White Paper

Inline vision Inspection

By John R Henry

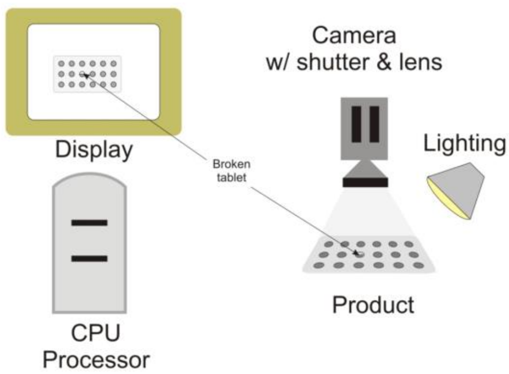
Machine vision inspection means using an automated system to replace human visual inspection. Some systems do this using photoeyes. For example to detect a missing cap, label or other component. In general when we speak of machine vision, we mean camera based systems. These take a picture of the element of interest then process the image in a computer to determine whether the element is within specification.

Machine vision is also used for other operations besides inspection but this paper will focus only on inspection uses.

Common elements inspected include missing components, presence and correctness of lot and date codes, label skew, cracked glass and much more.

Most machine vision systems inspect 2 dimensionally, meaning they can only see what is on the surface, They cannot detect, for example, a tablet with the back half missing. Several companies in recent years have begun offering 3D vision systems that may be useful in these applications. It is still a new technology with limited applications so this whitepaper will focus on 2D systems.

Any vision system consists of 5 components:



Vision inspection schematic

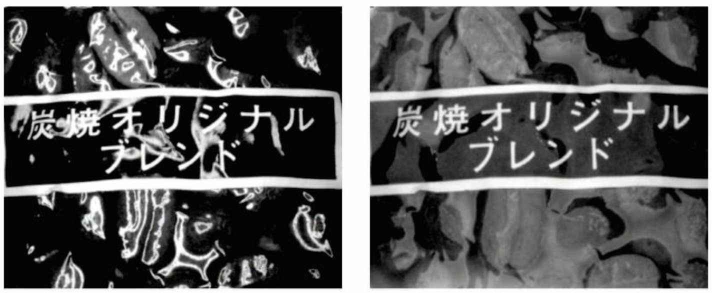
- Lighting
- Camera
- Lens
- Shutter
- Processor
- Display (optional)

Lighting

All 5 components are critical but the most critical is the lighting. If the lighting is not correct, the camera will not be able to clearly "see" the element which means that the system will not be able to evaluate it.

This picture shows a package with standard and enhanced or specialized lighting. The characters in the second picture are much easier for the camera to see.

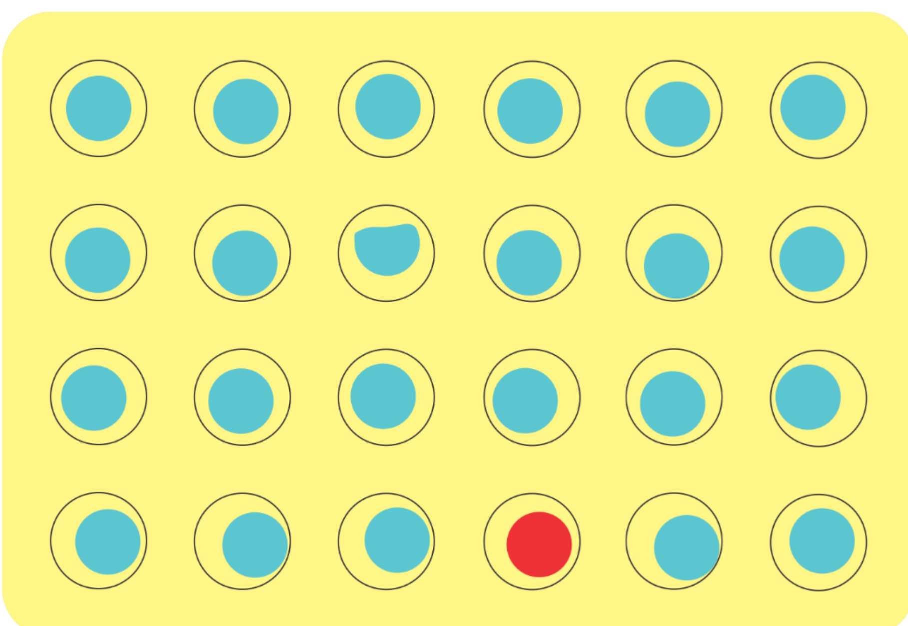
In some cases it may be possible to use a vision system with standard ambient lighting. Dedicated lighting should always be used. In one instance where ambient lighting was used, maintenance changed the fluorescent tubes to a new, energy efficient tube. The vision system still worked but became erratic and untrustworthy. As maintenance had not realized that the tubes would have effect, nobody on the line was notified. It took some time to track the problem down.



Normal lighting Enhanced lighting

Lighting can be from the front when something like the above package is to be inspected.

In other cases, the vision system may be looking for the edges of the product as in this blister:



Backlighting, where the light is behind the transparent blister and blocked by the tablets may be more effective in detecting the broken tablet. The system is looking for a pattern of 24 circles, the tablets. In this blister one of the tablets is not a circle and will cause the system to reject the blister. Another tablet is red and this this will also cause rejection, though front lighting will be required as well to see it.

