Practical applications in film and optics measurements for dual light source interferometry

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ABSTRACT

Current inspection and QA technology is dominated in the packaging industry by on-line beta gauges, capacitance testing and infrared technology as well as off-line microscopy and basis weight processes. The optics industry uses standard interferometers, gauge block comparators and other contact technology. Current Dual light source interferometer technology, employed by Lumetrics, allows rapid off-line and on-line non-contact inspection of multi-layer plastics and coating applications, as well as optics and optical assemblies. Practical applications in numerous industries will be discussed. Results of online testing of a multi-layer label stock will also be presented.

INTRODUCTION

Lumetrics, an optical measurement solutions company from Rochester, New York, developed a new interferometric device based on technology licensed from Eastman Kodak Company. The DI 330 OptiGauge™ Thickness Measurement System has applications in various markets measuring everything from multilayer plastics and films to tubing and glass, to optics and optical assemblies of various types. A description of some of these capabilities will be described. Results will be presented of tests conducted in the measurement of single and multi-layer films on a moving web. The tests were conducted in October and December of 2003 at Black Clawson's Manufacturing lab in Fulton, New York.

These tests involved measuring single and multi-layer plastics on a moving web of various speeds, with a single probe. Those tests showed a consistent reading of single thickness plastics up to 600 feet per minute with no issues reading at faster speeds. A three-layer sample was tested at speeds of 300 feet per minute with no loss of measurements, and faster speeds are possible with no expected issues.

Tests were also conducted at a specialty films manufacturer measuring coating applied to a clear film. These tests were conducted in July of 2004. During these tests a probe measured film and coating thickness as material left a drying oven. Line speeds were decreased and increased and the thickness of the coating was immediately observed and measured.

OPERATION AND TEST EXAMPLES

The technology used is a high-precision, fiber-optic dual interferometer called the DI 330 OptiGauge Thickness Measurement System, which uses light reflections to provide extremely accurate and rapid measurement of multi-layer webs and coatings. The dual interferometer uses two light sources, a simple light source (Light Emitting Diode or LED) to produce reflections from surfaces and a second light source (laser) to accurately calibrate those reflections.

Light is projected from an LED onto a surface. When light hits the surface some light is reflected back and some continues through the material. At each new surface or layer, more light is reflected back, and these light reflections are directed to the system. The index of refraction between the different layers must be different enough for the system to detect a difference but that difference is slight. Reflected light is directed to fiber stretchers, which cause the generation of interference patterns and measurement peaks.

The laser acts as an internal clock and reference to measure the distance between these peaks. A signal converter and processor contain the specialized algorithms and application software that produce extremely accurate physical measurements. These calculations are all done in real time and then this information displays on the screen. Measurements can be transferred to software that controls the production process.

The DI 330 OptiGauge technology is useful in measuring many types of materials. The system has been used to test multilayer plastics, which will be described as part of this paper. It has also been used as a laboratory instrument to examine and measure ball lenses, flats, lenses and lens assemblies, silicon assemblies, medical tubing, multilayered safety glass, bottles and containers, liquids and many other materials.

The system is extremely flexible in what it can measure and also how it can measure. Multiple applications can be implemented because the probe can be remote from the dual-interferometer, and because various types of probes can be swapped in and out depending on the application. Some of these applications will be described below.

Lenses and lens assemblies can be measured with extreme accuracy. Tests were conducted with simple tabletop fixturing that enabled lenses in molds to be placed under the standard probe and center thickness measured in seconds. This setup also allowed simple lens stacks to be measured including the lenses and the air gaps between them. This same fixturing allowed ball lenses to be measured. With relative ease, the center of the ball lens is located and when light passes through the total thickness can be determined. If the ball is then rotated randomly by a mechanical means in the same location, a series of total thickness can be obtained and the sphericity of the lens determined.

In a similar vein, using curved surfaces, single layer and multilayer medical tubing can be measured with the Dual-interferometer. Figure 1, below, shows the path of light and how the multiple layer thicknesses, OD, ID can all be determined instantaneously with a single probe. Figure 2 displays a single thickness tube looking down through the top center of tube and bottom.

