Economic Analysis of On-Line Gauging for Coating/Laminating Process
Tan Srinivasan, EGS Gauging Inc.
900 Middlesex Turnpike, Billerica, MA 01821, USA

Abstract

This paper discusses in detail the economic impact of quality improvements on finished roll goods in an Extrusion Coating/ Laminating process derived from application of on-line gauging system with available sensor and process control technologies.

Accurate on-line measurement of the base, coat and laminate at high production speeds, is essential to coating processors to consistently manufacture high quality rolls. Various measurement sensor technologies and their economics are compared.

Available process control technologies to minimize cross direction as well as machine direction variations are reviewed. Optimization control strategies are explored.

Typical economic savings that accrue to the processor in utilizing an appropriate on-line measurement and control system in the areas of material savings, scrap reduction and productivity improvements due to faster start-ups and product change-overs are discussed. Economic impact of high quality rolls on downstream processing is also reviewed.

An economic worksheet for ROI computation of investment in an on-line gauging system for an Extrusion Coating/Laminating Line for both “soft” and “tight” market conditions is provided. An example of a spreadsheet for Multi-station Extrusion Coater is provided.

Introduction

The Coating/Laminating process includes a wide range of applications from single coating to multi-station coatings. A variety of polymers are used from commodity resins to copolymers & specialty resins to impart specific properties such as barrier properties in aseptic food packaging. Substrates include uncoated paper, printed-paper and coated paperboard in a wide range of weights. Laminates may include Aluminum foils and blown films.

The wide range of application calls for suitable sensor technology to deliver precise measurement of coat weight, independent of substrate & laminate variations.

Need for on-line gauging system

Coating/Laminating processors need coating weight/thickness information in real-time during the high-speed manufacturing process to produce consistently good quality rolls. End of roll sampling for quality control provides only historical data and therefore, is inadequate for control of coating weight during production. On the other hand, an on-line gauging system provides precise measurement of coating weight distribution on the substrate continuously. Coupled with process control features, the on-line gauging systems provide the processor the tool needed to manufacture consistently good quality rolls at increased production efficiency and low cost.

Selection of an on-line gauging system for coating process

The coating/laminating process poses challenges for precise measurement of coating weight distribution on light to heavy substrates, at high production speeds. In many cases multiple coating stations are employed for multilayer coatings. Oftentimes, co-extrusion of various polymers imparts specific properties to the packaging product.
The systems must be capable of precise measurement of coating weight, independent of variations in substrates and laminates. Accurate measurements of thin coatings on thick substrates are required. Discrimination of different layers in a multilayer coating is necessary. On-line gauging systems incorporating multi-frame multi-sensors meet these challenges effectively.

Various on-line sensor technologies are available in the marketplace for precise measurements of coating weight/thickness. A thorough understanding of the various sensors in terms of measurement capability and cost is necessary to make an optimal selection for the specific application. The lowest cost system does not necessarily provide the maximum quality and economic benefits.

The following table provides a comparison of various sensors in terms of key selection criteria:

<table>
<thead>
<tr>
<th></th>
<th>Speed</th>
<th>Resolution</th>
<th>Composition</th>
<th>Plateau/Alignment</th>
<th>Safety/Licensing</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensors</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beta</td>
<td>Good</td>
<td>Good</td>
<td>Low</td>
<td>Good</td>
<td>Yes</td>
<td>Average</td>
</tr>
<tr>
<td>Gamma</td>
<td>Slow</td>
<td>Low</td>
<td>High</td>
<td>Critical</td>
<td>Yes</td>
<td>Low</td>
</tr>
<tr>
<td>X-Ray</td>
<td>Fast</td>
<td>High</td>
<td>High</td>
<td>Good</td>
<td>No</td>
<td>Average</td>
</tr>
<tr>
<td>Infrared</td>
<td>Good/Slow</td>
<td>Average</td>
<td>High</td>
<td>Good</td>
<td>No</td>
<td>Average</td>
</tr>
<tr>
<td>Spectrometer</td>
<td>Fast</td>
<td>Good</td>
<td>Low</td>
<td>Good</td>
<td>No</td>
<td>High</td>
</tr>
<tr>
<td>Interferometer</td>
<td>Fast</td>
<td>Good</td>
<td>Low</td>
<td>Good</td>
<td>No</td>
<td>High</td>
</tr>
<tr>
<td>Caliper</td>
<td>Slow</td>
<td>Low</td>
<td>Low</td>
<td>Critical</td>
<td>No</td>
<td>Low</td>
</tr>
</tbody>
</table>

