The History and Future of Measurement Technology in Sumitomo Electric

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This paper looks back on the history of the development of measurement technology that has contributed to the improvement of Sumitomo Electric's quality assurance levels for 50 years. It also includes technical explanations of the measurement and inspection equipment that the company has recently developed as well as crack detection technology on which the company has particularly focused its efforts. Finally, this paper describes the future of image processing technology and other measurement and inspection technologies that Sumitomo Electric is currently working on for further improvement in its quality assurance levels.

Keywords: measurement, inspection, image processing, sensor, camera

1. Introduction

High quality manufacturing at a defect rate of some parts per million is required in all industries, especially in the automotive industry, while the miniaturization of products is advanced. How we assure product quality has become a big issue, and accordingly sophisticated measurement and inspection technology is increasingly required. In Sumitomo Electric Industries, Ltd., we initiated the development of technology for the measurement and inspection of our own products. We also established new facilities, applying the technology in the 1960s. Since then the technology has greatly contributed to the improvement of the quality assurance level and product quality itself, supporting the base of our manufacturing.

In this paper, I review the history, along with some development examples, of the measurement and inspection technology that has served for quality improvement in the Sumitomo Electric Group. This paper also describes the latest technologies exemplified by image processing technology.

2. The History of Measurement Technology Development

The history of measurement technology development in our company dates back to the 1960s, when we started developing the eddy current test technology to confirm the quality of electric wires, our core products at that time. The eddy current test technology used annular coils for the in-line detection of scratches formed on the wire in the rolling and drawing processes. Essentially the detector used the disorder of the eddy current to find scratches. To eliminate the influence of wire vibration, we connected the detecting coil that was originally placed inside the excitation coil differentially in a longitudinal direction. As a result, we succeeded in making the detectors robust to disturbance, and the detectors came into wide use in our company to assure product quality.

In the 1970s, we promoted the development of magnetic test technology and its practical use to raise the quality assurance level of our wire products. For example, we devised an effective method to distinguish scratches from magnetic foreign bodies (ex. iron dust) in non-magnetic wire. In this method, the wire was passed through between the excitation coil and the detecting coil, as shown in **Fig. 1**.

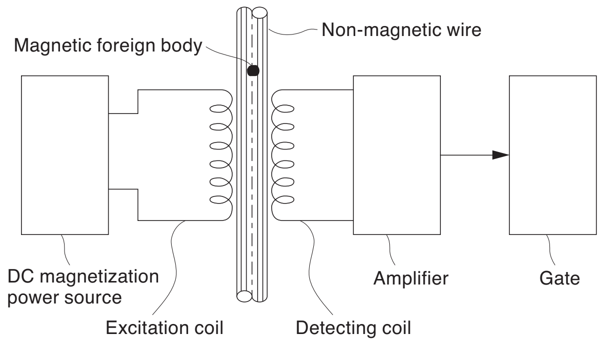

Fig. 1. Detecting system of magnetic foreign bodies on non-magnetic wire

In the 1980s, we advanced this detecting method by adopting optical technology. As illustrated in **Fig. 2**, parallel light was emitted to the wire and its shadow was projected on the slit photoelectric cell. Two sets of this unit were placed in a longitudinal direction of the wire, so that the difference in the quantity of received lights could be detected. This technique greatly improved the quality of our wire products.

In the late 1980s, in response to the global demand for inspection technology for product appearance, we shifted our development focus to the measurement and inspection technology using camera image processing. We also initiated the development of the measurement and inspection technology that used ultrasonic waves and laser beams in order to cover a wider variety of products manufactured by the Sumitomo Electric Group. These technologies are detailed in the next chapter.

The above technological development is based on the core policy “We shall develop the technologies if they have not yet been developed.” Following this policy, we have continuously invented technologies that did not exist in the world and applied them to quality assurance and product quality improvement. We have thus enhanced the originality of our products and secured a dominant position in the global market.

