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Uncompromising Eyes
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PE surface protection, interlayer, label and laminating films have to meet very high quality requirements. In particular, these films must have the lowest possible number of fish-eyes, which are unavoidable in PE films. Fish-eyes are small film homogeneities characterised by their area (size in transmitted light) and protrusion above the film surface. The fish-eye count is to some extent an inherent film property. Film manufacturers and users therefore try to minimise the fish-eye count and fish-eye size to a level where the fish-eyes pose no problem for the particular film converting process and intended application (Fig. 1).

Causes of Fish-eyes

If higher-molecular-weight constituents from the polymerisation process or foreign polymeric materials do not completely melt, they form fish-eyes. Contaminants such as dust from bulk containers, abraded particles in material transfer lines and foreign materials, e.g. from poorly cleaned silos, can also cause fish-eyes. During the transfer of PE pellets in pipelines, some of the PE pellets melt and smear on the walls of the pipe due to abrasion and form ribbon-like streamers (angel hair) that gradually flake off into the pellet stream. While the streamers are still adhering to the pipeline walls, their large surface area comes into prolonged contact with atmospheric oxygen. This gives rise to reactive molecular groups, which - on eventual entry of the streamers into the extruder - tend to crosslink and form fish-eyes. Deposits on the inside wall of the extruder or excessively long thermal exposure during a stoppage can lead to fish-eyes with characteristic brownish occlusions. Poorly homogenised additives such as pigments, antiblocking agents, etc. act as nuclei around which polymer accumulates to form fish-eyes (Figures 2 and 3).

Problems with Contaminants

Surface protection films are coated with adhesive and bonded to high-gloss metal surfaces (aluminium sheet, stainless steel sheet) or scratch-sensitive plastic surfaces (PMMA, PC, PVC) to protect these vulnerable surfaces during further processing and transport. In thermoforming — for example into headlamp reflectors or kitchen sinks — excessively large fish-eyes press slightly into the surface and leave behind noticeable imperfections, which are not accepted in final quality control inspection. The same effect can occur with interlayer films wound up in aluminium coils to protect the aluminium layers from each other. As a result of the winding pressure, marks can be left (Title picture).

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Labelling films and special laminating film are printed with sophisticated motifs. The fish-eyes give rise to blank unprinted dots, which show up particularly in large plain-coloured areas. In addition, in the laminating process, the fish-eyes can be pressed into the film. This results in indentations that are many times larger and therefore much easier to see than the fish-eyes that produced them. In the subsequent printing operation, no ink is deposited in these indentations and once again, there is a "halo" around the fish-eye (Fig. 4).

PE laminating films are bonded to other materials (e.g. PET, PP, PA, aluminium) with adhesive. If there are fish-eyes present in the film, a "halo" is again formed around the fish-eye, rather like an air-filled bubble, which is far larger that its origin and therefore much easier to detect as a flaw. The most critical flaws are brownish or black fish-eyes from extruder deposits, which are interpreted as contamination. Such defects are absolutely impermissible in the pharmaceutical and food packaging industries. In film composites with aluminium foil, large fish-eyes can even impair barrier properties in the worst case scenario.

Film Inspection

Modern-day inspection systems have a data rate of up to 160 MHz per camera (Fig. 5) because of the "Embedded PC" concept. This concept permits the storage and transfer of all measurement data via the Ethernet to a server. According to the application, CCD line cameras with 2,048, 4,096, 6,144 or 8,192 pixels can be used. These achieve image acquisition rates ranging from 72,000/s at 2,048 pixels to 18,000/s at 8,192 pixels. So even at very high web speeds, high resolution in the web machine direction is obtained. Through the use of special lenses and the further development of CCD sensors, the reproduction quality of long CCD lines (e.g. 8,192 pixels) is just as sensitive as for shorter CCD lines (e.g. 2,048 pixels). This means equally good inspection results for considerably lower investment costs.

A simple example will serve to illustrate the advantages of using long CCD sensors. A blown film line with a width of 2,600 mm and maximum web speed of 120 m/min is to be inspected with a resolution of 200 µm in both the web travel and transverse directions. To achieve this resolution, either four cameras with 4,096 pixels each or two cameras with 8,192 pixels each can be used. With 8,192 pixel cameras, a better price/performance ratio is obtained with equally good inspection results because of the lower purchase, maintenance and operating costs.

