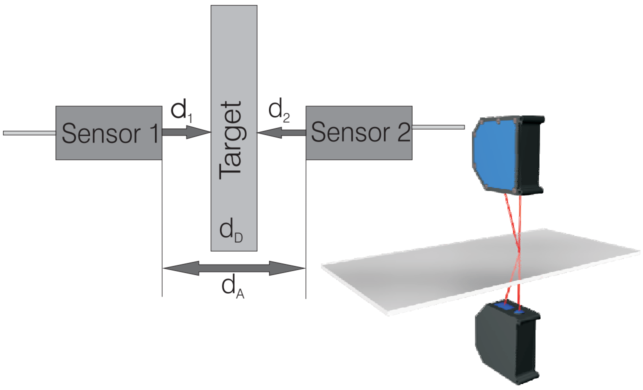
Thickness measurement - Linearity optimisation

For thickness measurements, two sensor systems with the same or different measurement principles can be combined. These can be arranged on one or both sides of the target. Due to the use of two sensor systems, their non-linearities are added together.

There are basically two different principles in measuring technology for determining the thickness of a work piece or material using displacement sensors.

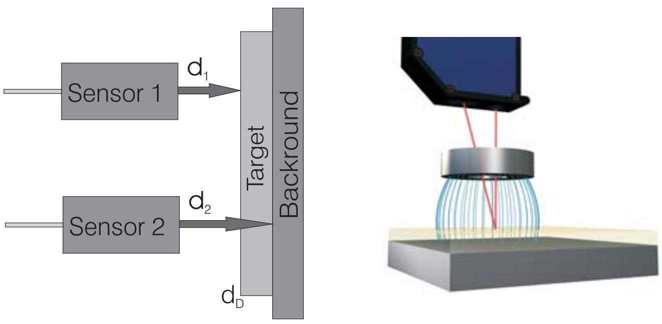
A) Facing thickness measurement



Two sensors are placed at a known distance d_A on both sides of the measuring object (= target) which each measure the distance to the object. The distances d_1 and d_2 are subtracted from the sensor distance d_A in order to determine the thickness d_D of the target.

Formula: $d_D = d_A - (d_1 + d_2)$

B) One-sided thickness measurement



Two sensors are placed at the same distance d_1 from the measuring object on one side of the target. One sensor measures the distance d_2 to the background which is on the opposite side of the object. The thickness d_D of the target is calculated by subtracting the signals from one another.

Formula: $d_D = d_2 - d_1$

For example, the thickness of an electrically-conductive work piece can be measured with two capacitive sensor systems, using the first method outlined above. The second method is suitable for thickness measurement of non-conductive material in front of an electrically-conductive background, e.g. film that is transported over a roller.

Determination of sensor nonlinearities

The determination of sensor non-linearities is a very complex technical task, since highly precise reference measurement systems are required for this. The linearity of a sensor system is dependent on the installation conditions and on the condition of the measuring object material. Therefore, the reference measurement system must integrated into the thickness measurement system. This results in a thickness measurement system that is highly complex in terms of mechanical design and so is difficult to realise in practice.

In the context of thickness measurement, Micro-Epsilon's special technique makes use of the fact that it is not the linearity of the individual sensors that is important here, but instead the combined non-linearity of both sensor systems. In this case, there is a reference measurement system - the measuring object as reference or master target with known thickness d_s . Thus, the combined non-linearity nj can be calculated for each pair j of measurement results $j=(d_1,d_2)$.

Formula: $n_j = d_S - (d_A - (d_1 + d_2))$

If the measuring range of each sensor system is considered as an axis in a two-dimensional co-ordinate system, the pairs of individual measurement results, which are generated by displacement of a reference object in the measuring gap, produce an approximate diagonal. An error range across several diagonals when using different reference objects is produced by applying the calculated non-linearities n_j across the diagonal.