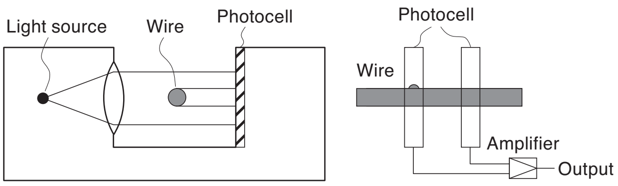

Fig. 2. Detecting system for foreign bodies on wires with photocells

3. Development Examples

There are two applications of our measurement technology. One is the automation of product inspection to raise the quality assurance level and to reduce labor costs; and another is the automation of machining and assembly processes to improve product quality. In this chapter, I introduce the two application examples of the technology.

3-1 Automation of Inspection

As shown in **Fig. 3**, our products are classified into three production types: Assembly type (A-type) products; Bulk type (B-type) products consisting of a number of pieces; and Cable type (C-type) products. Required inspection items are different according to the production type as shown in **Table 1**. In this chapter, I introduce some inspection cases for each production type. The detection of cracks on the surface of B-type products is described separately in Chapter 4 as the technology has a long history and many topics to be discussed.

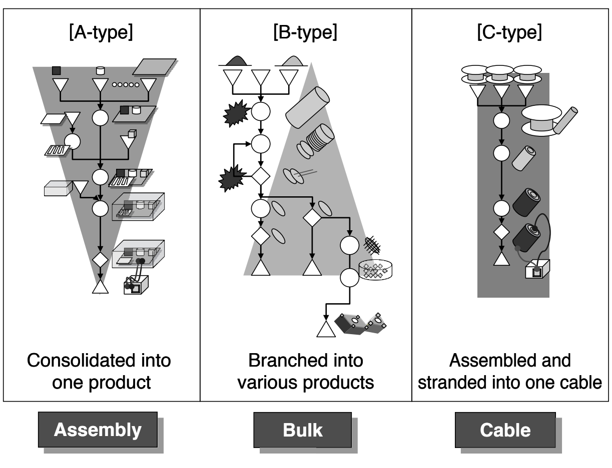

Fig. 3. Our three production types

Table 1. Inspection items in each production type

Production type	Inspection item	Technological feature
A-type products	Missing parts Misassembled parts Misplaced assembly parts Stamp errors	Applicable to a wide range of products Shortened time for tool change
B-type products	Size Appearance (Scratch, Crack etc.) Inner defects Mixed foreign objects Stamp errors	Applicable to a wide range of products Quantification of quality Automatic supply
C-type products	Outer diameter Coating thickness and Unevenness Scratch and Foreign body adhesion Length	Applicable to moving objects Inspection of the entire circumference and length of the product

(1) Inspection equipment for A-type products in the assembly process

In order to improve the level of quality assurance, we developed equipment which detects missing and misassembled parts by processing images sent from the camera installed in the robot, as shown in **Fig. 4**. The image processing algorithm uses pattern matching, in which a correct product image is registered in advance to find the correct pattern in the image sent from the camera. This is a popular algorithm that many image processors in the market adopt, and you may be familiar with it. Technical points in this case are as follows:

- Diffused lighting for inspection from every direction
- Color extraction for reliable inspection