Most applications leave the light on continuously while the system is in use. This eliminates issues of timing a strobe, package and camera. In high speed systems, over 500ppm or so, a strobe light may be used instead. The camera is left on continuously but turned down so that in normal light is sees nothing. When the product passes, the strobe flashes, generating an image in the camera.

Camera

The camera is a solid state, digital electronic camera. It is similar to the camera in today's smartphone, though with some higher capabilities. As the object to be inspected passes in front of the camera, a sensor is triggered. This causes the camera to take a picture. This electronic picture is then sent to the CPU for processing and comparison to the element being inspected.

The main criteria for the camera is that it must be fast enough to take a picture, send it to the CPU and be ready to take the next picture. On a line running 1,000ppm, there is less than 0.06 seconds to do this.

Most modern inspection cameras are color but if color is not needed a black and white camera may be used to reduce the amount of processing required. In the blister above, if the camera needs only detect the presence or absence of a complete tablet, black and white will work fine. In a blister like this, it is probable that the camera is expected to detect the tablet color to avoid mixups and a color camera will be used.

Lens and shutter

Digital cameras do not have mechanical shutters. Shutter speed refers to how quickly the camera can turn on and off to capture an image. If inspecting a stationary element, this is not too critical. When inspecting "on the fly", moving elements, it will be critical.

The shutter speed must be fast enough to capture the image before the element moves significantly. If the element moves while the picture is being taken, it will be out of **OUT OF FOCUS WORD???** In other words, rather than stopping the element physically, it is being stopped optically.

The lens is the eye though which the camera sees. It must be able to capture a clear image. Some inspection elements, such as manufacturing codes, may be microscopic. One company laser etched diamonds with a 40 micron high code. The lens in the vision system must be powerful enough to resolve this image.

Normally, there will be some variation in the position of the element being inspected. A code may never print in exactly the same place, or a bottle may never pass the camera exactly the same way. These variations are normally minimal but the lens must capture an area large enough to accommodate it. On the other hand, the large the image captured the more processing must be done, slowing system capacity. The image area should be as large as needed but no larger.

CPU (Processor)

Once the image is captured, it is sent to the CPU or processor for evaluation. There are two ways to do this.

During setup an image of a good product is captured. Using the blister above as an example, the good product image would show 24 blue circles and approximate locations for each defined by the blister cavities. This image is stored in the CPU as a template. During operation each image captured by the system is compared to the template. If they match the blister is accepted. If not, the blister is rejected.

Vision systems can also evaluate elements. Although not common in packaging, in other manufacturing operations vision systems can capture an image of a part and measure one or more dimensions, recording the actual measurement as opposed to comparing it to a standard.

Display

Although not strictly required, many vision systems will have a display or monitor. This display is used during setup and to review operating statistics while running. In most cases, the display will also show what the camera is seeing at any given moment, allowing for some latency.

Camera

Packaging machines are generally reliable but will never be perfect. Inadequate maintenance, improper settings, inattentive operation or variable materials can all cause out of specification products to be produced. Inspection of the finished product will always be needed. The term "inspection" will be used in this chapter to denote the automated verification of one or more parameters of the package, the components or the product contained therein. "Good" and "bad" will be used to describe whether the package meets specifications and is accepted or whether it does not and must be rejected. False rejects and false acceptance is another potential issue with inspection. A false reject is a product that is actually good but erroneously rejected by the inspection system. A false acceptance is a product that is bad, but is erroneously accepted. Systems should be designed so that when that when they fail, they fail safely rejecting good product rather than accepting bad product.

Inspection may be done manually by operators or quality inspectors but it is generally more effective to use automated systems. It may be possible to manually inspect only a sample of the packages. Defective packages may be missed in the sample and, if found, it may be necessary to reject or reinspect all the production since the last sample. When 100% inspection is performed, it is likely to have a high error rate due to the nature of human inspection. Automated systems will have a higher initial cost but this is usually recovered fairly quickly through reduced rejects and labor costs. As the cost of automated inspection systems continues to drop, there is less and less justification for continuing to perform manual inspection. Automated systems can inspect every package, at high speeds, with a much higher reliability of finding out of specification conditions than any operator can.

Automated inspection systems can be used to detect a wide variety of out of specification conditions ranging from simple part presence such as a missing cap to sophisticated machine vision systems that can verify the printing on a package, to x-ray systems that can detect bone, glass or metal chips inside closed, opaque, containers. Other applications include the detection of contaminants, verification of fill volumes and weights, identification of broken or damaged product and containers, internal container pressure and verification of proper cap torque to name a few.

Detection of out of specification conditions is not, by itself, enough. Any inspection system must include a rejection mechanism to remove the defective package from the process. Most inspection systems will keep track of the number of packages removed and why. More sophisticated systems will keep track of the parameters of all products, both good and bad. These can incorporate Statistical Process Control (SPC) techniques to provide as the measured parameter drifts away from its ideal. Monitoring these trends allow a process to be stopped or adjusted before it produces an out of specification package.

This chapter will discuss some of the various types of inspection systems in common use in packaging today. It will also discuss different types of rejection systems used.

