More Than Defect Detection – The Real Value of Web Inspection

Brian W. Heil, Vice President – Sales
ISRA Surface Vision
4357 Park Drive Suite J, Norcross, GA USA
email: bheil@isravision.com

ABSTRACT
This article explores opportunities to maximize the value of automated on-line film inspection. Examples are presented of implemented inspection systems that provide critical real time process and converting information to maximize yield, improve raw material quality, and strengthen customer relationships. A solution for automated re-wind control for defect removal that increases converting throughput is discussed. The implementation of this technology offers its users a variety of methods to achieve value. The user realizes the maximum value when all of the possible methods are implemented.

INTRODUCTION
Implementation…...this is the difference between success and failure of any plan. The best plans, ideas, technologies, strategies, directives, and mandates are useless unless they are implemented. The top performing companies are top performers because they spend much effort on new ideas and technologies and much more effort in implementing these ideas and technologies. This comes from the top of the organization and sets an example of follow through. We can all think about a capital project that was a failure, a piece of equipment that “never worked” or the “person left the company” that had the project, or the “operators never used it”. Occasionally this can be the result of a bad idea, but in an overwhelming majority of cases, good ideas and technology failed because they were never implemented.

This stated, we arrive at the topic of this paper – The Real Value of Web Inspection. We will explore how web inspection systems can be implemented to achieve maximum value. When defects occur in an extrusion process they can be just a nuisance and have no cost ramifications or they can be catastrophic in terms of causing product performance or aesthetic issues. An example of nuisance defects would be small gels and carbon specks in plastic grocery sacks. If your process only creates nuisance defects you are fortunate in this respect, however, these products usually are high volume, low margin commodity products that are purchased primarily on price and involve high customer turnover.

Of greater concern and cost are defects that affect the aesthetics and/or the functionality of the extruded product. Examples would be carbon specks that affect the appearance and holes that affect the function of flexible food packaging. Functional defects are always catastrophic by causing the product to fail its intended use or required specification. Aesthetic defects can sometimes be catastrophic by prompting customers to return the product or change vendors. When aesthetic and functional defects are not controlled, returns occur, customers are lost, yields shrink, manufacturing costs rise, and the ability to compete in the market place is compromised. The cost of identifying and removing defective product from finished rolls is significant. The cost of failing to accomplish this is also significant. Inspection or lack thereof carries a high cost. Various opportunities exist to turn this cost into a profitable investment.
LIMITATIONS OF STATISTICAL SAMPLING

Controlling extrusion related defect occurrences is sometimes attempted by statistical sampling. A small piece of the film from the end of each roll is analyzed in the lab and the roll is considered to be acceptable or unacceptable. This strategy has many limitations. The occasional catastrophic defect cannot be controlled and real time process improvement is not possible as many rolls can be produced before the lab results are analyzed. In addition, rapidly changing process variations are missed, as the lab sample represents only a snapshot in time equating to as little as 0.001 percent of the produced product.

Figure I shows the variation of gel counts for a single roll of blown film. The data was collected with an on-line surface inspection System that classifies, maps, and trends defect counts. The system counts gel, speck, and gels containing specks per square foot of inspected film. The trend graph in Figure I shows defect counts for each size class and type of defect per square foot of film. Within a five minute interval the total gel counts range from 2.5 to 20 gels per square foot of film and every ten minutes the counts are similar. In this case, statistical sampling, in terms of analyzing the gel count of a piece of film from the end of this roll, would provide erroneous results that would initiate the wrong process control action.

By itself, statistical sampling may provide a low cost alternative to inspection, but its limitations result in higher risks with regards to missed catastrophic defects and higher costs due to reduced process efficiency.

*Figure I – Trend graph of defect counts per square foot of inspected film showing short term variation of gel counts*
HUMAN INSPECTION

The next level of controlling defects involves statistical sampling and human inspection. A sample is removed from the end of each roll for lab analysis and one or more inspectors are positioned on the production line to watch for and flag catastrophic defects. The flagged defects will then be removed in a subsequent converting process. A significant limitation of this strategy is human error resulting in missed defects, inconsistent flagging between inspectors, and inspector turnover and training issues. Human factor studies show that nondestructive examination (NDE) reliability is dependent on an inspector’s training, required field of view (area to be inspected), minimum defect size, defect signal to noise (contrast), and time between rest periods. [1] The frequency of missed defects and false positives increase if the defect contrast is low, when production speeds are high, and/or if the inspection field of view is large. In addition, severe injuries have occurred as a result of an operator placing a flag on the moving web.