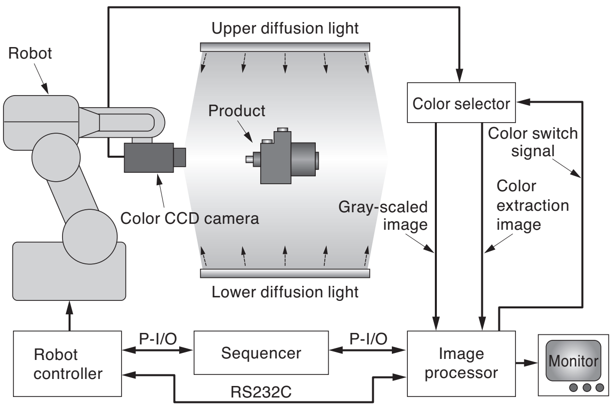

Fig. 4. Assembly inspection equipment

(2) Inspection equipment for internal defects of B-type products

To detect defects which cannot be seen with the eye, we developed equipment which can detect internal defects, such as cracks, in metallic products using ultrasonic waves, as shown in **Fig. 5**. As we need to cover the entire length of the product, the ultrasonic sensor moves along the axial direction of the cylindrical product placed in water. The product is rotated so that the ultrasonic wave can be applied to the product spirally. The other technical points of this equipment are as follows:

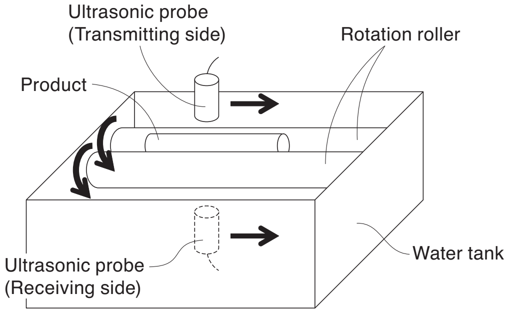

Fig. 5. Inspection equipment for internal defects

- Optimization of frequency according to the product material and size
- Improved detection sensitivity by the focused ultrasonic wave
- Prevention of bubbles in the water which obstruct ultrasonic waves

(3) Measuring equipment for the coating thickness of C-type products

In order to assure and monitor the quality of wires, we developed equipment which can measure the coating thickness of (stranded) wires using a laser outer-diameter measurer and an eddy current displacement meter, as shown in **Fig. 6**. As we need to measure the coating thickness over the entire circumference and length of the wire, we arranged the measurement units in four directions around it. Moreover, we coped with the change of the pass line to be able to drive the whole measurement parts. The other technical points of this equipment are as follows:

- Temperature correction of the eddy current displacement meter.
- Algorithm to eliminate the influence of ruggedness on stranded wire

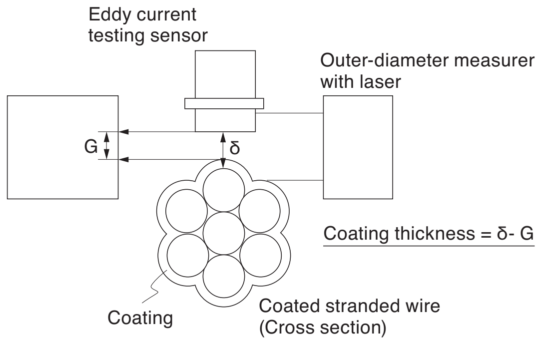

Fig. 6. Coating thickness measuring equipment

(4) Visual inspecting equipment for C-type products

In order to assure wire quality and reduce labor costs required for inspection, we developed equipment which detects holes and foreign bodies on the surface of (stranded) wire, as shown in **Fig. 7**. As we need to detect them over the entire circumference and length of the wire, we arranged the detecting units in four directions around it. Moreover, the processing speed was increased to ensure real time detection for all defects according to the linear speed. The other technical points of this equipment are as follows:

- Uniform lighting to the entire circumference of the stranded wire
- Image processing unaffected by the brightness of the wire surface

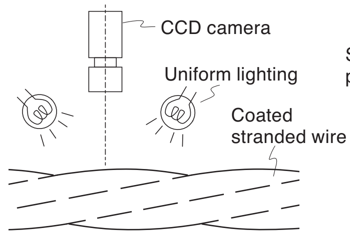

Fig. 7. Visual inspecting equipment for C-type products

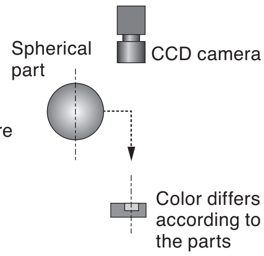

Fig. 8. Alignment and assembly equipment

3-2 Automation of machining and assembly processes

I introduce two types of equipment as the application examples of measurement technology to machining and assembly processes.

