Illumination for inspection systems

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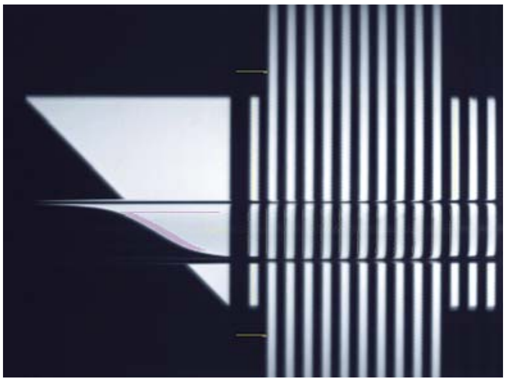
Glass, like other transparent objects, is difficult to illuminate. The surface is reflecting and the material diffracts the light. Different defects in glass require different illumination techniques: diffuse lighting, spot light, light slots and light boxes with different patterns. Structured lighting can enhance special defects and suppress others. Developing structured lighting is more like an art than pure engineering. Experience from many different applications is the best background in this technological field where a well arranged illumination often is the key to success. In the following the design of lighting for vision systems to inspect glass tubes, tube ends, containers, tableware, flat glass, and special applications will be discussed.

ECLAIRAGE POUR LES SYSTÈMES D'INSPECTION

Le verre, comme les autres objets transparents, est difficile à éclairer. Sa surface est réfléchissante et le matériau diffracte la lumière. Les divers défauts du verre requièrent différentes techniques d'éclairage : lumière diffuse, spot, fentes et boites à lumière. Un éclairage structuré peut amplifier des défauts spéciaux et en supprimer d'autres. Dans l'article qui suit, on discute des systèmes d'éclairage destinés à inspecter les tubes de verre et leurs extrémités, les emballages en verre, la vaisselle et le verre plat et on considère également le cas d'applications spéciales.

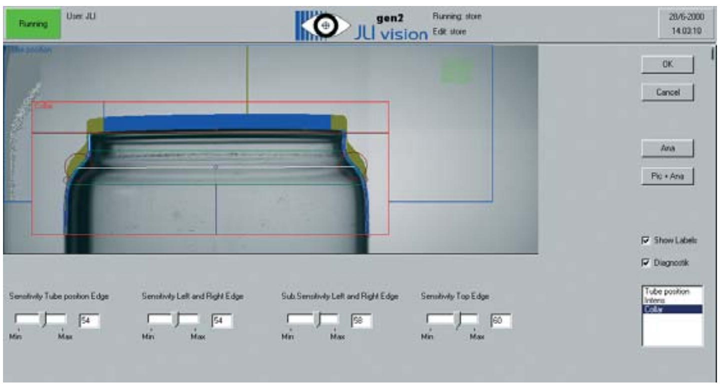
GLASS TUBES

Glass tubes are drawn at speeds up to 15 meters a second. Finding defects down to 0.02 mm is a real challenge.
To achieve this, you need a very fast exposure time to avoid motion blur. It is also important to design the optical system with an acceptable depth of field so both the front and the back of the tube can be inspected. A good depth of field demands a small aperture.
Looking at all these requirements, you inevitable end up with the need for a very powerful lighting system.
In our glass tube inspection systems, we have to run the line scan cameras at an exposure rate up to 1/40 000 second or 800 times more



Glass tube illuminated to detect stone, knot & cord

Tube inspection using powerful light. The system is installed at the line where the glass tubing is drawn at high speeds.



Fluorescent tube end inspection

than the ordinary video camera exposure time.
An exposure time of only 25 micro seconds demand a lot of light. In the glass tube inspection systems we have solved this by using ordinary sodium street lighting but pulsed by special electronics drivers. The light is intense but the life time of the lamps is still in excess of three years.
The glass tubes should be round with even wall thickness and free of defects. Dimensions are best measured by laser systems. VMA are experts in this field.
The defects are stone, knot and air lines. Stones are inclusions, typically refractory material, than finds its way through the process. Knots are badly dissolved glass that appears as lumps. Air lines come from air being trapped at the mandrel in the Danner process. These small air pockets are then stretched as the glass tube is drawn. The mandrel rotates and therefore the airlines are twisted giving a cork screw effect. As the tractor does not allow any rotation the tube passing the vision system will see the airlines as spirals embedded in the glass wall.
The airlines are down to 3 μm so in order to detect these; the vision system software utilizes the fact that this particular defect is thin, long and fairly straight. Fairly - because of the cork screw shape.
Stone are found by simply detecting the black inclusion as it passes the line scan cameras. Normally the system is helped by the optical effect associated with the stone. There will always be a small lump that acts like a lens dissipating the light from the illumination and therefore making the dark defect appear larger.
Knots have the same optical effect and therefore they are detected more or less as stones. It is possible to distinguish between stone and knot if the stone is large enough. The section of tube will be rejected for both faults, but it is important for the factory to know the relation between stones and knots in order to understand and optimize the process.
Depending on the type of tube being produced it may be acceptable to let faults below a pre-selected size pass. However, it is not acceptable if too many small faults cluster in a small area. Therefore the system software counts and calculates distances in order to grade each section of tube to make sure that the limits are not exceeded.
After the rough cut, the tubes are transferred sideways, and the ends are cracked and finally glazed.
A further process may be to shape the end for fluorescent lighting. This process is fairly straight forward but it is still necessary to inspect the ends for cracks, checks, geometry and size of glazing. The speed is typically very low with a maximum of five tubes a second.
Three ways of inspection can be used. The tubes can just pass on the pegs. If there is no rotation at least three cameras must be arranged to get a complete coverage.
If the tube rotates while it is transported, one camera can do the job, but rotation under transportation requires a fairly large picture field and therefore the camera must have a high resolution and the software must ensure dimensional calibration all the way through the inspection zone as the perspective changes.
The best method of presentation for the vision system is if the tube can be stopped and rotated. Thereby a small picture field can be used and this gives high resolution and sensitivity. The drawback is complicated mechanics and slow speed.
The backlighting system is different for each inspection method. If multiple cameras are used it is important to fire the lights in sequence to avoid interference between the light sources. Not taking care of this detail will produce reflections in the geometry of the shaped ends.

