The Use of Non-Contact Thin Gap Sensors
in Controlling Coater Gap Uniformity

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Summary

This article will cover the use of capacitive non-contact thin gap sensors in controlling coater gap uniformity

The discussion will begin with a description of various coater die gap applications. It will lay out the measurement challenges facing these applications as well as the traditional methods used to measure gaps. Next will be a brief description of capacitive technology. This will be followed by a detailed description of the development of a new capacitive sensor system including specialize sensor wands and customized fixturing, sensor electronics and signal conditioning software.

The conclusion will show how the use of this new system has made dramatic improvements over traditional gap measurement methods achieving coater gap uniformity better than 10 microinches (0.25 microns) across the full length of the coater die.

Application Description

Capacitec has been working closely over the past 10 years with the leading global manufacturers of tapes and films for various commercial and industrial uses. The development was pursued directly with end users as well as with various coater suppliers.

The common thread between these users is the utilization of slot extruder dies to apply a variety of very thin chemical, adhesive and photographic coatings to a variety of media.

Specific examples of applications include:

- Adhesive coatings onto labels
- Chemical coatings onto films and tapes
- Photographic coatings onto films
- Manufacture of plastic tapes

In a typical applications the coater die slot gap sizes range from 0.006″ (150 microns) to 0.024″ (600 microns) with a typical set of slots being 0.006″, 0.008″, 0.010″, 0.012″, 0.014″ etc. The length of the slot gap is typically 3 to 6 feet (1 to 2 meters) wide.

Since there is a direct relationship between setting the width of the slot gap and the thickness of the coating material, it is critical for manufacturers to set a very uniform gap along the full length of the coater die. The uniformity must be held at the microinch level (0.01 microns). (See Figure 1)

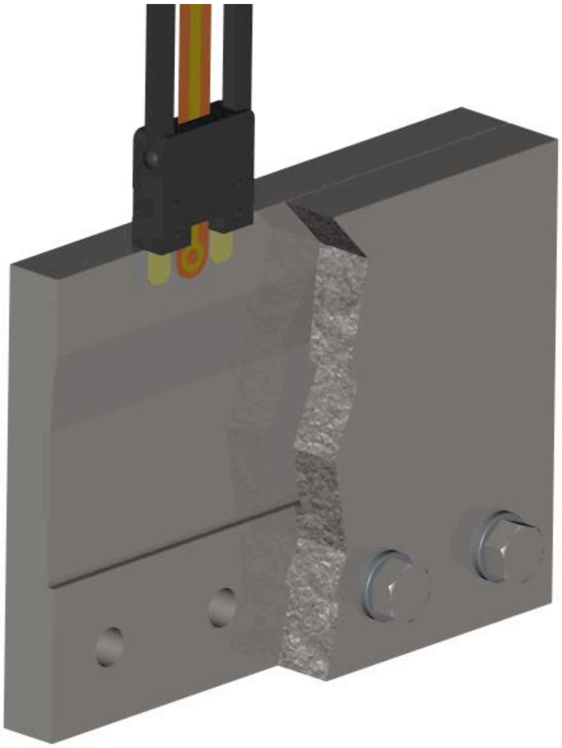


Figure 1
Gap measurement fixture in the process of measuring coater slot gaps

Traditional Measurement Methods

In earlier days, manufacturers using old measurement methods were forced to live with gap variations of more than 50 microinches (1.25 microns) over the length of the coater dies. They would set the gaps in a variety of time consuming methods using traditional standard metrology tools.

One method was the use of feeler gauges. This procedure could not provide the required accuracy and the repeatability was poor due to the subjective variation between users. In addition the feeler gauge method suffers from the following problems:

- Could damage highly polished surfaces such as the mouth of a coater
- Once the gap is set it is very difficult to recheck the actual dimension
- Feeler gauges cannot accurately measure "inboard" gaps

Another traditional method would be to split the extruder die in two and put each half on a granite metrology table. Flatness measurements would then be taken with the use of displacement sensors measuring from above. The next step would be to polish each side to obtain an ideal matched set and bolt the two sides back together. Gap uniformity variations are caused by two factors. The first is a result of variations in the planarity in each half of the die as measured on the table. Additional variability could be seen during re-assembly of the die as a result of variations in the torque applied to the mounting bolts. The combined impact of these factors results in a gap uniformity variability of 10 to 40 microinches (0.25 to 1.0 microns). Another challenge with the granite table method was to measure not only the gap along the length of the coater mouth, but also selected profile points within the coater to identify "choking points" inboard in the die.

