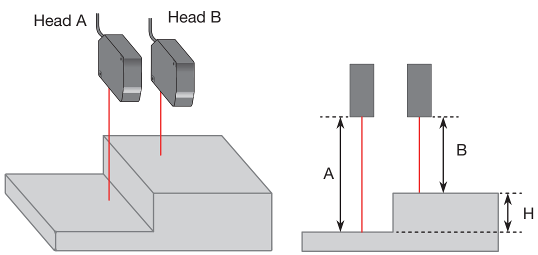


5-2. Height Difference Measurement

By installing two laser displacement sensors next to each other and subtracting their measured values, it is possible to measure the height difference.

Height difference H = A - B

- When measuring the thickness of sheets wound around rollers, the sheet thickness can be calculated by measuring the roller surface and the sheet surface.

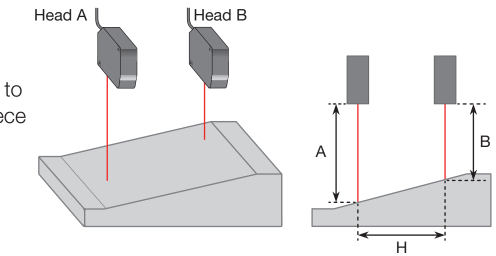


5-3. Slope Measurement

The slope can be measured by dividing the height difference by the installation distance (H).

Slope θ = (A - B)/H

- This is used not only to inspect for variations in the slope during workpiece processing but also to control devices to match slopes and to judge whether a transported workpiece has arrived at the correct position.

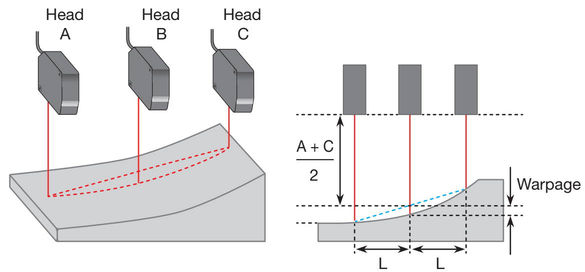


5-4. Warpage Measurement

By installing three laser displacement sensors at regular intervals and calculating their measured values, it is possible to measure the warpage.

Warpage = B - (A + C)/2

- The amount of warpage is considered to be the difference between (1) the line connecting the measurement points of laser displacement sensors A and C and (2) the measured value of laser displacement sensor B (see the diagram on the right).



6. Important Points

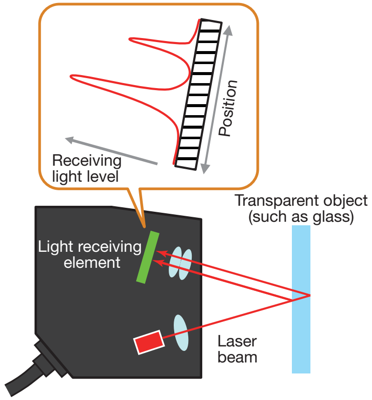
When using laser displacement sensors, exercise caution regarding the following points.

Point 1 About the receiving light waveform

Because laser displacement sensors can use feedback processing to optimize the receiving light level, normally there is no need to check the receiving light waveform. However, in the following situations, check the receiving light waveform, change the sensor's installation method, or implement similar countermeasures.

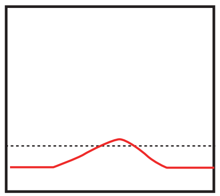
● Measuring transparent objects

When measuring transparent objects, it is necessary to install the sensor at the correct angle to ensure that the specularly reflected light is received. The margin for the angle is approximately 2 to 5 degrees (this varies depending on the model), so use the receiving light waveform to check whether measurement is possible. When measuring the thickness of transparent objects, two beams of reflected light are received: one from the front and one from the back of the transparent object, as shown in the diagram on the right.



● Black workpieces

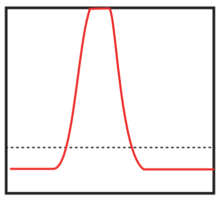
The larger the sampling frequency, the shorter the measurement time and the smaller the light level. Therefore, when performing high-speed measurements of workpieces with low reflected light levels (such as black rubber), use the receiving light waveform to check whether the receiving light level is sufficient.