The deficiencies of human inspection become clear when inspection results from an automated on-line inspection system are correlated with those of human inspectors. During a recent installation and validation of an inspection system, automated results were being compared to human inspection. During the late shift, the inspection system detected a catastrophic defect type that an inspector had missed. When the inspector was questioned about this, she stated that she saw this defect but it was her understanding that she was not supposed to flag a defect of this type. The shift supervisor quickly corrected her. Because of this simple training error, one can only imagine how many defects of this type this inspector found but did not flag.

Though there is a high cost of labor and a high error rate associated with human inspection, it is commonly used for higher value extruded products that have functional defects. Unfortunately, it offers no possibilities to acquire data that can be used to reduce defect occurrences and increase yield. The manufacturer is burdened with a cost associated with labor, the lack of process improvement, and the risk of missing catastrophic defects. The cost of this approach, by itself, is much higher than statistical sampling and its limitations preclude it from becoming a profitable investment.

AUTOMATIC ON-LINE INSPECTION

The next level of controlling defects involves on-line operator aided inspection. This method provides an automatic on-line inspection system that inspects 100% of the product, alerting the operator to any catastrophic defects and real time process upsets. The operator will then make an assessment as to flag the defect or a section of the roll and/or alter process variables. Reports are generated for converting and data is archived by Lot and Roll ID. This objective information is used to achieve long term process improvements and yield maximization.

IMPLEMENTATION OF ON-LINE INSPECTION TECHNOLOGY

Three examples are discussed showing how manufacturers, through implementation of automatic inspection technology, have turned the cost of controlling defects into a profit. The first example is a manufacturer of cast film used for pharmaceutical packaging. The process results in a clear film with frequent carbon specks, gels, and gels with carbon specks, and occasional bubbles. To meet customer expectations, the frequency of these defects must be controlled. The manufacturer utilizes an ISRA Surface Inspection System to inspect 100% of the film. Large catastrophic defects are mapped for converting and smaller defects are trended for process control. Real time alarm limits are set for allowable frequencies of each defect type and size class as shown in Table I.
Table I - Real time process defect alarm limits for each defect class

<table>
<thead>
<tr>
<th>Defect Type</th>
<th>Size Class</th>
<th>Alarm Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gel</td>
<td>200µ - 400µ</td>
<td>5/square foot</td>
</tr>
<tr>
<td>Gel</td>
<td>400µ – 800µ</td>
<td>1/square foot</td>
</tr>
<tr>
<td>Gel</td>
<td>&gt; 800µ</td>
<td>Any occurrence</td>
</tr>
<tr>
<td>Carbon Speck</td>
<td>200µ – 400µ</td>
<td>5/square foot</td>
</tr>
<tr>
<td>Carbon Speck</td>
<td>400µ – 800µ</td>
<td>1/square foot</td>
</tr>
<tr>
<td>Carbon Speck</td>
<td>&gt; 800µ</td>
<td>Any occurrence</td>
</tr>
<tr>
<td>Gel w/Carbon</td>
<td>200µ – 400µ</td>
<td>5/square foot</td>
</tr>
<tr>
<td>Gel w/Carbon</td>
<td>400µ – 800µ</td>
<td>1/square foot</td>
</tr>
<tr>
<td>Gel w/Carbon</td>
<td>&gt; 800µ</td>
<td>Any occurrence</td>
</tr>
<tr>
<td>Bubble</td>
<td>200µ – 400µ</td>
<td>5/square foot</td>
</tr>
<tr>
<td>Bubble</td>
<td>400µ – 800µ</td>
<td>1/square foot</td>
</tr>
<tr>
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<td>Any occurrence</td>
</tr>
</tbody>
</table>

When a defect alarm occurs, an alarm light flashes, and the Operator places a flag in the roll and then acknowledges the alarm via an HMI, which changes the alarm light from a flashing status to an illuminated status. A separate flag signifying “Defect End” is placed in the roll if the alarm condition exists for a few minutes and then stops. If the alarm condition continues, the Operator reports the condition to the QC department. The QC Technician reports to the line and determines if more drastic action is required. Based on input from the QC Technician, Operators are trained to make process adjustments based on the types of defects causing the alarm condition. If the alarm condition is related to gels, temperature adjustments are made. If the defect alarm is a result of carbon specks, the melt filters are changed. If the defects are mostly gels with specks, the melt filters are first changed and if the gels with specks persist, the resin lot is then changed. If the alarm is related to bubbles, process changes are made and if the problem persists, the resin lot is changed.