The only way to actually check the results of this measurement method was to remount the die in the coater and make a test run of material. The coated material would then be measured after the fact to determine relative uniformity of the coating deposited on the media.

This "metrology table" gap setting method presented a variety of problems and challenges such as:

1. The process was time consuming requiring many hours from skilled technicians

2. Combined flatness variations of at least 10 to 40 microinches (0.25 to 1.0 microns).

3. Measurement of success required performing several test runs wasting time and high dollars especially when exotic material was involved.

4. Since nominal gaps are set based upon minimum dimensions, material is often wasted to normalize coating thickness across the remainder of the product.

5. It is difficult to measure variation or "choke points" inbound in the coater.

Over many years of using the traditional measurement methods manufacturers came to the conclusion that the most critical and root cause of these sundry problems is maintaining coater die gap uniformity to higher levels of accuracy. Several set a benchmarking goal to attain a level of less than 10 microinches (0.25 microns) gap uniformity across the full length and width of the slot.

The ultimate advantage of controlling the constancy of the slot gap will allow manufacturers to move from Post-Process Control (where measurement is done after the coating takes place) to Pre-Process Control (where measurement and adjustments are done before the run is started).

Measurement Solution

The benchmark level of less than 10 microinches (0.25 micron) gap uniformity of slot die gaps has recently been accomplished. In fact in some applications it has been exceeded with uniformity being maintained at levels down to 5 microinches. The goal was met after several years' development with close participation with customers. This next section will describe the steps taken on the road to success.

The first step in the solution was the selection of capacitive technology as the basis for sensor design. The choice of capacitive was based on several of its inherent advantages including:

- Non-contact measurement method
- Ultra thin composite sensors
- Linear analog output
- Excellent repeatability
- High temperature capability
- Good value solution

Principle of Operation

Coater gaps are measured with two capacitive displacement sensors mounted back-to-back at the end of a flat wand. Each sensor has a central sensing element with a typical diameter of between 0.079" to 0.197"(2 to 5 mm). A ring layer called a guard, which is approximately twice the diameter of the sensor, surrounds the sensor. The guard serves to focus the capacitive change field and both parts are separately connected to a 100% shielded coaxial cable as seen Figure 2.

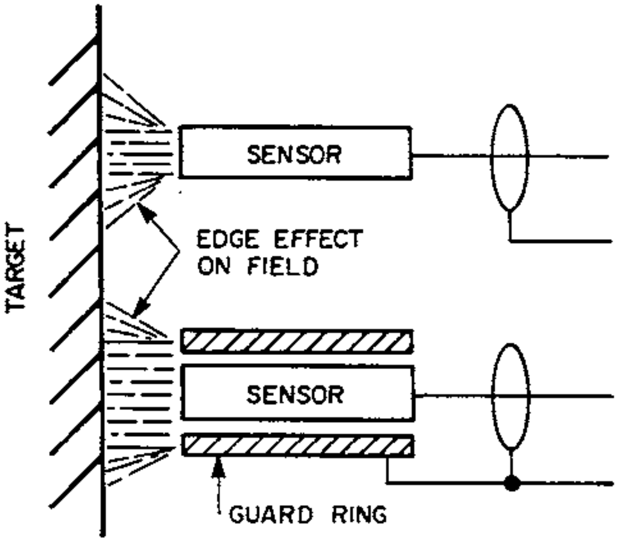


Figure 2
Distortion of electrostatic field minimized by guard ring.