Presence detection

Presence is perhaps the simplest thing to inspect for. This may be the presence of a desirable condition, such as a cap on a bottle. It may also be the presence of an undesirable condition such as an open flap on a carton. A simple presence detection system can be constructed of 2 photoeyes with a relay to trigger the rejection mechanism. One application is to verify the presence of a cap on a bottle as it moves along the conveyor. A trigger photoeye is set to detect the leading edge of the bottle as it exits the capper. The presence sensing photoeye is set to look at the top of the bottle. When a bottle with a cap is present, both photoeyes will activate and the bottle is accepted. When there is a bottle with no cap, the trigger photoeye will activate but not the sensor photoeye. This will cause the relay to activate the rejection mechanism. This basic configuration can be used with any other type of sensor such as a capacitance sensor to detect the presence of a foil liner under a cap.

This or any other type of inspection system should be designed to be "fail-safe". In the system described, this is accomplished by having the trigger photoeye send a rejection output for every bottle that is senses. A time delay incorporated in the relay prevents the signal from taking effect immediately. If the presence sensing photoeye detects a cap, it cancels the rejection signal. If it does not sense a cap, whether due to absence of a cap or some fault with the system, the rejection is allowed to take place.

Normally there will need to be adjustments to the photoeyes as packages change in height and diameter. Photoeye sensitivity may also need to be adjusted. These adjustments can sometimes be a bit tricky and require a technician to get set correctly. One way to avoid this is to use multiple photoeyes. A cap detection system for 4 bottle sizes might have an array of 4 trigger photoeyes as well as the sensing photoeye. These would all be connected to the system relay via a selector switch. During machine setup the selector switch is set to position 1, 2, 3 or 4 depending on the bottle to be inspected. This eliminates the need for a technician and save the time and potential problems of making adjustments.

FIG 3-1 Cap presence pic here

Color inspection

Some products, such as some pharmaceuticals, use different cap colors to indicate different strengths. The above system will detect whether a cap is present but not whether it is blue or green. It can be modified to do so by changing the presence sensing photoeye for one with a color filter. This will allows the photoeye to distinguish the blue from the green, sensing and accepting one but failing to sense the other, triggering a rejection.

Vision Inspection

The systems above use simple, binary, sensors that are either on or off. They can be used to detect presence/absence of the cap or gross variations of color eg; green vs blue. They generally cannot be used to detect more subtle variations in colors eg; medium green from light green or a cap that is incorrectly applied. More sophisticated inspection may be done using machine vision systems. These are often called simply "vision" systems for convenience. Vision systems use a camera to capture an image of the package feature to be inspected. Software examines the captured image to verify that it is within specification. If it is not, the software sends a signal to the rejection mechanism. Vision systems can be used to detect not just the presence of a glass vial at the filling machine, but whether it is chipped or cracked. They can determine not just the presence of a label on a bottle, but whether it is the correct one. They can determine not just the presence of an expiration date on a carton, but whether it says 1234S or 12345. This is not a simple task. If the package is running at 500PPM (8.3 packages/second), the vision system has less than 120 milliseconds to capture an image of the feature, evaluate it and reject or accept it.

The typical vision system consists of six major components: Camera, shutter, lens, lighting, software and display. The camera takes a digital picture of the features to be inspected. The proper lens and shutter are important to assure that the camera captures a clear image in the very short time that is available. The term "shutter" in this case is a bit of a misnomer. A typical film camera has a physical shutter that opens and closes to expose the film. The "shutter" in a digital camera turns the camera on and off. A digital shutter is more than a simple switch since it must operate very precisely at very high speeds, sometimes 20 times per second or more. If left open too long, the movement of the product will cause blurring. If not left open long enough, it will fail to capture the image at all. High speed applications may dispense with the shutter altogether using a strobe light to capture the image. The lens is stopped down so that in normal lighting the camera does not register an image. When the package is in position for inspection, a very short duration, high intensity strobe light flashes and the camera registers the image.

Fig 3-2 Vision system schematic pic here

Lenses are critical to the system because if the image is not sharply in focus, the software will not be able to determine good from bad. Focus can be difficult because the package is usually moving across the camera's field of view. Depending on how tightly controlled the package position in front of the camera is, the distance from the lens to the package may vary. A lens with good depth of field may be selected to deal with this varying focal point. The lens should be sized to capture the smallest possible area that includes the feature to be inspected. Slight variations in the position of a printed lot code are normal and the area to be captured the camera must be large enough to include all acceptable variation. The area captured must not be larger than absolutely necessary since the larger the area the more, the larger the image that must be captured and evaluated. This additional evaluation takes time and will limit the system capacity.

Lighting for a vision system must be carefully selected and designed to optimize the image captured by the camera. Some vision systems may work satisfactorily in ambient lighting. Even where this is the case, dedicated lighting should always be provided. The problem is that suitable ambient lighting that is suitable today today may not be suitable tomorrow. If light sources are added or removed or incandescent lighting replaced with fluorescent, it will affect the quality and quantity of ambient light. This will affect how the camera sees the package. A feature that stands out clearly and is easily captured by the camera under incandescent light may be obscure and hard to capture under fluorescent lighting and vice-versa.

Direct or indirect lighting may be used depending on the application. Direct lighting shines directly onto the feature being inspected. This illuminates it well but if there is a glossy surface, it may reflect the light back into the lens causing glare and interfering with the image quality. One way to combat this is to angle the lighting, the camera or both so that the glare does not reflect into the camera. Diffuse or back lighting illuminates the package from behind. This can be useful where the edges, rather than the surfaces, of the package are to be inspected. One application would be determining whether a cap is completely and squarely seated. It can also be useful when inspecting the contents of a package such as looking for particulates in a solution. Lighting color and wavelength can also make a feature stand out. The more contrast there is between the feature and its background, the easier it is for the system to evaluate. "Invisible" printing, such as ultraviolet (UV) ink, will require special illumination with UV light to allow the camera to capture the image.