Compensation of combined sensor non-linearities

By approximating the error range using suitable function models, it is possible to determine a two-dimensional correction function d_N (d_1, d_2). This contains the measured values of both sensors as a function of the argument and provides the combined non-linearity as a function value, which can now be subtracted from the measured result for the correction. The objective of the approximation method is to achieve good results with as few reference parts as possible. The non-linear optimisation methods have proved themselves best here. The use of one reference part is often sufficient for these methods. The acquisition of the non-linearities and the calculation of the correction function are carried out in a calibration phase. Depending on the measuring task and/or system design, the sensor emulator or the reference target is displaced.

In routine operation, the corrected thickness value d for each measured value pair $j = (d_1, d_2)$ is calculated as the difference between the measured thickness value d and determined Non-linearity d_N (d_1, d_2).

Formula: $d_k = d_D - d_N(d_1, d_2)$

$$d_k = (d_A - (d_1 + d_2)) - d_N(d_1, d_2)$$

Implementation of the algorithms

The algorithms are implemented in the ICONNECT software tool as modules. This is a graphical development and run-time platform developed by Micro-Epsilon, which provides a solution for measuring and testing technology problems. It provides the most common algorithms in sensor signal processing in the form of a module library. The modules are connected to a block diagram using “place and route”. The block diagram (signal graph) is an executable programme in the run-time environment.

As well as the signal processing algorithms, ICONNECT provides input and display modules, which allow the design of a Windows-compliant user interface. The creation of the user interface is also performed graphically.

Many other module groups such as hardware and file input/output, logic and control modules complete the functional scope and make ICONNECT a very flexible tool.

Example display of the bearing shell measurement process

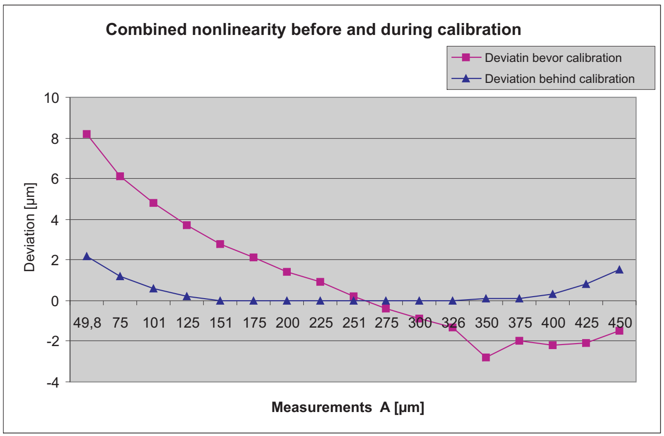
For this application, bearing shells glide through a measuring station on an air slide. The wall thickness of the shells is measured using two, type S601-0.5 capacitive sensors. Both sensors are mounted on a carriage system so that they can be moved up or down in the calibration process.

A reproducibility of 0.2µm for 99.9% of all measured values is required for this measurement. In order to meet this requirement, a linearity that exceeds the 0.3% given by the sensor system, added to the 0.6% for the thickness measurement is required.

For this application, the measuring electrode of the upper sensor must be round . Shells with a small radius can also be measured without the sensor making contact with the shell wall.

This mechanical modification of the sensor electrode significantly degrades its linearity so that the combined non-linearity is finally around 1%.

The sensor measuring range from 100µm to 400µm is used for the measurement. Limited to this section, the combined non-linearity is still 0.7%. The linearity of the thickness measurement apparatus can be improved by more than 10 times using the linearisation process,to a combined non-linearity of 0.06% in the range used.



Summary

The methods explained and the results achieved by using these methods clearly show that Micro-Epsilon's very high precision thickness measurement sensor systems can still be improved by using the software compensation technique using combined sensor non-linearities.

The determination and compensation of combined sensor non-linearities in thickness measurement are protected by Micro-Epsilon patents.

Only complete systems from Micro-Epsilon can achieve and guarantee such high precision.

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