When positioned parallel to an earth grounded or conductive target, the sensor/ guard combination measures a capacitance proportional to the air gap. When the signal is input to a specialized signal conditioner amplifier, the output can be linearly spread between 0 – 10.000 Vdc as related to a gap spacing from almost touch to some full-scale dimension. This operation allows the ability to show one part in ten thousand resolution. For example a full scale range of .010″ divided by 10,000 yields a resolution of 1 microinch/mVdc (0.25mm divided by 10,000 yields 250 nanometers resolution)

Sensor Selection

The capacitive sensors are attached back-to-back on a sensor wand. The configuration, thickness and material of the sensor wand depend on the application at hand. Sensor wands come in two groups (Kapton® or Composite) depending on thickness. When very thin gaps are measured (from 0.009″/ 0.23 mm to 0.10″/ 2.5 mm) the sensor wands are typically made of Kapton® in thickness ranging from 0.009″ (0.23 mm) to 0.040″ (1.0 mm). Standard Kapton® wand length is 7.8″/200mm. (See Figure 3)

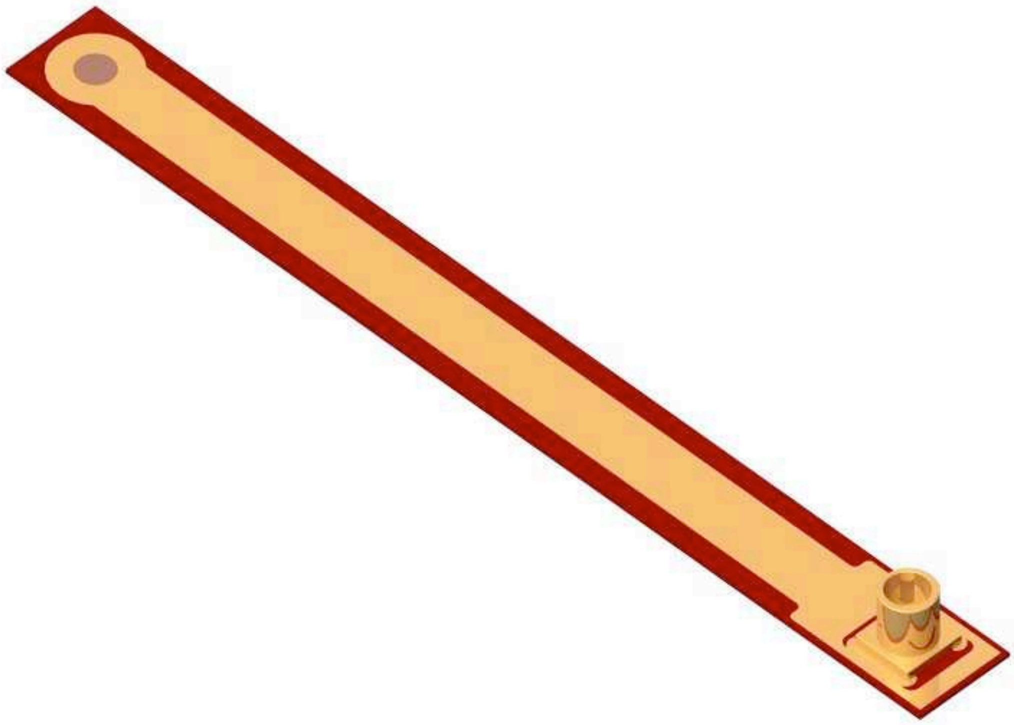


Figure 3
Kapton® style Thin Gap Wand

In applications where the gaps are wider (from 0.40"/1.0 mm and up) the two sensors are mounted on composite stainless steel laminated wands with plastic protective covers. (See Figure 4)