Once the image has been captured, it is processed by the software using one of two basic methods. The simpler of the two relies on pattern recognition. Prior to the start of production, the system is "trained" by placing it in setup mode and capturing an example of an acceptable package feature such as the lot code or label placement. This image is stored in the system memory and becomes a template against which production images are compared. After training, the system is placed in production mode. As each package passes, the camera captures an image of the feature being inspected. This image is compared with the version captured during training. If they match, within determined tolerances, the package is accepted. If they do not match, the system invokes a signal to reject the package. One use of a vision system is to verify correct cap application. A correctly applied cap, screwed all the way down, might show a 1/16" gap between its base and the bottle neck on both the leading and trailing side of the image.

A crooked or "cocked" cap might have a gap of 1/8" on one side and 0" on the other. When this image is overlaid on the known good template cap, the gaps will not align. The software will detect this lack of alignment and reject the bottle.

A more sophisticated method captures the image as above but processes it differently. Instead of comparing the cap to a template, it measures the gap between the cap and neck and compares it to a value stored in the software. If the distance is greater than a value programmed in the system, or if the distances of the leading and trailing edge of the image are different, it rejects the bottle.

Perhaps the most common use of vision systems in packaging is the inspection of variable information such as lot, date and other codes which are printed inline at the point of use ie; on the labeling or cartooning machine or offline just prior to production. (See Chapter 6 for discussion of inline printing/coding technologies) The word "code" will be used in this section as a shorthand for any printed information to be inspected. This code will normally vary from lot to lot or day to day but will be constant within the same production run. Some coding systems may be used to apply a time stamp or serial number so that each code within the production run will be different. Inspection requirements will be different depending on the variability of the code.

Two methodologies are in common use for package code inspection. These are Optical Character Recognition (OCR) and Optical Character Verification (OCV). Both systems use similar cameras, lenses, lighting and so on. The major differences are in how the image, once captured, is processed.

OCV "verifies" the code as an image rather than as a series of alpha-numeric characters. It cannot distinguish between English or Chinese characters, all it can do is determine whether the captured image aligns with the stored, known good image. During system setup, the camera is used to capture an image of a code known to be good. This image is then stored in the system memory and becomes the template to which all other codes will be compared. If the production code does not match the template code, the package will be rejected.

OCV has the advantage of being simpler and faster than OCR. It is a go/no-go system and requires less computational power for each inspection. The code characters and positions are known. A disadvantage of OCV is that it requires retraining each time the code is changed. This restricts its use where the codes will vary within the production run such as a serial number.

Optical Character Recognition or OCR recognizes the characters of the code without reference to a previously learned template. OCR reads the code as a string of individual characters rather than verifying a match between the overall code and the template. The system is programmed to know the range of permissible characters in each position. The fewer the number of possible characters, the faster the system will respond as it will have a shorter dataset to work through with each inspection. Thus, if a lot code always begins with an "A" or a "B", the system will be instructed to only look for these two characters in the first position. If the second character can be a number 0-9, it will need to look for all 10 numerals in order to determine what the character is. Once it determines that it is a 7, for example, it will need to determine whether a 7, in that position, is acceptable. If not, it will send a signal to reject the product.

OCR systems, because they must determine each character, require more computational power than an OCV system for a similar application. This computation takes place quickly but does require time and computing power.

An issue that arises in both OCV and OCR inspection systems is that some characters are similar to others. An S and a 5, or a B and an 8, can look very similar to the system. This is aggravated when the printing system is not precisely adjusted and the characters are not as sharply or as well printed as they should be. Fonts used for code printing should be selected to optimize the ability of the inspection system to discriminate between the various characters. There are specialized fonts such as OCR-A and OCR-B which are designed to maximize differences between characters specifically to facilitate automated inspection.

Fig 3-3 OCR vs standard font

A specialized type of vision inspection is barcode verification. Barcodes come in many forms or symbologies, including linear (sometimes called 1 dimensional or 1D) Matrix (Sometimes called 2 dimensional or 2D codes.) and hybrids combining elements of both linear and 2D codes.

Fig 3-4 1D-2D barcodes

A well known example of a 1D code is the Universal Product Code (UPC), which appears on all consumer goods. Most are also likely to be familiar with the problems caused at checkout if the UPC is not present and readable. In addition to the UPC, other barcode symbologies are used in packaging for various purposes. Many cartons and labels have barcodes for internal use to assure that the correct component is present at a given manufacturing stage. When similar cartons are used for different products, mistakes can happen and the cartons can get mixed. A bar code scanner or reader mounted on the carton magazine can read at each carton as it is pulled into the cartoner. If the correct barcode is not present, it will stop the cartoner and sound an alarm. Other manufacturing uses of barcodes include internal manufacturing information, serial/sequential numbers, time stamping, customer ID and more. A number of different symbologies are available but their discussion is beyond the scope of this book.