**Summary:**

a) Nuclear Sensors measure basis weight, while caliper sensor measures total thickness.
b) Infrared sensor measures basis weight or thickness of the coating *directly* on a substrate or laminate based on reflectance technique, while Beta sensors use differential (subtractive) technique for coating weight measurement.
c) On-line Beta sensors use synchronized same-spot measurement of various frames to minimize effect of substrate variations in coat weight measurement.
d) On-line Beta sensors also employ substrate-independent calibration techniques to provide true net-coat measurement.
e) Nuclear sensors cannot discriminate between co-extruded or multiple layers.
f) Conventional IR sensors using spinning-wheel technology suffer from spatial displacements and also are restricted in the number of multilayer measurements.
g) On-line spectrometers using FullSpectrumInfraRed technology (FSIR) are the most versatile sensors available for precise measurement multilayer coatings.
The configurations based on the three major sensor technologies suited to the coating/laminating process, depending on the applications, are:

1) Differential Beta, multiframe/multisensor configuration
2) Conventional IR, single or multiframe, single or multisensors
3) FSIR, single frame or multiframe, single or multisensors
4) Combination of IR or FSIR and Beta, single or multiframe

**Optimization Control Techniques**

Systems with on-line sensors provide continuous measurement of coating weights. Further, they display coating weight distribution profiles in the transverse or cross-direction as well as trending of coat weight average to depict long term machine direction variations. These CD (profile) and LTMD variations can be controlled either manually by the line operators or more effectively through use of automatic control features of the systems.

Optimizing control techniques employ AutoProfileControl (APC) with advanced control algorithms such as Accelerated Time Response to control commercially available automatic dies, to minimize CD variations.

Control of MD variations is achieved through automatic control of Extruder Screw/Pump speed or line speed to control coat weight to desired target. An optimizing control strategy involves target management control (TMC). The system automatically calculates the optimum target to take advantage of reduced CD and LTMD variations. The TMC provides considerable material savings while ensuring low average as well as low point coat weight protection.

**Quality improvements from using on-line gauging systems**

The total coat weight variation comprise of transverse (cross direction or profile) and machine direction variations. In an Extrusion coating process the profile or CD variation derives from the non-uniform distribution of the coating from the die-lip. The machine direction or MD variations comprise of two components, the controllable Long Term (LTMD) and the uncontrolled Short Term (STMD). LTMD derives from long term drifts due to melt changes, temperature drifts etc., while STMD is caused by process equipment related high frequency variations, such as screw surge, out-of-round rolls etc. Most systems provide a diagnostic tool such as Fast Fourier Transform (FFT) feature to analyze causes and magnitude of STMD variations.

The total variations can be shown mathematically as:

\[ 3\sigma_T = \sqrt{(3\sigma_{CD})^2 + (3\sigma_{LTMD})^2 + (3\sigma_{STMD})^2} \]

Typically, systems with on-line sensors incorporating process control reduce CD by 60-80%, LTMD by 80-90%.

Using the FFT process diagnostic tool, STMD may be reduced by 5-10% through timely maintenance of the process equipment.

Thus, a significant reduction in total variations of coat weight and target reduction can easily be realized by installing an optimal on-line measurement and control system on a coating/laminating line.
Economic Analysis Worksheet for Multi-station Coating/Laminating Process

Typical reductions in variations from an optimal on-line measurement and control system are:

Reductions in CD (Profile) variations  60 to 80%
Reductions in LTMD (Long Term Machine Direction) variations  80 to 90%
Reduction in STMD  5 - 10%
Average reduction in total variation: 50-70% range (conservative estimate)

CD is reduced by Automatic Profile Control of Auto dies.
LTMD is reduced by Screw Speed Control of Extruders.
STMD (Short Term Machine Direction) variation is uncontrolled. It is caused by equipment (worn out screws, out of round rolls etc.).