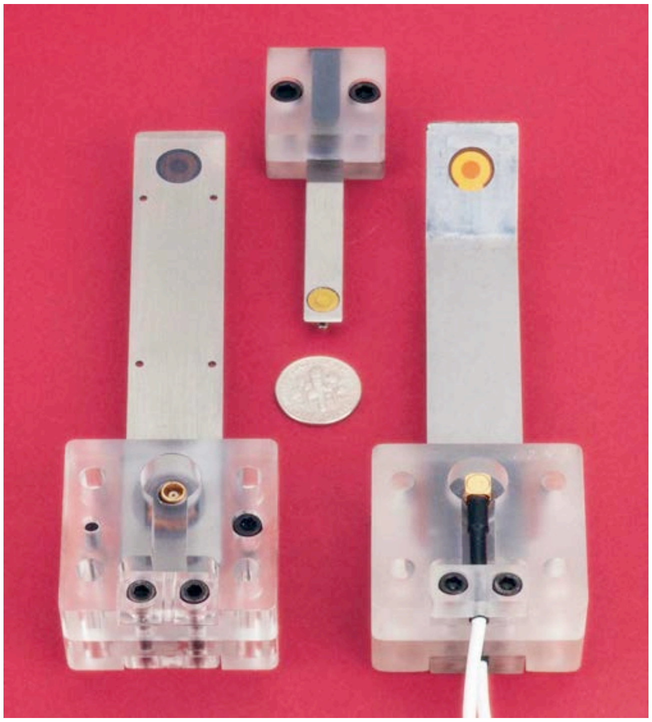


Figure 4

Composite stainless steel laminated wands with plastic protective covers.

Maximizing Accuracy

In the science of capacitive measurement technology there is a relationship between range and accuracy. The smaller the range, the higher the accuracy and linearity. The selection of the sensor wand thickness is therefor made in relationship with the gap size. Wand thickness is selected to create an overall range of 0.010"/250 microns. This produces an accuracy of ±0.2% FS. Even higher accuracy can be attained by selecting the wand thickness to be a maximum of 0.004"/100 microns below the targeted slot gap. These two wand selection criteria combine to give and overall accuracy of better than ±0.1% FS
(e.g. 4 microinches/0.01 micron accuracy)

Custom Fixtures

An additional discovery uncovered during the design process was the importance of wand positioning when taking gap measurements. The best measurements were attained when the sensor wand was held stable in a parallel position relative to the two halves of the coater die. When the wand was allowed to twist or rock out of this position, accuracy and repeatability would deteriorate.

In order to assure best case parallelism between the sensor wand and the die slot, a special custom fixture was designed. (See Figures 5 & 6).

This fixture offers the following improvements to the measurement process:

- Allows for easy handling and positioning of the wand into coater die slots
- Prevents twisting of wand when positioning wand for measurement
- Prevents wand from rocking out of the ideal measurement area

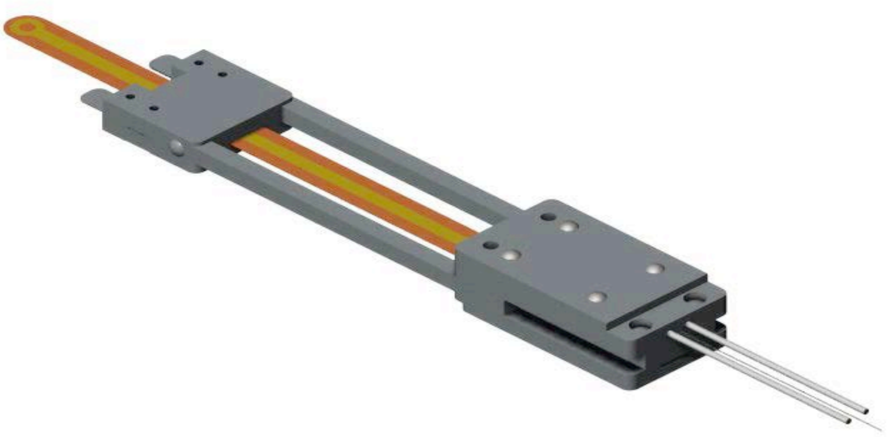


Figure 5
Custom wand holder with adjustable insertion length and slot guides

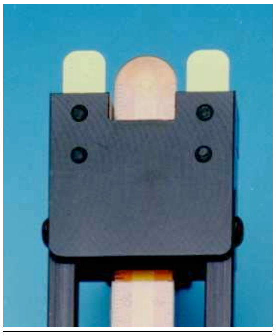


Figure 6
Custom Wand Holder (top section)