Two basic types of barcode scanner are widely used in today's packaging lines. One widely used style uses a laser beam and a mirror to "scan" the beam across the barcode. This is also the type found in most retail store checkout. The laser beam strikes the bars and spaces of the barcode and is reflected back to a sensor. The sensor sends the pattern of light and dark bars to software which converts it into a string of numeric and alpha characters in the system software. The characters are compared with the expected value and accepted or rejected or they may be used to identify the product in a database.

Camera based systems are becoming more common for barcode scanning as prices continue to fall. Similar to the vision systems discussed above, these capture an image of the code and decode it into its alpha-numeric characters.

If the barcode is for external use, such as a UPC code, it is not enough to be able to read it on the packaging line, it must be readable at the point of use. Conditions on the packaging line will usually include high quality readers, lighting and controlled scanning. These optimal conditions may permit a barcode of marginal quality to be read successfully. Conditions at the warehouse, retail store or other point of use may not be as good causing a barcode that was readable on the packaging line to be unreadable at checkout. In order to avoid these problems barcode verifiers should be used as a check on code quality. Verifiers read the code and grade it as A to F based on factors such as reflectance, contrast, decodability and more. This grade will give an indication of how well it can be read and decoded at point of use. Some end users require that all barcodes must achieve a certain grade. If not met, they may reject the shipment and/or impose a fine on the manufacturer. The use of barcode verifiers can avoid this problem.

Linear barcodes are limited in the amount of data that they can contain. A UPC code can contain a maximum of 12 numeric characters. Other symbologies can encode more data, including alpha-numeric characters. As more information is encoded, the code becomes longer and may require more space than is available. Some compression of the code may be permissible but there is a limit to the amount of information that can be encoded in a given amount of space. If more data is required than can be encoded in a linear code, a 2D barcode may be used. These codes are called 2D because in addition to encoding information horizontally as in a linear barcode, they encode information vertically as well. There are a number of different symbologies available, some of which can encode thousands of characters of information in a small area.

Camera based systems can read linear barcodes but scanner based systems cannot read 2D codes. One advantage of the camera based system is that if the image of the code can be captured, it can be manipulated in software and decoded. This allows 2D codes to be extremely small, even microscopic in some cases. A linear barcode scanner requires a certain contrast level between bars and spaces to read. A 2D barcode can be decoded with only minimal contrast. The major disadvantage of the 2D code is that it does require a camera based system for decoding. While these have declined dramatically in price in recent years, they are still more expensive and less common than scanner based systems.

Fill verification

The customer is paying for a certain amount of product in every package. If they do not get what they pay for, they will be disappointed and may become former customers. Worse, underfilling or shortages may also precipitate regulatory actions including fines. It behooves the packager to ensure that every product contains at least the quantity claimed on the label. Overfills may satisfy the customer and regulator but are costly. A 0.5% overfill may be acceptable on a low cost or low volume product. If that product is running at 200CPM, 0.5% results in the giveaway of the equivalent of 1 product every 2 minutes or over 100,000 bottles per year. Packagers must guard against both underfills and overfills, keeping product volume as close as possible to the label claim. This requires appropriate filling technologies but even the best needs monitoring. Fill volumes can be monitored inline by two principle methods: weight and level.

Level inspection, as its name implies, detects the level of product in the container. It does not detect the actual quantity of product. The quantity will be determined by the internal volume of the container. In some cases, such as glass bottles, this can vary. This variation will cause differences in level between bottles of the same product. If the product level is visible on the store shelf, this difference in level between bottles can cause a perception of under and overfilled product to the consumer and a lack of quality. The perceived fill volume for these products, evidenced by the level, is more important than the actual volume.

Simple level inspection may be performed using a photoeye system similar to those discussed earlier. The photoeyes are positioned to look through the container at the point of the normal product level. Two level sensing photoeyes are normally required in addition to the trigger photoeye. These are mounted one above the other for detecting under and over fills. If the lower photoeye senses the product and the upper does not, the level is in the acceptable range. Otherwise the reject mechanism is activated. A variation on this is to use ultrasonic proximity sensors mounted above the container. The sensor detects the surface of the product, calculates the fill level based on distance from the sensor and accepts or rejects accordingly. These work well with containers having a relatively wide mouth but may be problematic with small mouth containers.

These sensors cannot penetrate a metal can and another method must be used. One method uses gamma radiation to verify that the can is full. A gamma radiation beam is emitted by the system and focused in a narrow beam. The beam strikes a detector on the other side of the conveyor. As the can passes through the beam it interrupts it and the detector senses this loss of signal. Varying the sensitivity of the detector allows the system to discriminate between the beam passing through a void area in the can (underfill) and through can plus contents.

Fig 3-5 Gamma level detector

These level sensing techniques are simple and work fairly well for fairly gross variations of fill volume. They generally will not work where small variations need to be detected. One issue is sensitivity of the system itself, they may not be able to detect variations of less than 1/16" or so. Movement of the container may cause movement of the product, further reducing accuracy.

If more accurate measurement of fill volumes is required, weighing systems, generically called checkweighers, should be used. These are not to be confused with fill by weight filling systems as will be discussed in Chapter 7. Some checkweighers can provide feedback to the filler to control fill volumes but even when this is the case, they are still primarily a verification device. Checkweighers normally weigh the package while it is in motion. If higher precision is required, some architectures momentarily stop the container during weighing.