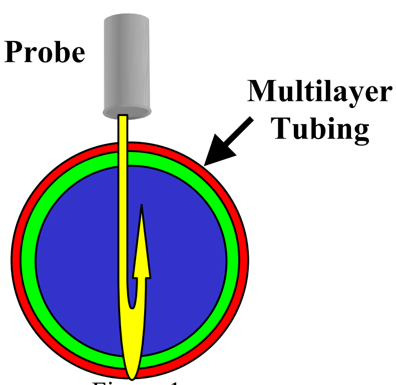

Figure 1

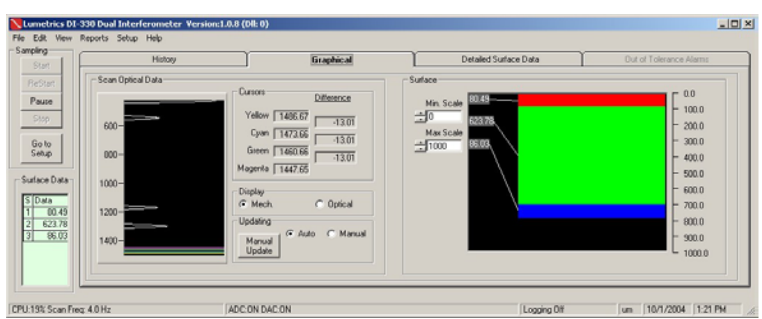

Figure 2 - Test screen with single layer tubing

Many materials can be scanned with a tabletop system that provides a cross sectional view of the material. Lumetrics scanned medical film with the simple setup shown in Figure 3.

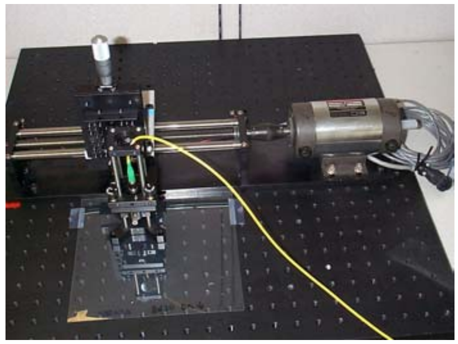

Figure 3

In Figure 4, below, the data was dumped to an excel spreadsheet where all layers are seen in their thickness order. The scanner system allows the data to be presented in any number of fashions. By examining this data the manufacturer is able to detect problems and issues both down and across the web. This also allows the manufacturer to examine layer consistency to ensure the correct amount of material is used; not too little or too much.

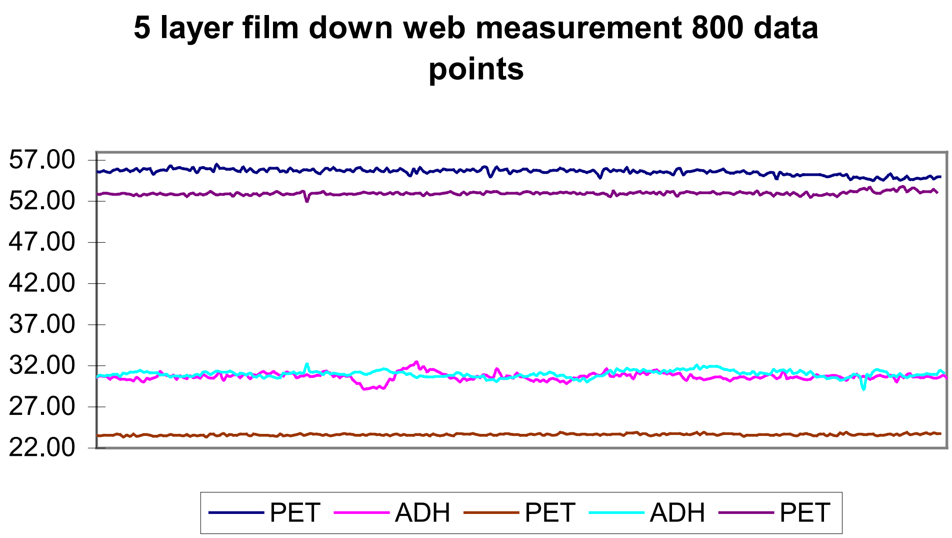

Figure 4

The following information pertains to three tests that were conducted using the DI 330 OptiGauge system to measure multilayer films and coatings.