Figure II shows two separate occurrences where high gel with speck counts precipitated a resin lot change that resulted in virtually immediate reduced defect counts.

The real time inspection data is also closely monitored during product changeover and line startup to determine when the lab should acquire a sample for physical property analysis. Acceptable results from the lab allow the Operator to start production of “good” rolls. The timeliness of these results increases production and uptime.

According to this film manufacturer, defect counts per square foot or defect densities are also correlated with additional process data “to help understand what process conditions have the largest effects on the defect level”. This manufacturer states that a future goal is to export the location of each large defect in the roll, which includes only those defects greater than 800µ, to a quality management software program that will combine lab quality information to improve yield in the slitting department by calculating optimum slitter setup for each roll of film.
This film producer has implemented an on-line inspection system and has realized value by making real time process changes based on defect densities that reduce defects, optimize extruder maintenance, maximize uptime, and provide customers a consistent product. In addition, this manufacturer implemented an attractive inspection system so it can be used as a marketing tool when current and prospective customers visit the plant site. Their customers see the inspection technology and are schooled in the how the inspection system is used and how it benefits them.

Figure III shows systems with similar inspection capabilities, the systems on the bottom are packaged in enclosures that match the color scheme of the line. These systems look good, more capable, and more expensive than the ones shown on the top. The “WOW!” factor is increased, providing a method to strengthen current customer relationships and acquire new customers.

Figure III - The inspection systems pictured on the bottom look more capable and offer greater marketing value

A second example involves a film converter that coats PET film that becomes thermal transfer ribbon used in bar code printers. The film runs in excess of 500 meters per minute which rules out any possibility of human inspection. For the last seven years, an automated inspection system inspected the film for coating defects. This system, when installed, was able to detect type A, B, and C size coating voids referred to as pinholes in the coating. Rolls are given a numerical grading based on the total occurrences of these defects in the roll and then slit in a subsequent converting process. Rolls must also meet additional quality grading criteria un-related to defect counts such as coating thickness and optical density. Defective areas of the rolls are then removed at slitting. The grading criteria is used to determine production targets and how much time is required in slitting to segregate defects from the rolls. When defects are found in slitting that were previously missed at coating, additional time is spent by the Quality and Coating departments identifying the losses.

Increases in production speeds over the years outpaced the detection capabilities of the inspection system to where only the large Class A defects were occasionally being detected. As a result, nearly 100% of the coated rolls being
sent to slitting were of the highest grade. The limited inspection capability eliminated any possibilities of coating process improvements and only the largest of defects were being removed in the slitting process.

Recently this film coater installed an ISRA Surface Inspection System to replace the existing inspection system. The new system was delivered with a capability to detect defects as small as 300µ at coating speeds much higher than 500 meters per minute. The sensitivity of this system enabled reliable detection and classification of not only coating pinholes, but a broader range of defects. Defects are now detected and classified as craters, large voids, A, B, and C pinholes, light density streaks, large dark spots and static defects. Smaller pinholes and small dark spots are not mapped, however, the counts per square meter of film of these defect types are trended for process monitoring. In addition, images of mapped defects are displayed and defects that repeat are alarmed. Figure IV shows examples of coating pinhole type defects. These appear as clear spots in a dark film. The picture on the left shows a few film samples exhibiting Type C pinholes that were cut from a roll. The images on the right are those of pinholes detected at speeds far greater than 500 meters per minute by the surface inspection system.

Figure IV - (Left) Photograph of small coated film samples with Type C Pinholes and (Right) Image of Type A pinhole (top left) and Type C pinholes acquired by the Inspection System

The mapped data for each inspected roll is used to grade the roll. An alarm light flashes when a defect count is exceeded or when a repeating defect occurs. When an alarm occurs, the Operator checks the inspection data, looks at the web, and if necessary, cleans the coating (gravure) roll. This procedure reduces defect occurrences resulting in higher grade rolls and higher throughput in slitting. Figure V shows a roll map showing the location and type of defects occurring in the inspected roll.