Fig 3-6 Checkweigher schematic

In addition to weighing the amount of product in the container, checkweighers are also commonly used to verify the presence of a product in a closed package. A case of 24 bottles may be weighed to verify that all 24 bottles are present.

Checkweighers consist of a package handling system, a scale and software to monitor the weight and take action if out of specification. A typical configuration on a bottle packaging line will consist of 3 relatively short (12" – 24") conveyors. The first, or infeed, conveyor accepts the package from the upstream conveyor or machine. Often it speeds it up to separate it from subsequent products as only one product can be permitted on the scale conveyor at a time. The second conveyor is mounted on a scale. As the package enters this scale, the checkweigher notes the increased weight and compares it to the programmed weight. The third, or discharge, conveyor carries the package out of the checkweigher to the subsequent downstream conveyor or process. A rejection mechanism is usually mounted on the discharge conveyor to reject over- or underweight packages. Speeds of all three conveyors are normally controlled by the checkweigher to ensure that only one package is on the scale conveyor at a given time.

Conveyors are common but other techniques are also used depending on the package and speeds. Tall, unstable, packages may not transfer well between the conveyors, tending to fall over. A pair of horizontal sidebelts may be used to prevent this. As the package approaches the checkweigher it is captured by the sidebelts, mounted to the scale, which carry it through the weighing section. Other designs use timing screws to singulate and move the package through the weighing section. Timing screws provide good control of the package, assuring that no more than one is ever on the scale during weighing. One issue with the use of timing screws is that the friction of the screw on the bottle will cause variation in the indicated weight. This can be avoided by using a screw with a dwell pocket (see the section on timing screws in Chapter 2) to momentarily pause the package during weighing. The dwell pocket should be relieved so that, while being weighed, the screw does not touching the package. Another technique uses an indexing starwheel. The packages are captured by the starwheel pocket and indexed onto the scale for weighing. For the greatest accuracy, the starwheel should move backwards slightly during weighing so that it is not in contact with the package.

Most checkweighers will record the weights of every package. This allows for Statistical Process Control (SPC) techniques to be used to track trends for better evaluation of the packaging process. The checkweigher display panel can usually show the weight of each package as it is weighed as well as average weight and standard deviation. Other information including throughput, trends, number of rejected packages and reason for rejection may be shown. Many checkweighers can display a graph of weights for quick visual reference.

The systems discussed above are gross checkweighers. They weigh the filled package and accept or reject based on total weight. They assume that the weight of the package components such as bottle and cap will be consistent enough not to unduly skew the indicated weight. In most cases this is acceptable but in some cases a higher degree of precision is required. Net checkweighing represents one solution.

Net checkweighing uses two checkweighers. The first or empty, checkweigher weighs and records the empty package prior to entering the filler. This is called the tare weight. The package is filled normally and, as it exits the filler, is weighed again with a second, full, checkweigher. A shift register assures that the full checkweigher can match its weight to the corresponding empty weight. If a package is removed between the two checkweighers this will cause them to be out of synchronization. The filled package is weighed and the tare weight subtracted. The result is the net weight of the tablets contained in the bottle. Net checkweighing eliminates the effects of any variation in bottle weight which might be incorrectly interpreted as under- or overfills.

A variation on the 2 scale system which also provides the net weight of product, is to incorporate the scale into the filling machine. In one design, the bottle enters the filling machine and is captured in the pocket of an indexing starwheel. The starwheel moves the bottle to the filling position which has a scale mounted underneath. Prior to filling, the empty bottle is weighed. Filling then proceeds normally. On completion of the cycle, the bottle is weighed a second time. Subtracting the tare from the gross weight, gives the net weight of the product.

In some cases variable weights are normal but it is desirable to know what they are. The packaging process for a product such as chicken parts can result in variable final weights. In this case the checkweigher can be used be used to determine the weight and send the information to a printer. The printer then prints the weight of chicken contained in the box either directly on the box or on a label which is placed on the box.

In all weighing processes, there is a tradeoff between speed and precision. The more time that can be allowed for weighing, the more precise will be the indicated result. This is due to the reaction time of the scale as well as dynamics associated with package movement. In some cases, if high precision is desired along with high speed, it may be necessary to use several checkweighers in parallel.

Contamination

Detection of contamination is particularly critical in food and pharmaceutical products but can be important in other products as well. One potential contaminant is metal which may fall into the product. There can be several sources for this. One is machine components such as nuts or bolts which might fall into the package or even be entrained in the upstream bulk product. Another source of metallic contamination can occur when internal machine parts wear or fail releasing chips into the product. Whatever the source, they must be detected and the contaminated product rejected from the process.

Metal detectors are relatively simple electronic devices with no moving parts. They consist of a aperture with a transmitter coil and two receiver coils. The transmitter coil generates an electrical field which causes a metal particle to respond, changing the characteristics of the field. The two receivers detect the disturbance to the field and react, causing the system controller to generate a reject signal. Metal detectors can be used in either vertical or horizontal applications. Vertical applications typically allow the product to fall through the aperture by gravity. Horizontal applications normally convey the product through the aperture with a belt of chain conveyor. Conveyor design is important in this configuration to avoid interference. Plastic or non-metallic frame conveyors should used. The belt should be plastic, rubber or synthetic with no metal reinforcing. If chain type conveyor is used, the links must be plastic and the hinge pins, normally of metal, must be non-metallic.