The systems detect and distinguish defects such as fish-eyes, gel particles, scorch marks, black specks, streaks, die lines and insects. Depending on its configuration, the inspection system can warn the operator of critical individual defects (e.g. a fly), defect trends (e.g. more than 10 gel particles in a diameter of between 200 and 300 mm per m2) or film rolls that are off-spec. Online, production trends can be mapped over extended periods of time, e.g. the last twelve hours. Offline, whole runs can be compared and analysed in order to assess, for example, the fish-eye count obtained with different raw material batches on specific extruders (Fig. 6).

Self-learning Systems

By using the so-called easy-teach-in-function, the operator can identify defects with the aid of defect pictures and sort them into classes. The classifier then automatically specifies the inspection parameters for the individual defects. Since these systems work with fuzzy algorithms, they are able, for example, to differentiate flies from black specks. This differentiation is crucially important, since the cause of the defect may lie in either the cleanroom environment or the production process. Similarly, fluff attracted by static charges is classified as such and therefore not identified as a defect (Fig. 7).

Lighting Technology

The use of the right lighting technology is vitally important for film inspection. The standard lighting normally comprises fast-pulse fluorescent tubes. But fibre-optic or LED lighting is also employed. The lighting may be used as reflected or transmitted light. If possible, transmitted light is preferred because it enables both sides of the film to be inspected. On the other hand, physical irregularities such as scratches, in opaque surfaces can be more reliably detected in reflected light. Another bonus of film surface inspection is that the absolute and relative opacity of transparent and translucent materials can be determined.

Integrated Quality Concept

For quality control of PE films, even today, film samples are still sometimes taken from the end of the roll and visually inspected by employees. The results of such an inspection are very sub-
jective and relate to only a tiny product quantity. In other words, they are not statistically meaningful. Counting the fish-eyes is a more objective method but very time-consuming. But here again, only a very small random sample is taken and the assessment of fish-eye size is also subjective. Counting the fish-eyes on the running machine by manual assessment is even less objective because of the film movement. In the random sample inspection at the end of the roll, defects are not identified until some hours after production. If the film is faulty, considerable amounts of material are wasted in this way and production times are squandered.

To ensure continuous monitoring of the production process, the subjective assessment of quality must be replaced by an objective method. For this purpose, surface inspection systems like the FSP600 film quality inspection system from OCS GmbH, Witten/Germany, can be used. At Orbita-Film GmbH, Weßling-Golzau/Germany, several such inspection systems have been installed since 1994. Some systems operate with one camera and scan widths of 300 mm or 700 mm. One system is equipped with three cameras and monitors a film width of 3,000 mm. The systems operate in transmitted light for transparent, translucent and opaque films up to a certain degree of opacity.

Most equipment does not inspect the whole film width but only a section. With this philosophy, only the homogeneously distributed defects are statistically detected. Depending on the film width, 30 to 70% of the entire film width is scanned in contrast to the maximum of 0.005% with manual inspection.

In transmitted light, only the optically effective surface of the fish-eyes in the plane of the film is detected. The fish-eyes that are actually detrimental, i.e., those which protrude significantly above the film surface, are far fewer in number than the measured and displayed fish-eye count. Because of the difficulty of picking out these “projecting” fish-eyes from the rest, the total fish-eye count is generally recognised as an index for the level of fish-eyes. The principal advantages of these systems are objective, reproducible inspection of surface quality and the possibility of reacting immediately to changes in the fish-eye level.

The systems are integrated into the company's internal network. With each roll change, the inspection data for the particular roll are automatically stored on an internal server by roll number and production date.

**Application Examples**

An example of the successful use of fibre-optic lighting by Orbita is the inspection of black and white surface protection films for stainless steel in transmitted light. Each fish-eye causes an optical dint in the stainless steel. This phenomenon is intensified by a thermoforming process. Because of its high opacity, the film is very difficult to inspect in transmitted light but double-sided inspection in reflected light is very costly and technically complex to achieve.

Inspection systems with a camera are used in the blown film lines. Only a section of the films are inspected with resolutions up to 100 µm. This statistical monitoring is sufficient to guarantee fish-eye-free film quality.

The cast film lines for self-adhesive film with widths of up to 2,600 mm are 100% inspected. In this case, a very high resolution is achieved to detect even the smallest defect. The 100% inspection also enables optimum setting of both the extruder and the die.

In the adhesive coating zone, Orbita also monitors the complete web. Here a wide variety of defects in the film are detected as defects of adhesive application. In this way, the coating process is optimised and absolute quality control achieved.

**Conclusion**

The use of online inspection systems for surface inspection of PE films has proved successful in practice and permitted faster, more efficient detection of surface defects in recent years. As a result, it has been possible to reduce the number of rejects and complaints. With these systems, it is possible to meet continually increasing product quality requirements, while ensuring efficient production.

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