«Electronic feeler gauges» for uniform slot die gaps

Bryan Manning, Commercial Director of Capacitec Europe, and Robert L. Foster, President of Capacitec, Inc.

INTRODUCTION. This article covers the gap measurement challenges faced by world leading manufacturers using slot die coaters in the process of depositing very thin layers of liquid films and epoxies onto a variety of media. The media ranges from paper and plastic films to dielectrics and metals as well as wood panel products. The products fabricated range from labels and specialty tapes and films to hybrid car batteries and medical diagnostic test strips. As new product specifications at these companies required thinner single and multiple layers of coatings, the need for tighter control and measurement of the slot die coating process increased substantially. It was relatively easy to control the deposition of thicker adhesive coatings onto industrial masking tape but more challenging in new applications. New applications often require better control of thinner and often multiple coating across the width of the coating surface which can measure 2 to 3 meters wide or more. Engineers have also established that maintaining the uniformity of slot die gap thickness across the full length contributes directly to the quality and consistency of «as built» thin film coatings. As an outcome the new measurement accuracy specification for gap uniformity across the full length of the coater has been set at below 0.25 microns.

TRADITIONAL GAP WIDTH UNIFORMITY MEASUREMENT METHODS.

SPLIT DIE FLATNESS MEASUREMENT. A traditional method to control gap width uniformity 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 dial indicators or displacement sensors. These would be run over the full length of both die faces – measuring from above. Each side would then be polished in the attempt to obtain an ideal matched gap set. After further flatness measurements, the two sides of the die would be bolted 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 face as measured on the table. Additional variability could be seen during reassembly of the die due to variations in the torque and position applied to the mounting bolts. The advantage of this method is that existing granite surface plate and dial indicator could be used to measure the open die surfaces. The disadvantages are a gap uniformity variability of several microns.

FEELER GAUGE METHOD. Companies using feeler gauges to measure gaps are forced to live with gap uniformity variations of more than 1.25 microns over the length of the coater dies. In applications where die gap are < 250 microns the users have no choice but to use feeler gauges. This is because they are not yet aware of the availability of more modern electronic methods, as will be discussed later in the article. An advantage of the feeler gauge method is low cost but this process suffers from the following problems:

- As it is a contact versus non-contact method, feelers could damage highly polished surfaces such as the mouth of a slot die
- The pressure applied by mechanical adjustments to the shims does not «tell» users of the actual gap thus adding to the uncertainty
- Once the gap is set it is very difficult to recheck the actual dimensions along any unit length of the die in previously adjusted locations except to find minimum gaps
- Feeler gauges cannot accurately measure «inboard» gaps
- The technique does not provide the required accuracy and repeatability due to the unknown subjective variations between users
- This subjectivity results in poor performance in a Gauge R&R repeatability and reproducibility test.

What manufacturers using slot die coaters to coat thin and multilayer coatings really need is a practical electronic tool, ideally non-contact to measure the uniformity of the slot die gap across the full length of the coater as well as the magnitude of the adjustment that they are continuously making.

NON-CONTACT CAPACITIVE GAP MEASUREMENT SOLUTION. Over the past 15 years market leading specialty film, adhesive label and medical test media have turned to non-contact capacitive technology as a solution to their quest for a more modern method to assure uniformity of slot die coater gaps. Over these several years of co-development between sensor suppliers and slot die coater users, the benchmark level of less than 0.25-micron gap uniformity of slot die gaps has recently been accomplished using non-contact capacitive gap measurement. In fact, in some applications it has been exceeded with uniformity being maintained at levels down to 0.125 microns. The goal was met after several years' development with close participation with customers, as was the case with the Slot Die Coater Gap Measurement System by Capacitec. This more modern new non-contact «electronic feeler gauge» method gives far superior results in the control of gap width consistency across the full length of slot die coaters. It includes the following modular components:

- flexible non contact capacitive gap sensor wands, (aka «electronic feeler gauges»)

- special sensor positioning wand holders,
- compact signal conditioning electronics and
- a slot die gap uniformity analysis software installed on a computer (laptop).

In a typical application the coater dies slot gap sizes range from 150 microns to 1.0 mm with a typical set of slots being 0.150 mm, 0.200 mm, 0.250 mm, 0.300 mm, etc. The length of the slot gap is typically 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 deposited on various media, 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 sub micron level (see Figure 1).

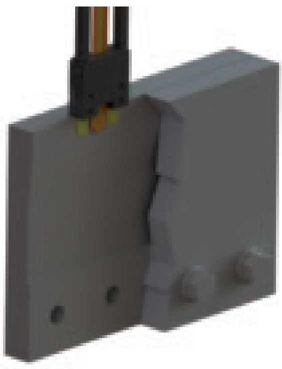

Figure 1: Measurement fixture (cutaway) in the process of measuring coater gaps

NEW COMPACT ELECTRONICS PACKAGE. The past generation Slot Die Coater measurement systems provided an electronics package with two 4100-S series capacitive amplifiers housed in a four channel 4100 series electronic rack (see Figures 2 A-D). Aside from the larger footprint, this system requires an AC power connection and custom analogue output ribbon cable connected to a PCMCIA A/D converter in the host computer.