Fig 3-7 Metal detector

X-Ray inspection

Some products are subject to non-metallic contamination. Food products may be contaminated by bone chips. Products in glass containers may be contaminated by glass fragments. If the container or product are opaque, this contamination cannot be detected by either vision or metal detection systems. X-ray inspection may represent the only viable alternative. An x-ray inspection system consists of an x-ray emitter and a receiver. As the package passes in front of the emitter X-rays are passed through it striking the receptor. Some of these X-rays will be attenuated by the package and the product, causing the receptor to register an image of the package. As in a vision system, the image is compared to a template of a known good product. If the product contains chips of a different density than the product, such as bone or glass, these will cause greater attenuation of the X-ray, and will show up in the receptor image as darker spots. Software, analogous to that describes above in vision systems, will detect and evaluate the spots. Those that are outside the normal range will cause the package to be rejected.

Particulate vision inspection

Contamination of injectable pharmaceutical products by small particles must be avoided at all costs. Some plants will use batteries of human inspectors to visually inspect each vial. This inspection can be automated with machine vision. One interesting point about these systems is that they agitate the product to put the particles into motion. This is usually done by spinning the vial momentarily. This has two effects. First particles will tend to settle and it will be hard to see them on the bottom of the vial. Spinning them gets them back into the main portion of the liquid where they may be more easily found. Second, it is easier for the camera system to detect a moving particle than a stationary one. Both of these factors allow increased speed and reliability of detection of very small particles.

An issue of agitation is that it may cause small bubbles to form in the product. These bubbles are harmless but to the camera can look like particles. Bubbles will rise in the liquid while particles will generally sink. The vision system determines the direction of motion and uses this principle to distinguish between bubble and particulate, accepting the first, rejecting the latter.

Package integrity

A primary purpose of the package is to isolate the product from the environment. This will include keeping the environment out of the package as well as keeping the product in. Package integrity testing is often done offline using destructive tests but there are also options for performing many tests inline in a non-destructive manner.

Cap torque

There are several techniques used in screw capping to determine the torque applied to screw caps on bottles and jars and these will be discussed in Chapter 8. These will determine the torque applied but not the torque required to remove the cap. There is a relation between application and removal torque but it is not direct. A cap applied with 5 inch-pounds of torque may require 10 inch-pounds to remove or vice-versa. Normally the relation between on and off torque should be consistent but may not always be. A cap applied with the proper torque may still be too loose or too tight. As cap removal torque is the key parameter, it must be verified. This is usually done by periodically removing samples from the packaging line, placing them in a benchtop torque tester and removing the cap by hand. The torque tester will show the maximum amount of force applied to remove the cap. These systems work well but have some disadvantages. First, they are highly dependent on operator technique. Identical removal torques may indicate differently depending upon how the cap is gripped and whether it is twisted slowly or rapidly. With food or pharmaceutical products, since the operator is handling the cap, the product may be considered to be compromised and need to be discarded. Various manual and automated systems are commercially available for offline testing. There are also systems available for automated inline testing. These remove a container from the line and gradually apply removal torque until the cap just breaks free. At this point the system stops removing the cap, records the torque required and retightens the cap. As the cap is never really loosened, in many cases this may be considered a non-destructive test and the container is replaced in the line.

Fig 3-8 Torque tester manual & auto

SEAL INTEGRITY

Vacuum and pressure packed products are similar in that the internal pressure of the container is different from the external, atmospheric, pressure. As vacuum is simply a negative pressure, this section will use the word "pressure" to apply to internal package pressure and vacuum. Failures in pressurization, leaky closures, caps or seals or pinholes in the packaging can all affect the internal pressure. Fortunately there are a number of ways to verify correct internal pressure.

Pillow bags, such as used with potato chips and snack foods, often contain excess air to produce a pillow effect to protect the product. Visual inspection may not detect a bag with a leaky seal. One way to verify seal integrity is to pass the bag between two conveyor belts. One belt is fixed, the other is movable and pushed in against spring pressure. As a bag enters the belts, it will push them apart. A detector will verify this movement, accepting the bag. When a bag with a leaky seal enters the belts, it will fail to push them apart. This is detected and the bag rejected.

Fig 3-9 Bag squeezer here

Carbonated beverages, aerosols and some other products are packaged in pressurized cans. If these cans are not pressurized before closing or pressure is lost due to a faulty closure, the consumer will receive a defective product. Internal pressure in a closed can may be detected by squeezing the can in a sidebelt conveyor system. This system consists of 2 powered side belts. The can enters the system and is captured by the belts. If the can is not pressurized, the side pressure from the belts will cause the can to deform slightly. An unpressurized can will deform more than a pressurized one. Strain gauges on the belts measure the amount of deformation. When it exceeds the limits, the can is rejected.

Cans and some vacuum packed bottles can be inspected by measuring deformation of the top. The vacuum in these containers will deform the lid, pulling it in slightly. This deformation can be measured and compared to a known good container. Containers without the proper amount of deformation will be rejected from the line.

Bottle integrity whether empty or full, open or closed may be inspected by the use of internal pressure. The bottle is brought under a testing station which lowers a sealing plate onto the bottle neck. An air nozzle though the sealing plate pressurizes the bottle to a known pressure. This pressure is then monitored for degradation. If the bottle has no pinholes or other leaks, it will maintain the pressure. Leaks will cause the pressure to call and the bottle will be rejected. The integrity of caps and other closures can also be tested by similar methods. A bell is placed over the neck of the bottle and seals against the shoulder of the bottle below the cap. Alternately, a larger bell may be used which completely encloses the bottle, sealing against the plate on which the bottle rests. The bell is either pressurized or evacuated to a known pressure or vacuum and checked for degradation. If the pressure or vacuum holds constant, the closure seal is good and the bottle is accepted. If the pressure or vacuum degrades, the bottle is rejected.