When the receiving light level is low

● Highly reflective metal workpieces

When measuring metals and other objects with high reflected light levels, a high laser power can lead to the receiving light level being saturated. Check the receiving light waveform. If the receiving light level is saturated, reduce the laser power, change the sensor's installation method, or implement similar countermeasures.



When the receiving light level is saturated

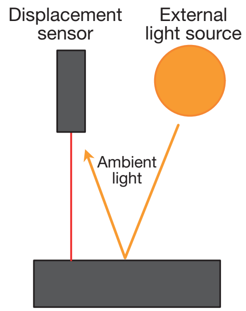
Point 2 About the effect of the environment

Ambient light and stray light are some of the reasons for unstable measurements. If light that is different from the normal measurement waveform is added to the receiving light waveform, errors will occur in the measurement results. Also, temperature causes the measured values of laser displacement sensors to change.

● The effect of ambient light and stray light

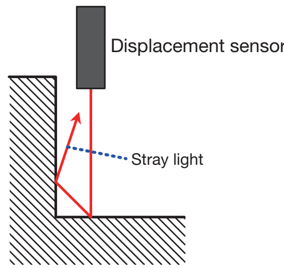
<Ambient light>

Ambient light refers to the intrusion of intense light from an external source. This occurs when sunlight or other intense light is present. This problem can be alleviated by blocking the external light.



<Stray light>

Stray light is light caused by reflections that are different from normal. Reflections from walls and similar objects close to the workpiece affect the measurement. It may be possible to alleviate this problem by changing the installation orientation of the sensor or by implementing similar countermeasures.



● About temperature changes

<Temperature drift>

This is the change in the measured value due to changes in the temperature. It is expressed like "±0.01% FS/°C."
This is listed in the specifications in product catalogs, so use this as a reference when selecting a model.

<Initial drift>

When a sensor is turned on, its internal temperature increases, which causes the measured value to change. Check the warm-up time listed in catalogs and perform measurements after this time has elapsed.

Hazard Degrees by Laser Class

[Class 1]

By design, these lasers are inherently safe. Regardless of the optical method that is used to condense the light, the level is such that eye safety is ensured. No countermeasures are especially required.

[Class 1M]

The wavelength range is 302.5 to 4000 nm and the output is low. Using an optical method to observe the beam may be hazardous.

[Class 2]

The light must be visible (the wavelength range is 400 to 700 nm) and the output is low. The eyes are protected by the blink reflex and other aversion responses.

[Class 2M]

The light must be visible (the wavelength range is 400 to 700 nm) and the output is low. The eyes are protected by the blink reflex and other aversion responses. Using an optical method to observe the beam may be hazardous.

[Class 3R]

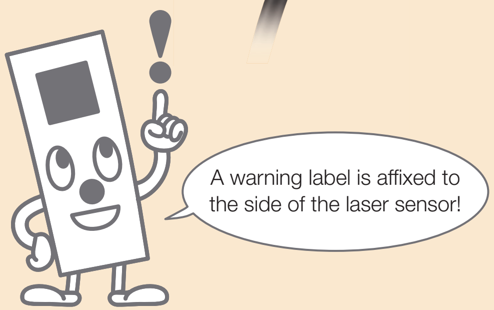
With these lasers, directly observing the beam is potentially hazardous, but the level of this hazard is lower than that of class 3B and higher lasers. The control countermeasures for manufacturers and users are more relaxed than those for class 3B lasers. The AEL (Accessible Emission Limit) is at maximum five times that of class 1 lasers for light other than visible light (wavelength: 302.5 nm or higher) and is at maximum five times that of class 2 lasers for visible light (wavelength range: 400 to 700 nm). These lasers do not require a key switch and an interlock system.

[Class 3B]

These lasers have an output of 500 mW or less. Observing the beam directly is hazardous. These lasers require a key switch and an interlock system. They also require a warning display or a similar device during use.

[Class 4]

These are high-output lasers that are hazardous even when viewing their dispersed light. They pose the risk of burns if they come into contact with the skin and the risk of fire if they come into contact with objects. Countermeasures such as ensuring that the emitted laser beam is blocked are required. It goes without saying that these lasers require a key switch and an interlock system. They also require a warning display or a similar device during use.