NEW METHOD SYSTEM. The new generation slot die coater measurement systems provide several advantages as will be shown below using the example of the equipment developed by Capacitec: it employs the new Capteura® Model 200-ENC stand alone enclosure with a compact footprint (200 mm x 90 mm x 30 mm). The enclosure houses a dual channel 220-S capacitive amplifier with the optional built-in USB data acquisition card option that receives full power from the host computer (laptop). This new modular compact size and enhanced connections simplifies the lab version of the Slot Die Coater Gap Measurement system as well as making it significantly easier for coating engineers to package and bring the system on the road for auditing slot die coater gaps at product specific production plant locations. Additional advantages of the Model 220-S-ENC-DAQ electronics package are lower signal noise, ability to withstand electrostatic discharge (20 kV) to the amplifiers/sensors, improved temperature stability, better repeatability and lower power consumption plus compatibility with existing sensors/wand holders. As was the case with the 4004 electronic rack, the new electronics combined with special features in the Bargrafx™ software, the slot die gap uniformity analysis software developed by Capacitec, results in the system only requiring two channels of electronics versus 12 channels to drive six different dual sensor gap measurement wands. The new compact package does not, however, support the switching style electronic cards for the GPD-2 150 micron dual switching symmetric sensor wand option.

Fig. 2 A: Previous Generation 4100
Fig. 2 B: New Generation 200 Series
Fig. 2 C: Before: 4 channel rack with AC power and custom analogue output ribbon cable
Fig. 2 D: After: 220-S-ENC-DAQ 2 channel enclosure with USB powered data output

SENSOR WAND 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. In the past several years Capacitec has developed new sensor wand configurations resulting in thinner wands and higher temperature capability. The standard range of probes with in-line back-to-back differential sensors measures gaps above 150 microns. Gaps below this range require a newly developed tandem front to back asymmetric sensor placement to attain a nominal thickness of 105 microns. Users in the medical field have successfully qualified model GPD-(3x1)-I-A-75 very thin tandem dual sensor wand with a custom wand holder and reduced (75 mm) length to repeatedly measure slot die coater gaps to down to (105 microns).

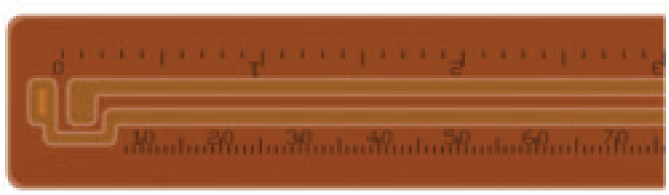

Figure 3: GPD-(3X1) tandem dual sensor wand measures down to 105 microns.

A new high temperature E series flexible wand can measure extruder lip gaps at constant operating temperatures of 200 °C. The new E+ series can withstand up to 250 °C. It functions the same as standard dual sensor wands except it opens up new possibilities for use in considerably hotter extrusion and coating die processes. Currently there are no electronic gap gauging tools to confirm gap sizes in adjustable extruder dies operating at 250 °C.

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 Figure 4).

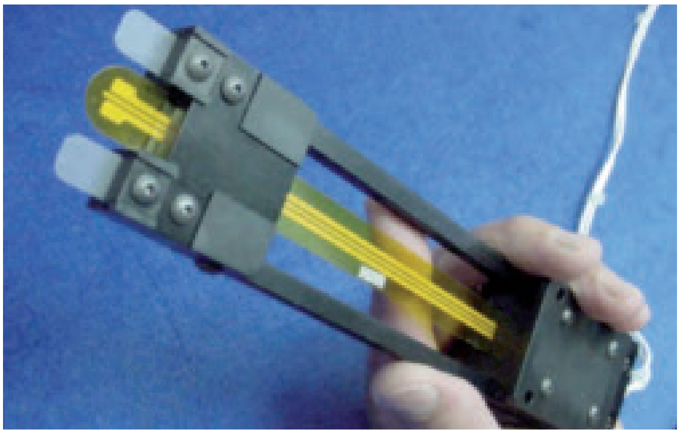

Figure 4: Adjustable Custom wand holder/positioner

BARGRAFX™ SOFTWARE. The Capacitec Bargrafx™ gap uniformity analysis software program was developed using the National Instruments' Lab View program. It now runs on Windows 7®. It has a real-time Calibration module that takes analogue output voltage and turns it into linear engineering units using polynomial interpolation (to the 5th degree). A general equation editor allows any linearized channel to be added, subtracted, multiplied or divided from any other linearized channel. Additional features are an equation editor, a limits module that allows the assigned bar graph display to reflect upper and lower limits and a data output feature with standard .txt store-to data file format.

NEW GAPMAN® $_{GEN3}$ FOR PRODUCTION SET UP APPLICATIONS. For users that would like the option of a simpler set up tool in production, a legacy Gapmaster3 semi portable shop floor system has been replaced with a fully portable Gapman®$_{Gen3}$. The main design enhancements of the Gapman®$_{Gen3}$ are accuracy of 0.5 µm and resolution of 0.1 µm for a 250 µm full-scale gap range. It offers 10,000 data point logging and storage capabilities, 22-hour life, and a simple PC user interface. It is lightweight (400 grams), fully portable using 3 AA batteries and has a rugged enclosure and built in meter. The Gapman®$_{Gen3}$ records and stores data points for easy transfer to SPC, in support of Six Sigma and other quality systems. An industry standard USB Type A port combines data output and external power. The data files are a .CSV file structure for simple import into Microsoft Excel®. The portable Gapman®$_{Gen3}$ non-contact gap measurement system can also replace feeler gauges as a set up tool in the measurement of extruder die gaps. See Figure 5.

Figure 5: Fully portable Gapman® $_{Gen3}$

Capacitec Europe SARL,
F-91000 Creteil,
www.capacitec.com