Rejection mechanisms

Detecting a defective product is only the first part of the process. It must also be removed from the line. In the simplest instance a defective package may stop the line and alert an operator to remove the package manually. This is generally not practical for reasons of line speed and human reliability. In practice any automated inspection system should include automated rejection. The rejection system should remove the product but not damage it while doing so. For simplicity the rejection station should be located immediately after the inspection station so that there are no packages in between. If the stations are separated, additional system logic called a shift register will be required to count the good product prior to the bad and assure that the rejection mechanism rejects the correct product. This not only complicates the system design, it also raises the possibility that someone may manually place or remove a package between inspection and rejection. If this happens, it throws off the count and results in the wrong package being rejected. If multiple products between inspection and rejection cannot be avoided, an acrylic plastic shroud can be placed over the conveyor to prevent addition or removal of bottles in this area.

Ideally, rejects should be rare and random. For these rare cases rejection of defective product is appropriate. Occasionally there will be a system failure which allows a number of defective products through. There should normally be an override and/or alarm mechanism associated with the rejection. If a labeler malfunctions and allows a number of bottles through without labels, it is not desirable to continue rejecting them. The inspection/rejection system should have an override to stop the labeler if more than 3 (or some other pre-set quantity) bottles in a row are rejected for lack of labels. This will allow the problem to be corrected before a large quantity is rejected.

In some cases, it may be desirable to reject multiple packages. There may be concern on a medium or high speed line that an error between the detection and rejection stations causes the wrong package to be removed from the line. In this case, the norm may be removal of the package before and after the defective package as well as the defective package itself.

There are several commonly used types of rejection mechanism:

Blow-off systems use a blast of compressed air from a nozzle to blow the package off of the conveyor. Their mechanical simplicity and very quick response make them suitable for high as well as medium and low speed applications. They work well with lighter weight packages but if the package is too heavy, the force of the air may not be sufficient to reject it. Blow-off systems are limited in the distance they can move the product as the force quickly diminishes the further it gets from the nozzle. Blow-off systems may also not offer precise enough control, knocking bottles over or failing to blow them to the desired location.

Pusher reject systems mount to the side of the conveyor and consist of an air cylinder with a pusher block or rail on its rod. On a signal from the inspection station a solenoid valve opens, extending the air cylinder and pushing the product to the side. This system can be rather abrupt and may not be suitable for fragile packages as it can cause damage or breakage. Another disadvantage is that its timing may be more critical than other styles to assure that it does not extend too early or for too long. If it extends too early, the package will hit the extended rod, causing a jam. If it stays extended too long, the subsequent package will hit the rod causing a jam.

Fig 3-10 Reject mechanisms

Diverter rejects use a hinged guide to gently divert the product off the conveyor. In normal operation the guide allows the package to pass through and continue to the next operation. When a reject signal is received, an air cylinder, solenoid or motor swings the guide sideways. The product is moved out of its normal path and into a diversion path. This may be a tray or turntable mounted on the side of the conveyor or it may be an additional lane on the conveyor. The gentle nature of the diverter makes it less likely to damage or overturn the package.

Pop-up rejection mechanisms may be used on roller conveyors. A pair of narrow belt conveyors is mounted between the rollers. These are normally positioned below the level of the rollers permitting the package to pass over them. On receipt of a reject signal, the conveyors lift up above the rollers raising the package and carrying it to the side. Depending on the speed and the nature of the package, this may be done while the package is in motion or a stop mechanism may detain the package on the conveyor while the pop-up mechanism activates.

Packages may also be rejected vertically. This method may be more useful in the case of non-rigid product such as bags or pouches. One style hinges the end section of the conveyor. In normal operation, the conveyor is horizontal and the discharge section is aligned with the infeed of the downstream conveyor allowing the package to transfer between the two. When inspection detects a defective package, an air cylinder or other mechanism pulls the conveyor section down, directing the package onto a reject conveyor or into a reject area below. A variation on this style uses a telescoping end section on the rejection conveyor. On a signal from the inspection station, the section telescopes in, opening a gap between the conveyor discharge and the infeed of the downstream conveyor. The package runs off the end of the upstream conveyor and falls to a bin or other collection station.

Successful package rejection depends on the package rejected being the same one that had been detected by the inspection system. On higher speed lines synchronization of inspection, package movement and rejection can be touchy. Some systems avoid problems by rejecting one or more packages before and after the the defective package. This can be wasteful even if the packages can be manually inspected and placed back into the production stream. It is better to have the package under positive control during the inspection/rejection process. There are a number of ways that this can be done. One way is to perform inspections while the package is still in the packaging machine such as a cartoner, filler or labeler. Another is to use specialized handling devices such as timing screws or starwheels to carry the package through inspection and rejection. One technique that works well with bottles and some other packages is to use a starwheel with suction cups in the pockets. The package is carried past the inspection station(s) in the starwheel. After inspection, the suction cups release the package at either a rejection or acceptance station.