I) Material Savings due to target reduction (S1)

Customer PE tolerance is ± 3 GSM per PE Layer.

RMS PE Tolerance = $\sqrt{3^2 + 3^2 + 3^2} = +/- 5.2$ GSM

Based on total of 67GSM of PE, the customer tolerance is 7.8%.

Target Shift Potential = 60% of 4.7%

Customer desired Target Shift Factor = $f$

Target Shift = $f \times 4.7\%$
II) Savings due to start-up scrap reduction (S2)

Typical improvements in start-up time

At start-up or product changeover, time to get on-spec can be reduced from 30-45 minutes to 15 minutes. This corresponds to a reduction of 50% to 67% in start-up/change-over time.

Resultant benefits are two-fold:
1) Reduction in scrap
2) Increase in productivity

Scrap Reduction at start-up/changeovers

% of production of various products = ai
Line speeds of various products = si
Widths of various products = wi
Weights of various Paper = pi

Start-up line speed = 200 m/min = s1
Average Width in mm = w = \(\sum (a_i \times w_i)/100\)
Start-up/change-over time in minutes = t
Product change-overs/day = n
Operating days/year = d

Production at start-up (m²/year) = F = (0.001 \times w \times s_1 \times t \times n \times d)
% of start-up production classified as scrap = f2
Reduction in start-up time = \((t_1/t) = f_3\)

Start-up scrap (m²/year) = F \times f_2 \times f_3 = G

Weight of PE = 12+20+35 = 67 GSM
Weight of Copolymer = 7 GSM
Weight of Alu Foil = 17 GSM
Average Weight of Paper = P = \(\sum (a_i \times p_i)/100\)

Example: 30% of 80 GSM paper + 40% of 200 GSM paper + 30% of 260 GSM paper

Average Paper weight = P = \((0.3 \times 80 + 0.4 \times 200 + 0.3 \times 260) = 182\) GSM

Enter this value in the column for average paper weight in Economic Analysis Spreadsheet.(P)

Savings due to start-up scrap S2 = G \times 0.001 \times \sum (Weight \times Cost of each layer)

III) Savings due to increased productivity (S3)

Increased productivity is derived from reduction of 50% to 67% in start-up/change-over times.

Machine overhead cost in $/hour = e
Savings in machine overhead costs
(due to reduction in start-up/change-over times) = \( t_1/60 \times n \times d \times e = S_3 \) ($/year)

### IV) Increased profit contribution in case of sold-out situation (S4)

Average line operating speed (m/min) = \( s = (a_i \times s_i)/100 \)
Increased production in m²/year = \( 0.001 \times w \times s \times t_1 \times n \times d = I \)

Profit contribution = (sale price – Cost price) /sqm
Note: Cost price includes material & machine costs

Increased profit contribution $/year = (Increased production x Profit Contribution) = S_4

### V) Total annual savings (S)

Case 1 : Excess capacity (Soft Market Conditions)

Total annual savings = (S1+S2+S3)

Case 2 : Sold-out situation (Tight Market Conditions)

Total annual savings = (S1+S2+S3+S4)

### VI) Other Savings (not quantified)

- Speed increase
- Downstream operations at slitter (due to improved quality)
- Decrease in customer returns
- Increased customer satisfaction
- Competitive advantage

**Economic Analysis Spreadsheet : Multistation Extrusion Coater**

CoaterEconomicAnalysis.zip

**CONCLUSIONS**

Economic impact of an on-line gauging system with the right sensor technology and process control and diagnostic features on a coating/laminating line is significant. The processor needs to evaluate these systems in terms of measurement and control performance in providing maximum quality and economic benefits to the specific coating/laminating application. The economic spreadsheet provides the processor a
tool to evaluate the ROI on an optimal on-line measurement and control system to make the best choice, rather than the lowest-cost choice.