(1) Supply machine in constant direction and position

In order to improve machining accuracy, we developed equipment which can supply materials accurately to the right position of a processing machine. We use image processing technology to recognize fed materials (about 30 mm square) and measure their direction and position, and the data is sent to the robot. Thus, we succeeded in supplying our products at an accuracy rate of ±0.1 mm or less and halved defective products. We used the geometry pattern matching technique that was evolved from the above-mentioned pattern matching technique. Moreover, using the original lighting system, we succeeded in distinguishing fed materials from their background, which was difficult with conventional techniques. The other points of this technology are as follows:

- Measuring slips in material pieces while holding them (for high accuracy)
- Automatic registration of correct patterns (for a wide variety)

(2) Alignment and assembly equipment

In order to improve the yield and assembly accuracy, we developed equipment which can locate two parts, adjust their centers using image processing technology, and integrate them, as shown in **Fig. 8**. We identified the centers of spherical parts by coaxial vertical lighting. For other parts, we used a multi-colored LED because the color was different depending on the parts. Thus, we improved assembly accuracy five times and eliminated defectives in the assembly process. The other points of this equipment are as follows:

- Image recognition of spherical parts in the adsorbed state
- Error handling technique using image processing technology to prevent integration of parts at wrong positions.

4. Detection Technologies for Cracks on the Surface

We have concentrated our efforts on the development of image processing and other technology for crack detection. In this chapter, I describe these technologies in detail.

Our first approach goes back to 1979. Cracks were found on certain products, and we started visual examinations. However, there was a problem that it cost a lot as it needed many people for the inspection of all products. To address this problem, we tried to introduce an automatic inspection machine. Because there were many types of product with different shapes and ruggedness on the surface, it was necessary to identify each shape and distinguish the ruggedness from cracks (about 0.1 mm square) of the product. We studied and examined technologies that existed in the world, but there was no technology that could meet our need. Believing that automatic detecting technology was indispensable, we started the development of this technology.

Until today, we have developed various methods, including image processing, with advanced sensors. In the following sections, I explain each method we have developed.

4-1 Optical reflection method

We first thought of recognizing cracks as an image by using light because, in visual inspections, cracks were detected by using reflection by light. Back in 1979, Matsushita Electric Industrial, Co., Ltd. (present Panasonic Corp.) was the only manufacturer of a monochrome CCD camera, and image processing technology was not as common as today and too expensive to be feasible. Therefore, we invented a method that detects cracks based on the quantity of reflection using light horizontally emitted from the differential optical sensor positioned above the product, as shown in **Fig. 9**. By this method, we detected cracks of about 0.1 mm in diameter on the straight side. While it was easy to detect cracks that existed on the vertical surface to the light in principle, it was difficult on the non-vertical surface. Therefore, it was difficult to light the target products correctly from the vertical direction if the products had various sizes of round corners, and cracks in corners were often overlooked. Although this technology couldn't lead us to the automatic inspection of all products, it was in the forefront of the application of an optical sensor.

4-2 Shadow detection method

In the 1980s, image processing technology using CCD cameras as optical sensors was applied to the factory automation field. In our company, we had also developed automatic inspection technology using CCD cameras, lighting equipment and image processors. However, it was too costly to build imaging algorithms which matched specific matters because the image processor relied on a special device to shorten the processing time. But as the performance of personal computers remarkably improved in the 1990s, image processing technology was widely used with personal computers. For this reason, we started the development of the crack detection technology that uses shadows made by lighting in order to develop the best imaging algorithm for detecting cracks.

