ABSTRACT This article explores opportunities to maximize the value of automated on-line metalized and laminated 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. 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 effectively implemented. The top performing companies are top performers because they spend much effort on implementing new ideas and technologies. They have a mentality of continuous improvement and expend much more effort in implementing effective new
ideas and technologies. This attitude comes from the top of the organization and sets an example to the remainder of the organization. We can all think about a capital project that was a failure, a piece of equipment that “never worked” or the “person that left the company” that had the project, or the “operators never used it” or “it is too complex to operate”. 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 effectively conveyed and implemented. Most of us have worked within organizations where this has occurred. New ideas usually come from operating personnel to management or new people in the organization. Unfortunately, if the new programs or ideas are not effectively “bought into” they never become effectively implemented. The seasoned troops get cynical and the idea or program falls short of expectations. This “attitude” affects the profitability of the company over time and must be recognized if a new idea or program is to achieve expectations.

This stated, we arrive at the topic of this paper – *The Real Value of Web Inspection*

When defects occur in an extrusion, lamination or coating process, they can be just a nuisance and have no cost ramifications. 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, but living on “borrowed time” versus the competition--if you make no effort to improve the process. The products that fall into this category are usually high volume, low margin, commodity products that are purchased primarily on price. Of greater concern and cost are defects that affect the aesthetics and/or the
functionality of the product. Examples would be carbon specks that affect the appearance and holes that affect the functionality of flexible food packaging materials. Ed Cohen, a Consultant for AIMCAL, has developed a LEXICON of many of the common defects and a “trouble shooting” guide in addressing the defect problems. This is a very valuable resource to have as a reference guide to assist in understanding and eliminating the defects and maintaining a more efficient, profitable process. Many defects (such as, chatter, chevrons, ribbing and coating voids) are tedious for humans to see visually. Functional defects are always catastrophic by causing the product to fail its intended end use or required specification. Aesthetic defects can sometimes be catastrophic by prompting customers to return the product or change vendors, if it occurs too frequently. When aesthetic and functional defects are not controlled, returns occur, customers are lost, yields shrink, and 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.

HOW THE INSPECTION SYSTEM WORKS

Single or multiple WEB INSPECTION cameras are positioned across the material. Data analysis is accomplished with signal processing, thresholds, and filter functions. The camera(s) scans and acquires a continuous image of 100% of the material. The material is scanned at up to 19,000 times per second, resulting in high-resolution defect images. A
13 by 13 inch area will include 4 Mega-pixels when inspecting a material moving at 600 feet. Each scan of the image is compared to 1 to 14 user definable thresholds. Any portion of the image that exceeds a high or low threshold is classified and reported as a defect.

Filtering functions with independent thresholds operate concurrently, allowing a single camera to detect subtle defects such as streaks, spots, bubbles, scratches, and high contrast tiny defects such as pinholes at high line speeds.

Classification of defects is based on the signal level (intensity or contrast) created by the defect and the thresholds that are exceeded and by the size (width, length, area, and length/width) of the defect. These operations occur in real time. Line scan cameras reduce the amount of data from the web surface to a minimum and only transfer defect position, defect class, defect size, and the defect image to the PC. Communication of defect data from the processing board to the database is digital (fail-safe), using Ethernet (TC/PIP). I/O for real time flagging/marking, rejecting, and/or alarming is via a standard field-bus (CAN Device-Net).

ADVANTAGES

Advantages of the SMART line scan camera:

- Multiple thresholds and filtering algorithms that operate concurrently to detect a variety of defect types
σ Maximum data reduction in the camera eliminating additional processing in the PC
σ Reliable high speed digital data transmission via Ethernet and Field-bus
σ 60 MHz pixel processing providing high resolution defect images
σ Cost effective easy to install equipment that results in a scalable system

SHORTCOMINGS 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, based on that sample. This method of inspection has obvious 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 1% of the produced product. Figure 1 shows the variation of gel counts for a single roll of blown film. The data was collected with an on-line Surface Vision Film Inspection System that classifies, maps, and trends defect counts. The system counts gels, specks, scratches, bubbles, coating skips, roll marks and other anomalies by distance or area. The trend graph in Figure 1 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 regard to missed catastrophic defects and higher costs due to reduced process efficiency.

HUMAN INSPECTION

The next level of controlling defects involves human inspection. The machine operator or inspectors are positioned on the production line to watch for and flag catastrophic defects in high value applications. The flagged defects will then be removed in a subsequent converting process. A significant limitation of this strategy is human judgment---resulting in missed defects, subjective 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), time between rest periods and process speed. The frequency of missed defects and false positives increase if the defect contrast is low, when production speeds are high, or the inspection field of view is large. In addition, injuries have occurred as a result of an operator placing a flag on the 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, he stated that he saw this defect but it was his understanding that he was not supposed to flag a defect of this type. The shift supervisor quickly corrected him. 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 and achieve more effective control of the process. 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 automated 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. An automated ink or label marking system can also be added for a complete identification and marking solution without human intervention. The finished rolls can then be sent to a rewind station where the “Rewind Manager” allows the operator to stop on the desired defects to “slit out” defective areas, as desired. This increases yields and reduces costs.

IMPLEMENTING 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 casts 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 a Surface Vision Film 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.

<table>
<thead>
<tr>
<th>Defect Type</th>
<th>Size Class</th>
<th>Alarm Limit</th>
</tr>
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<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>
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</tr>
<tr>
<td>Bubble</td>
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*Table 1- Real time process defect alarm limits for each defect class*

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, for example. 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 and/or a sample of resin is taken to the lab for analysis.
In the near future, the real time inspection data will also be used 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 affect on the defect levels”. This manufacturer states that starting next year, the location of mapped defects, which include only those greater than 800µ, will be exported to a quality management software program that will combine lab quality information and will be used 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 more 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 3 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.

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 unrelated to defect counts such as coating thickness and optical density. Defective areas of the rolls are then removed at slitting. The grading criteria are 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 Vision 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, their counts per
square meter are trended for process monitoring. In addition, images of mapped defects are displayed and defects that repeat are alarmed.

Figure 4 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 ISRA Surface Vision 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 5 shows a roll map showing the location and type of defects occurring in the inspected roll. Unexpectedly, the new inspection system quickly identified some defective sections of coated rolls that were not a result of coating process conditions, but a result of static on incoming PET rolls that resulted in coating defects. In the past, this problem would have been identified in 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 6 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.

According to the coater with the new inspection system in place, fewer rolls meet the established grading criteria and the capabilities of the ISRA Surface Vision 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 plans on implementing a more meaningful roll grading criteria and 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 calendering and laminating operation that produces a wide sheet used for commercial roofing. Prior to the installation of an ISRA Surface Vision Inspection System, four inspectors inspected both sides of the sheet. 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. By demonstrating the
system and providing objective documentation to the supplier, the manufacturer is
planning on 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.

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.

This figure 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 reliably detected. The cost of inspection is high until it is used to achieve additional goals besides reliable defect detection.

Technology purchased without specific process goals relating to process improvement has only the value of finding the defects. The implementation of this technology not only to find the defects but also reduces them is where the real value lies.

There is no end point to this process; the implementation must be ongoing and for continuous improvement. In all cases, the frontline people make the system work, once an inspection system is installed, the project has not ended; the project has just begun.
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