Test Setup Test 1

Two tests of the dual interferometer were conducted in October and December on a cast film line. The tests were made to prove the ability of the system to measure both single thickness and multi-surface plastics along a moving web. In the first test, single thickness polyester with a nominal thickness of approximately 54 microns was tested. The sample was measured; using a single probe, Figure 5, at rest and then at graduated speeds from 50 ft per minute to 600 ft per minute.

Figure 5: Probe setup

The dual interferometer was consistently measuring 80 microns optical thickness, 53 microns physical thickness across all speeds. An adjustment was later discovered that accounted for the one-micron difference in these sets of measurements. Additional measurements were taken and verified via micrometer gauges and a beta gauge.

The optical thickness must be divided by the index of refraction for the material being tested to obtain the actual measurements. An average 1.5 index can be used for very accurate approximations. A menu of indexes is included in the system to more accurately measure various polymeric materials. Also, different measurement scales can be designated within the system to provide measurements in microns, inches, mils, etc.

The test results are indicated in the table 1 below.

Summary of Data - Test Run 10/01/03

Material: Polyester Film

Web Speed (ft/min)	Average Optical Thickness (Microns)	(mils)	Standard Deviation (Microns)	(mils)	Number of Data points taken at 1 per second (30 Hz. Averaging)	Averaging StDev (Microns)	(mils)
50	80.290	3.161	0.321	0.013	193	0.625	0.025
100	80.320	3.162	0.311	0.012	162	0.948	0.037
150	80.444	3.167	0.299	0.012	165	0.952	0.037
200	80.348	3.163	0.253	0.010	115	0.943	0.037
250	80.357	3.164	0.238	0.009	128	0.899	0.035
350	80.405	3.166	0.268	0.011	121	0.939	0.037
450	80.202	3.158	0.223	0.009	103	0.918	0.036
550	80.250	3.159	0.250	0.01	153	0.872	0.034
600	80.329	3.163	0.210	0.008	156	0.854	0.034

Table 1

Test 1 total thickness single layer results interpretation. The standard deviation of the material (4th and 5th column) showed that the film thickness was constant across the many feet of plastic sheet that went by. The averaging standard deviation of the machine (7th and 8th column), which shows the variation of the instantaneous measurement of thickness, was less than 1 micron. This shows that the interferometer was producing precise data. The number of data points taken at 1 per second was actually an average of 30 per second and that average was recorded as a single data point by the system.

The results show that film speed seems to have little or no effect on the data. Based on this data, speeds of 2,000 ft per minute and above should show the same consistency of measurement. This test showed the efficacy of the dual interferometer in measuring single thickness plastics across a moving web.

Test Setup Test 2

Improvements were made to the dual interferometer because of the special challenges of measuring multi-layer plastics both in the lab and across a moving web. The previous testing showed that the temporary support beam for the probe had considerable vibration. This vibration introduced noise into the input signal that complicated the test readings. As a result a new electronic filtering and amplification circuit was added to make the dual interferometer less sensitive to vibration. Additionally a redesigned mounting bracket was provided as a sturdier platform for the fiber optic probe.

The second test was conducted on a three-layer sample of polyester, adhesive and polypropylene with nominal thicknesses of 32, 17, and 49 microns respectively. A screen print of the material is shown on Figure 6. The screen shows a mirror image of the film, with the center peak being the measurement start position. For this test and following graphs, surface 1 is total thickness, surface 2 is polypropylene with adhesive; surface 3 is the polypropylene and surface 4 is the polyester. Adhesive measurements were obtained using subtractive methods.