CONTAINERS

Glass containers can be inspected both in the hot or the cold end. Each location has its drawbacks and benefits.
In the hot end the operators get instant feedback, but it is not possible to obtain a 100% inspection. It is for instance not possible to pick up the red hot container to inspect the base of the bottle.

Birdswing deteted by backlighting

The best inspection is done by backlighting. Other methods relying on Near Infra Red radiation exists, but the results are not reliable. NIR reflections from neighbouring containers, difference in cooling and many other factors disturb the picture and the results are prone to misinterpretations. Therefore, the best way is to use backlighting where all NIR radiation is eliminated and a dependable illumination is arranged.
To get good dimensional measurements the light box must not be larger than necessary. Seen from the camera the light

box must only illuminate the back of the container plus approx. 5 mm on each side. Having a larger opening in the light box will generate reflections from the sides of the container and the dimensional accuracy will be reduced.
With a good illumination system the dimensions can easily be measured at an accuracy of 0.1 mm. This is far better than the container tolerances, but this accuracy allows for an efficient way of monitoring the process. Any drift in the production parameters instantly shows up on the dimensions. If one cavity is running hot the container will sink and this is easily spotted on the trend graphs.
A well regulated and monitored backlighting system can also be used for wall thickness measurements. The light passing through the glass wall is dampened and with tight control on the measurement loop, this reduction can be calibrated and translated to wall thickness dimension with a resolution of 0.01 mm.

Mould ring enhanced by structured lighting

TABLEWARE

Tableware, especially stemware, has a much more complicated range of shapes. To illuminate these it is not enough to just cover part of the backlighting light box. In fact the light box should be shaped to match the article to be inspected. This can of course be done by conventional blinds but it is a lot smarter to use a dynamic light box. This is basically a LCD screen where the vision computer displays patterns of black and white sections. Typically the shape of the stemware is displayed allowing the particular stemware to fit in the illuminated area bordered by black. This way, very accurate dimensional measurements can be achieved.
But the dynamic light box can do a lot more. Certain defects like mould rings, waves, checks and cracks can only be seen if the tableware is inspected against a special pattern. This can be vertical or horizontal stripes. These may even sweep across the light box.
As the vision systems have become very fast, up to 25 images a second can be analysed, consequently a typical production speed of three glasses a second allows for six or seven specific illuminations and analysis as the tableware passes on the conveyor.

FLAT GLASS

Flat glass presents similar problems. If the objective is to find black spots it is easy to just use an even illuminated light box. If you are looking for variation in thickness you can exploit the distortion of a grid or stripe pattern presented by the light box to the camera. The illumination can also enhance waves in one direction and suppress waves in other directions. Using the dynamic light box this can be done actively in all directions.
Surface defects may be inspected by monitoring the reflection from the surface. Also here it may be necessary to use structured light.

SPECIALS

Working in these areas and providing practical solutions on the factory floor has given a lot of experience in designing special illumination and vision systems. The glass industry has many challenging inspection applications. To find solutions it is often necessary work very closely with the production. Sometimes we find that the products have other defects than the factory expected. It can therefore become an important job to make sure that the acceptable deviations do not trigger a reject. Running the systems in is therefore often a fairly long process. This has turn out to be a lot easier after the Internet has become available also on the factory floor.
After installation and a basic set up, the system is run in under actual production typically with large tolerances. These tolerances are then progressively narrowed down giving the desired product quality.
We can connect to the systems from our office in Denmark and operate them just as well as if we were on site in Japan, USA or where our systems are installed. The remote control together with a comprehensive built in SPC function is a great aid when tuning the system to just the point the factory want.
Surveillance of the inspection system is achieved with a software monitoring system. The software looks at a number of computer components and measures temperature, voltages, fan RPM, hard disk condition etc. Also the application software can report to this monitoring system. If the set alarm levels are exceeded the system will send an email to our office with system identification and a report describing the problem. If it is a fan running slow we can email the factory and ask them to clean the air filter.
The factories become more and more automated and a lot of equipment must work to get products through to the customers. It is reassuring that the systems look after themselves and alert the supplier in case of concern. This is preventive maintenance at its best ■