In this development, we set up three cameras in the above, straight and corner sides so that cracks were detected as shadows in the bright view when vertical diffusion light was applied. Moreover, we developed the mask pattern method (See **Fig. 10**.) and applied it to the detection of cracks in corners. As a result of repeated evaluations using prototype equipment, two problems were revealed. One was the difficulty of detecting all "various form" cracks by relying only on the shadows made by lighting. Another was false detection of unevenness on the surface, dirt and foreign bodies. But this technology was innovative in the point of the construction of an original image processing algorithm and led us to future development.

4-3 Laser displacement sensor method

To solve problems associated with the method described in the previous clause, we changed our conception from indirect detection of cracks using shadows by lighting to direct detection of cracks by regarding them as microscopic order ruggedness, and developed detection technology using a laser displacement sensor which can detect ruggedness in the micron order.

This is the method (See **Fig.11**) of detecting ruggedness caused by cracks through recognizing the contour shape of the product by image processing and accurate tracing of the product shape a little inside from the outline with the displacement sensor. This method had an advantage that the detection result was unaffected by optical noise, such as irregular colors and dirt, on the surface. Needless to say, this method alone did not solve all problems; we applied differential processing to the acquired data, as shown in **Fig. 12**, to eliminate the influence of undulation on the product surface.

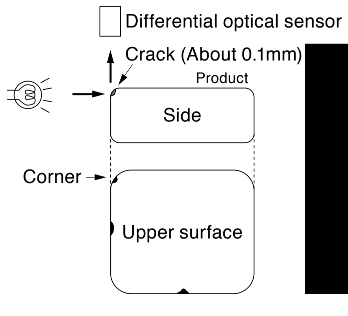

Fig. 9. Optical reflection method

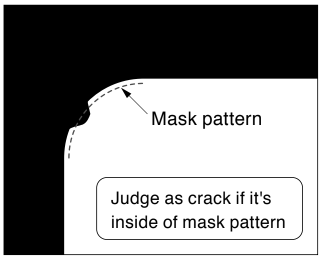

Fig. 10. Mask pattern method

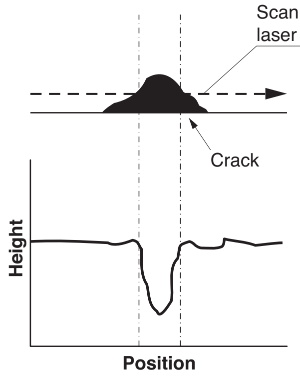

Fig. 11. Laser displacement sensor method

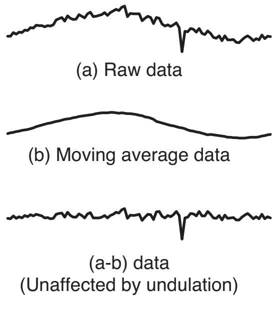

Fig. 12. Differential processing

This method had a big advantage of distinguishing cracks (concave) from adhesion things (convex) so as to avoid false detection of adhesion dust, which was inevitable with the above-mentioned method using lighting, because convex parts were indicated as waves in the minus direction and concave parts were indicated as waves in the plus direction. But there was a problem that this method detected slight displacement (See **Fig. 13**) caused by the gap of tracing positions because the slope of the tracing surface was large when R-chamfering was large and this method was limited to parts with small R chamfering.