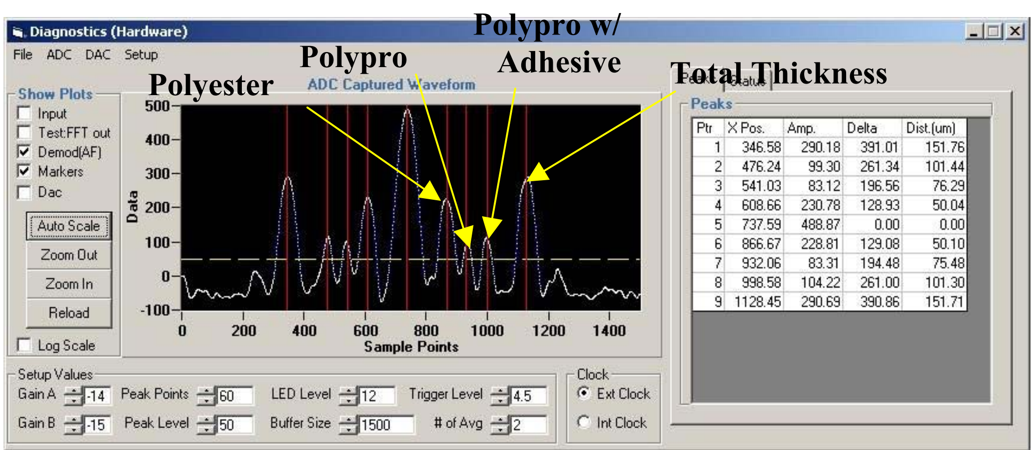

Figure 6: 3-layer sample – original test screen

Since test time, a redesigned probe and improvements to the software allowed the adhesive to be observed separately. A second layer within the polypropylene structure was also visible. Probe design improved the visible layers; Figure 7 shows the actual layer of adhesive and two layers of polypropylene in a newer graphical representation.

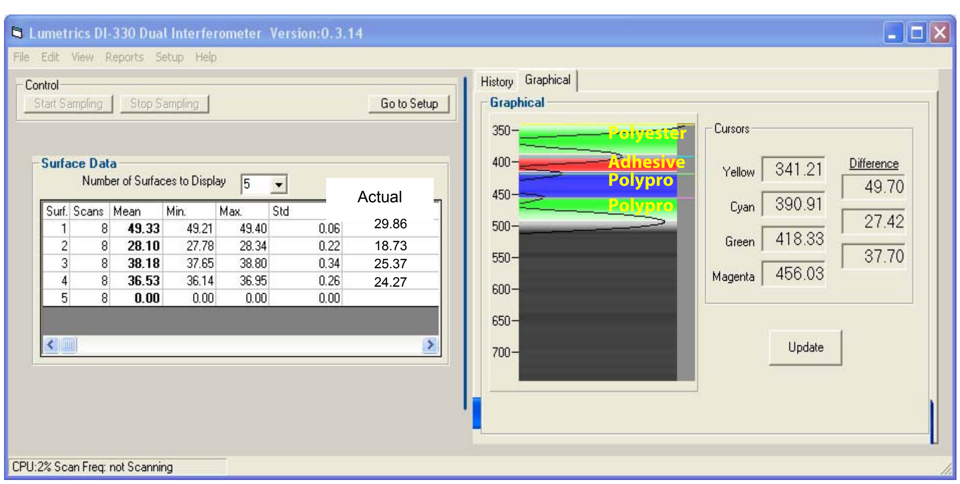

Figure 7: 4-layer sample – newer screen display

Tests were taken while the sample was still and then at speeds of 50, 150, and 300 ft per minute. Faster speeds were not possible during this test because of the small sample roll size. For the static measurements, data was taken at a 30 Hz rate average; 30 samples thus give data points at 1 per second. The following table shows the results of a data run at 300 fpm.