Figure V - (Left) Roll map of a Grade 1 Roll showing location and type of defects in the roll and (Right) Defect classes showing totals of mapped defects
Unexpectedly, the new inspection system quickly identified some defective sections of coated rolls that were not a result of coating process conditions, but were a result of static on incoming PET rolls that caused coating defects. In the past, this problem would have to be “caught” by the Operator during slitting. According to the film coater, the capability of detecting this at the coater “was huge for us” and provided objective information for a “quality claim” (a vendor reimbursement for bad PET film) and saved machine time and reduced yield losses. Figure VI shows a roll exhibiting static related coating defects caused by defective rolls from the supplier. An image of this defect clearly shows its unique characteristics.

Figure VI - (Left) Roll map showing location of “Static” related coating defects in a coated roll and (Right) displayed image of a coating defect caused by static in the film

According to the coater “With the new inspection system in place, fewer rolls meet the established grading criteria and the capabilities of the web inspection system have focused attention on how the criteria were established as well as establishing new guidelines for product grading”. For the short term the slitting operation is much busier, however, the burden of inspection is no longer theirs as defects are found and their source isolated before they reach slitting. There now exists an opportunity to improve the process and reduce defect occurrences that will actually increase slitter throughput. In the past, with nearly every roll being the highest grade (due to the inability to reliably detect defects) there was no way to accurately grade rolls or achieve any process improvement related to coating defects. Now there is an inspection method implemented with the sensitivity (detection capability) and ability to acquire meaningful data that is enabling this organization to achieve raw material and coating process improvements that reduce waste and increase coater efficiency. This film coater has since implemented more meaningful roll grading criteria and is using the roll maps to further increase yield in the slitting department to objectively remove defective areas of a roll.

A third example involves a calendaring and laminating operation that produces a wide sheet used for commercial roofing. Prior to the installation of an ISRA Surface Inspection System, both sides of the sheet were inspected by four inspectors. When a defect was seen, an adhesive flag was placed on the edge of the sheet by the inspector. The defects were then removed in a subsequent slitting operation. The manufacturer states that they purchased the inspection system “Because they were getting hammered from (customer) complaints and could offer (their customers) no certainty on how to fix the problems.” The inspectors were missing defects and there was no data being generated to determine how to improve the process to reduce defect occurrences. The inspection system was installed with an automatic flagging device. Now, with automated inspection, defects are reliably flagged and defect data is generated and analyzed to prioritize problems.

Though the initial purpose of the system was to reliably flag defects, the defect data is also used to document incoming raw material quality. Prior to using the automated inspection system, it was known that a large percentage of defects were the result of one component of the finished product that was supplied by a single supplier. Unfortunately, according to the manufacturer, “There was never any way (objective data) to substantiate enough of an action that resulted in any action (quality improvements from this supplier)”. Soon after its installation, the
inspection system was demonstrated to the supplier. During the short system demonstration, three of four reported defects were a result of the supplier’s product. The manufacturer stated that “I did not have to say anything, I could just see how big their eyes were!” referring to the supplier’s reaction of seeing their material defects in the final product. By demonstrating the system and providing objective documentation to the supplier, the manufacturer is working with the supplier to install identical inspection capability. This will result in defect free raw material.

This manufacturer was able to eliminate the high cost and inconsistency of human inspection, concurrently reducing customer complaints. The data is being used to have a raw material supplier commit to a higher quality standard. The supplier now has an opportunity to strengthen his relationship with his customer by acquiring inspection technology and supplying defect free product.

ELIMINATING DEFECTS AT THE SLITTER

Once defects are detected, classified, and mapped, the catastrophic ones need to be removed from the product prior to adding any additional value to the product or shipping the product to a customer. Generally, defect removal is accomplished on a re-winder or slitter/re-winder. Using the roll map generated by the inspection system or watching for flags in the roll, the re-wind operator will stop the re-winder at the location of the defect and remove or repair it. This process works fine for small length rolls, however, when rolls contain hundreds or thousands of feet of product, the time it takes to slow and stop the re-winder at the defect location can cause throughput problems. A Re-Wind Management System is available that automates the re-wind process, reducing the time to stop the re-winder for defect removal and ensuring that the re-winder is only stopped for defects of importance.

The Re-Wind Management System reads code marks applied to the web edge during the inspection process. The code marks are read during the re-wind operation and enable the Re-Wind Management System to display on a PC the next defect in the roll that has been classified as a defect that should be removed from the roll. The system initiates an output at the correct time to automatically slow and stop the re-winder at the precise location of the defect for removal. During the re-wind process, the Operator views an image of the next defect that will be automatically stopped on. Figure VII shows an example. He can override this stop signal. This automation improves throughput by braking and stopping the re-winder with minimal time loss and eliminating stopping on defects that are acceptable; i.e. defects that do not have to be removed from the roll.