Instrumentation

The dual-sensor probes are combined with a matching Capacitec 4100 Series electronics package that consists of an electronics rack, power supply, cables and amplifiers. The Capacitec dual-sensor probes are usually matched with 2 channels of amplifiers, one amplifier for each of the 2 sensors on the probe. (See Figure 7)

Figure 7
Two channel system with instrumentation, wand holder and calibration block

Maximizing System Value

In traditional systems each gap sensing probe is matched to a dedicated set of two amplifiers. Since most Coaters have a range of different die slot sizes (e.g. 0.008", 0.010", 0.012") users would need a large number of dedicated amplifiers for each of the gap sizes. This requirement could push up the cost of a system significantly.

Concerned about total system costs, users asked for ways to reduce the overall expense of a multi gap measurement system. In response to this need a specialized software program called BarGrafx™ was developed.

The software reduces cost through a method which allows two amplifiers, normally dedicated to only one dual sensor gap wand, to be used on several sets of wands without additional cost. This is accomplished by using the software to create "virtual" amplifiers from two actual amplifiers used for one of the dual-sensor probes in the systems' multi-probe sets. A pair of virtual amplifiers is then used for each of the additional dual-sensor probes in the set.

The technique for creating "virtual" amplifiers with the BarGrafx™ program is linked to the sensor channel-to-amplifier calibration process required for each channel (sensor) of the dual-sensor probes as part of the measurement system implementation. Each of the 2 channels of the first dual-sensor probe is calibrated to a matching amplifier The calibration sensitivity is 0-0.10″ (0-250 microns) = 0-10VDC. The analog output voltage from the calibration process is fed into the BarGrafx™ program which has a real-time calibration module that takes the analog output voltage from the amplifiers and turns it into linear engineering units (either English or metric) using polynomial interpolation. The next dual-sensor probe is then matched to the same pair of amplifiers with the polynomials adjusted to calibrate the second wand. This process is then repeated to create a set of virtual amplifiers for each additional dual-sensor probe used with the system. The calibrations that have been created for each dual-sensor probe are each verified with a primary standard that has the precise dimensions of the extrusion slot being measured.

The linearization feature of the BarGrafx™ program also helps to reduce cost. This feature allows the use of lower-priced Capacitec amplifiers while still offering repeatability of ±0.01% of FS and an accuracy of ±0.1% of FS or better.

BarGrafx Software

The Capacitec BarGrafx™ program was developed under National Instruments' LabView program and operates under Windows 95/98/M.E. and 2000 on standard PC's (the program is typically used in conjunction with PCMCIA data acquisition cards that are widely available for use with portable computers). The BarGrafx™ program has the following features and functions:

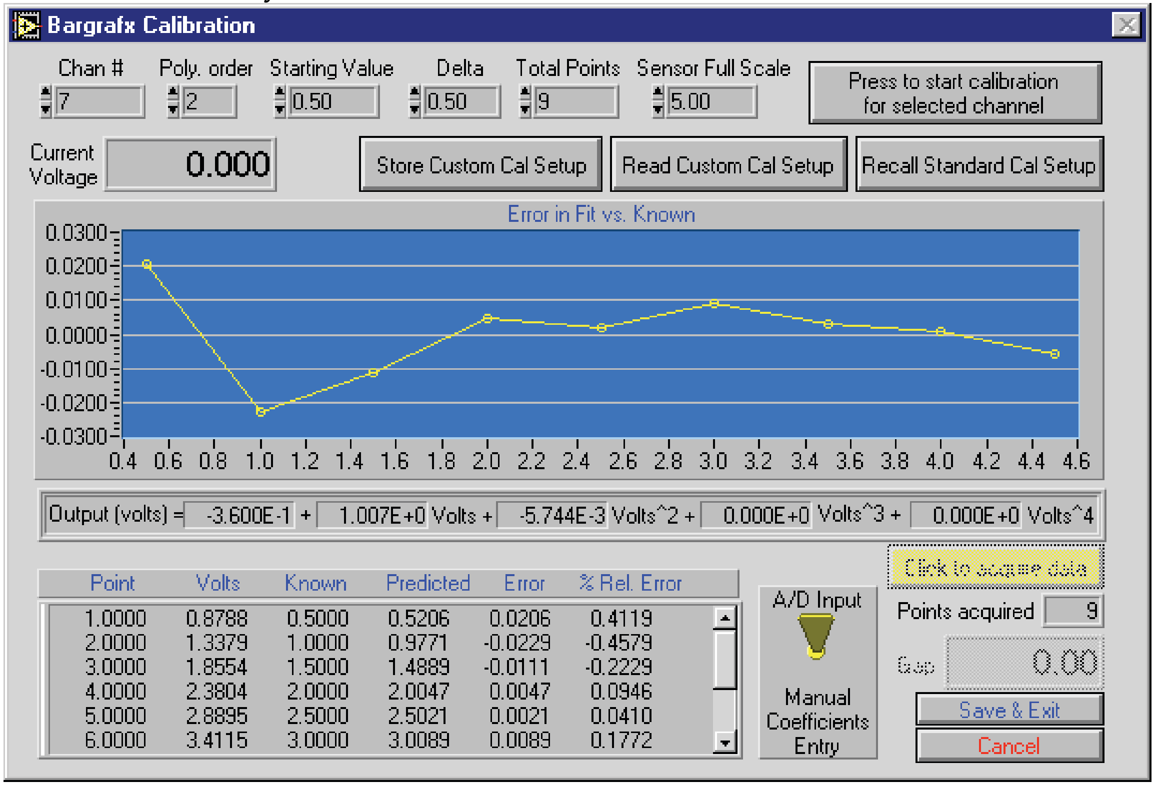
- A real-time Calibration module which takes analog output voltage and turns it into linear engineering units (either English or metric) using polynomial interpolation (to 4th degree).

- A general equations editor that allows any linearized channel to be added, subtracted, multiplied or divided from any other linearized channel for subsequent arithmetical relations such as sum, gap thickness, tilt, deviation, etc.

- The BarGrafx Equation Editor allows these linear equations or arithmetical equations to be assigned to 8 display bars for a general bargraph user interface.

- A Limits module that allows the assigned bargraph display to reflect upper critical, upper warning, lower critical, lower warning and other displays for quick user recognition (see Figure 8).

- A data output feature that enables the use of a standard .txt store-to data file format (such as can be easily exported to MS Excel, for example) or data can be directly sent over an RS232 to an external data acquisition system or computer-based control system.



Chan # 7
Poly. order 2
Starting Value 0.50
Delta 0.50
Total Points 9
Sensor Full Scale 5.00

Current Voltage 0.000

Output (volts) = -3.600E-1 + 1.007E+0 Volts + -5.744E-3 Volts^2 + 0.000E+0 Volts^3 + 0.000E+0 Volts^4

Point	Volts	Known	Predicted	Error	% Rel. Error
1.0000	0.8788	0.5000	0.5206	0.0206	0.4119
2.0000	1.3379	1.0000	0.9771	-0.0229	-0.4579
3.0000	1.8554	1.5000	1.4889	-0.0111	-0.2229
4.0000	2.3804	2.0000	2.0047	0.0047	0.0946
5.0000	2.8895	2.5000	2.5021	0.0021	0.0410
6.0000	3.4115	3.0000	3.0089	0.0089	0.1772

Points acquired 9

Gap 0.00

Figure 8

Screen shot showing upper and lower critical value display

New Benchmarks

Capacitive non-contact thin gap sensing systems have met current customers benchmark requirement to control gap uniformity in slot die gaps to a level of 10 microinches. (0.254microns). New customer benchmarks under development at Capacitec include:

- Measurement of thinner gaps down to 0.005”(0.125 microns)
- Higher temperature sensor wands up to 482°F /250°C
- More rigid sensor wands and more advanced fixturing

Capacitec will continue to push the technology to develop gap sensing systems to improve throughput, reduce cost and improve the quality of their customers’ products.