Web speed 300 fpm

	Avg. Optical Thickness						
Surface 1:	150.14	**StDev =**	0.78	**Max =**	152.20	**Min =**	149.13
Surface 2:	101.57	**StDev =**	0.87	**Max =**	103.46	**Min =**	100.23
Surface 3:	75.20	**StDev =**	0.58	**Max =**	76.12	**Min =**	73.83
Surface 4:	48.61	**StDev =**	0.32	**Max =**	49.10	**Min =**	47.73

Test Setup Test 3

The third test was conducted on a live production line of a specialty film manufacturer. The tests involved setting up the probe over a line that was applying coating to a polyester base. A photograph of that setup is shown in Figure 8. Note, that the probe was installed with tie wraps to mount it and a nickel to adjust alignment. This was due to the temporary nature of the testing. Even with this crude arrangement the return signal from the probe was excellent and measurements were easily taken.

Figure 8 - Specialty film manufacturer test setup

The data set consisted of logging the base-line adhesive thickness and then making changes to the line speed to induce a thickness increase as well as a thickness decrease. A base line was taken for about 30 minutes. Then the line speed was slowed at approximately 5:39 PM. This new thicker layer was left for about 5 minutes and then the line speed was increased at about 5:46 PM. This thinner layer was run for approximately 5 minutes. The Figure 9 graph shows a plot of this data run.

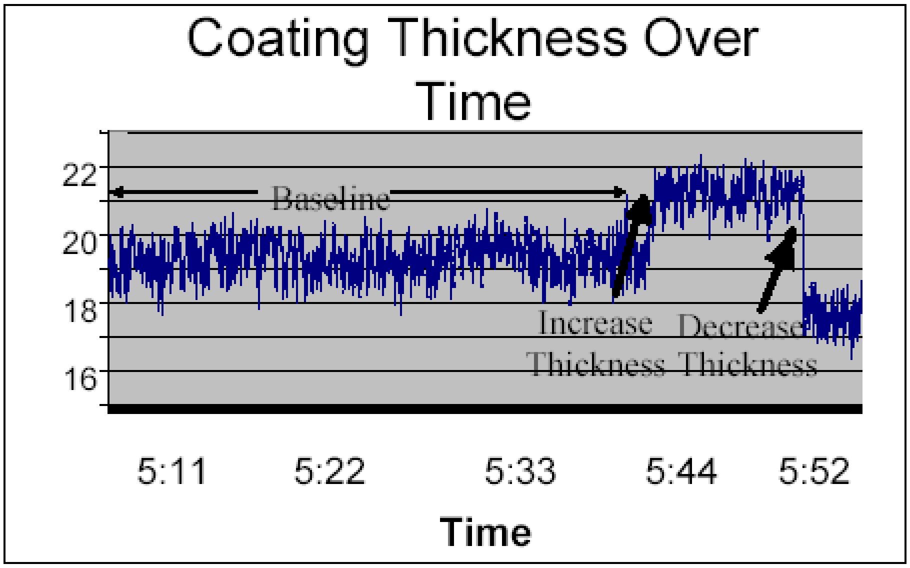

Figure 9

From the data on Figure 9 the change in thickness is clearly evident as the line slowed down and was sped up. Additionally there is a wave pattern that can be seen which indicates a potential problem with a process or equipment. These types of issues might never be seen with standard measurement and inspection systems. If a standard manual inspection was done on this film at a single point, decisions would be made that do not reflect the true condition of the film.

CONCLUSION

The data from the three moving web trials shows consistent readings across the various speeds. Measurements were confirmed with micrometer readings where possible. The standard deviation of the data did not change as the speed was increased indicating that there was no degradation in the data quality. Expectations are that similar data with higher web speeds could easily be obtained. Testing also showed that the system performed best when the mounting system was designed to limit vibration.

Results for static, single layer, and multi-layer films showed that dual interferometer technology is usable and extremely beneficial in the measurement and production of multi-layer plastics. The DI 330 OptiGauge is also applicable to measurement of the application of coatings on a moving web. Systems can be effectively used on-line or off-line to verify layer and coating thicknesses.

There are numerous other applications that can use this technology because of its flexibility in setup and use. Online and offline applications are being investigated on a weekly basis with great results.

ACKNOWLEDGMENTS

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