Figure VII – Operator display showing position, type, and image of next defect that will be automatically stopped on for removal
SUMMARY – TURNING THE COST OF INSPECTION INTO A PROFIT

The previous examples illustrate various ways of implementing inspection technology, all of which provide some value to the user. The highest value is achieved when inspection technology is fully implemented. Full implementation occurs when defect data is used:

1. To objectively convert defective material.
2. To make real time process improvements.
3. To improve the process long term.
4. To improve raw material quality.
5. To strengthen customer and vendor relationships.

No doubt, every converter wants to continuously realize these goals. The implementation of inspection technology can realize these goals and result in tremendous value for the organization.

Figure VIII shows a “Value Pyramid” - as inspection technology is fully implemented, it changes from a cost to a profit. The least value is realized when defects are just detected. The cost of inspection is high until it is used to achieve additional goals besides defect detection.

It should be understood there is no end point to this process; the implementation must be ongoing and continuous. In all cases, the frontline people make the system work, once an inspection system is installed, the project has not ended, it has just started. Michael Sullivan, Senior VP and CFO of Inland Paperboard and Packaging, recently wrote “The relationship between new technologies and business improvement is anything but obvious when technology is purchased in, of, and for itself. Without an overarching business vision and dissatisfaction with current conditions, technologies will not lead to an improved performance reality. [2]

The fact is inspection technology in and of itself has no value. The implementation of this technology is where the value lies.

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References

More Than Defect Detection -
The Real Value of Web Inspection

Presented by:
Brian W. Heil
VP - Sales
ISRA Surface Vision

Generally accepted web inspection methods

• End of roll sampling for off line analysis
• Human inspection – part time
• Human inspection – full time
• Automated inspection

Limitations of end of roll sampling

• Decisions made on insignificant sample size
• Delay in results risks large amount of material being produced out of specification
• Provides no assessment of random catastrophic defects
• Miss short term process trends and upsets
Human Inspection

- Inconsistent from person to person
- High cost
- Training intensive
- Limited or no data collection for process improvement

Automated Inspection

- 100% Inspection
- Consistent and accurate results
- Data collection for process analysis/improvement
- Potential for High Value

> 300% change in gel counts every 5 minutes
• Regardless of the method - defect detection by itself is costly
• How can we take this cost and turn it into profit?
• Difficult task without automated inspection

Highlights of three case studies regarding implementation of automated inspection technology

• Each user implemented inspection technology beyond defect detection
• Case study 1: Film extrusion (Pharmaceutical Packaging)
• Case Study 2: Coating (Thermal Transfer Ribbon)
• Case Study 3: Calendering/Laminating (Roofing Material)

Case Study 1 – Film Extrusion (Pharmaceutical Packaging)

• Customer driven purchase decision
• Implemented real time alarm limits based on trend of gel counts to increase yield
• Scheduled maintenance based on defect trends
• Invested in additional enclosure that provided a high tech integrated look for marketing purposes
Real Time Process Improvement

- Replaced system with new system with much higher resolution and sensitivity to coating voids
- Ability to trend smaller defects for objective roll grading
- Real time objective data for incoming rolls
- Reduced scrap from bad incoming rolls
- Increased throughput at slitter

Detecting a specific defect at the coater (before slitting) “was huge for us” and provided objective information for a “quality claim” from base film vendor

Case Study 2 – Coated Film (Thermal Transfer Ribbon)

- Replaced system with new system with much higher resolution and sensitivity to coating voids
- Ability to trend smaller defects for objective roll grading
- Real time objective data for incoming rolls
- Reduced scrap from bad incoming rolls
- Increased throughput at slitter
Case Study 3 – Calendering/Lamination (Roofing Material)

- Human inspection was missing too many defects
- Automated system replaced four inspectors per shift
- User demonstrated system to vendor showing vendor’s defects occurring real time in final product
- Implemented flagging system to flag defects for easy removal at re-winder.
- Defect frequencies analyzed to prioritize problems

The inspection system was purchased “Because they were getting hammered with (customer) complaints, and could offer (their customers) no certainty on how to fix the problems”

Managing defects at the slitter/re-winder

Every converter wants to realize these goals:

- To effectively remove catastrophic defects at converting (slitting/re-winding)
- To make real time process improvements
- To improve the process long term
- To improve raw material quality
- To strengthen vendor and customer relationships

This can be accomplished with automated inspection!