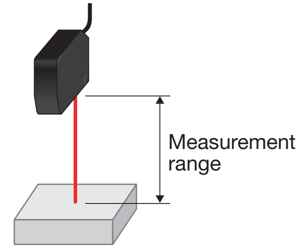


7. Selection Procedure

The main procedure for selecting a laser displacement sensor is explained below.

Step 1 Measurement range

Determine the required measurement range from factors such as the distance to the measurement target and the size of the workpiece.



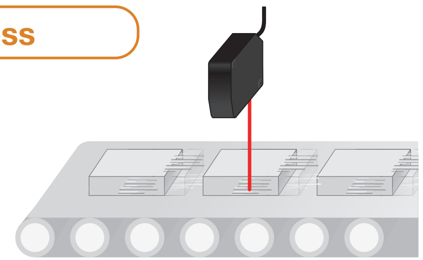
Step 2 Measurement details

Check the color, size, tilt, and surface conditions of the workpieces.

Workpiece information	Tips
Color	**Reflection rate size. Transparent, opaque, etc.**
Size	**Does the workpiece size comply with the sensor's measurement range?**
Tilt	**A large tilt tends to lead to unstable measurements.**
Surface Conditions	**Rough surfaces lead to variations in the measurements.**

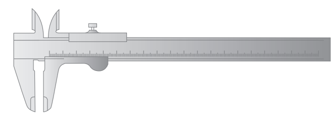
Step 3 Responsiveness

Check the movement speed and takt of the line on which measurements will actually be performed. If high-speed response is required, select a model that can perform high-speed sampling.



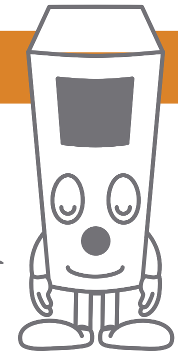
Step 4 Accuracy

Determine the accuracy that meets the required specifications. The repeat accuracy varies depending on the combination of the laser displacement sensor and the workpiece, so we recommend that you perform tests with the actual workpieces and devices (line).



8. Products

Optex FA's lineup of laser displacement sensors, which realize non-contact and stable measurement, is introduced below.



This is the last page in this handbook.
Thank you for reading it all the way to the end!

Laser Displacement Sensor

From low-cost models to high-end models, a wide variety of units are available to match various repeat accuracies.
These are spot-light-type laser displacement sensors.

Series	Light source	Light receiving element	Structure	Repeat accuracy	Linearity	Sampling period
Ultra high-accuracy laser displacement sensor **CDX series** NEW World's number 1 linearity 	Class 1 laser	CMOS linear image sensor	Built-in amplifier	0.25 µm or more	±0.015% of F.S. to ±0.04% of F.S.	12.5 µs to 1 ms, AUTO (8-level switching)
CMOS built-in amplifier type **CD33 series** Cost effective laser displacement sensor for built-in use 	Class 2 laser			2 µm or more	±0.1% F.S. to ±0.3% F.S.	500 [750] to 2000 µs (4-level switching) The value in [ ] is for the CD33-250.
Compact type **CD22 series** Smallest displacement sensor in class 	Class 1 laser (CD22-15, CD22-35) Class 2 laser (CD22-100)			1 µm or more	±0.1% F.S.	500 to 4000 µs, AUTO (5-level switching)

2D Displacement Sensor

Parallel line laser light enables 2-dimensional detection of workpiece surface shapes.
Detects items such as height, width, thickness, pitch, groove depth, tilt, and presence.

2D displacement type
LS series

2-dimensional measurements at a significantly low cost. Optex FA's proprietary method enables high speed and a compact size.

Control Unit

This control unit makes it possible to connect Optex FA displacement sensors to PLCs and networks.

Displacement sensor control unit
UQ1 series

This communication unit makes it possible to easily connect our displacement sensors to the Mitsubishi Electric MELSEC-Q series of PLCs.

Supports the CD33

Displacement sensor amplifier unit
CDA series

By connecting to a CC-Link communication unit, it is possible to manage the displacement sensor over CC-Link.

Supports the CD22