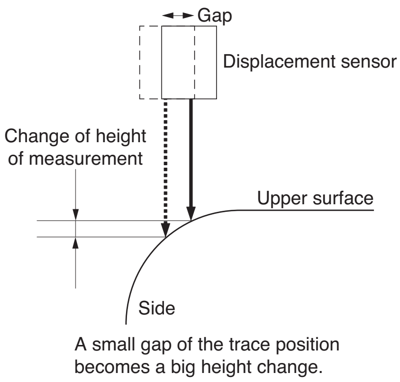

Fig. 13. Problem with laser displacement method

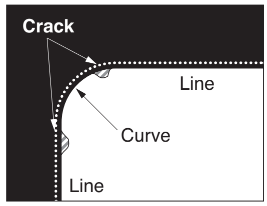

Fig. 14. Detection method

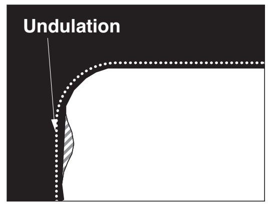

Fig. 15. Incorrect detection

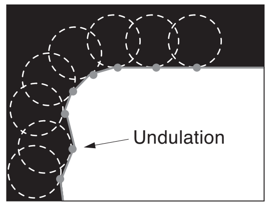

Fig. 16. Rolling circle method

4-4 Orthorhombic penetration lighting method

There was a manufacturer that produced an inspection machine specializing in crack detection in Germany at that time. This machine took images of the silhouette of ridge line parts with the camera by using penetration light and detected cracks by image processing. This method had the feature that it was unaffected by optical noise, such as irregular colors and dirt, on the surface, as the laser displacement sensor method was. At that time, the maximum permissive size of cracks was several tens of microns, and how to distinguish slight ruggedness from undulation on the surface was a difficult problem. Therefore, we conceived two ideas to detect minute cracks and solved this problem. One was the rolling circle method; and another is the self-comparison method.

(1) Rolling circle method

If the ridge line of the product can be approximated by lines and curves, cracks can be detected by making a comparison with the outline of a non-defective product that has no cracks shown in the lines and the curves (See **Fig. 14**). However, because actual products are subject to undulation and processing variation, this method detects non-defective products by making a comparison with approximated lines or curves, as shown in **Fig. 15**. To approximate the arbitrary curve, we invented the rolling circle method.

This method approximates a curve as a set of short straight lines which connect the contact points of a circle roll and the arbitrary curve. As this method can restore the former curve even if there is undulation as shown in **Fig. 16** on the surface, it can prevent false detection. By adopting this method, it became possible to detect cracks generated on the ridge line of a complex shaped product which could not be approximated with equations.

(2) Self-comparison method

We could detect cracks occurred on the ridge line, such as the arbitrary curve, by using the rolling circle method. When we applied the method to the product with a corner part of the shape indicated in **Fig. 17**, detection failed. There was a method of detecting cracks by calculating the difference between the image of a non-defective product and cracks, but when the shape of each product was different, detection failed. Therefore, we decided to calculate the difference of the image of each corner of the product (See **Fig. 18**) and to detect cracks based on the fact that there were two or more corner parts in one product, and the product shape was constant because of its production process. As a result, it became possible to inspect products with specially-shaped corners.

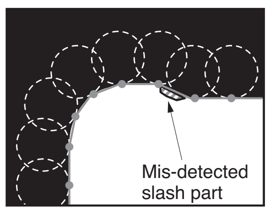

Fig. 17. False detection at corner

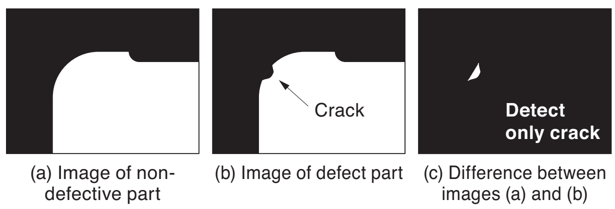

Fig. 18. Self-comparison method

Both the rolling circle method and self-comparison have wide technical application ranges. They have been applied to cracks and foreign body inspection for B-type and many other products manufactured by the Sumitomo Electric Group, showing good results.

4-5 3D measurement by image processing method

In the laser displacement sensor method, there was a problem of the trace position gap because it was 2D measurement by the displacement sensor in one dimension to measure the height. To solve this problem, we started the development of 3D measurement technology, which was on the increase in the factory automation field in the 2000s.

Although there were various methods in 3D measurement, we adopted the all-focusing method. This method captured a lot of images while changing the focus position of the camera, as shown in **Fig. 19**, to measure the height of the position by finding the focused image in each pixel among the captured images. For the images obtained this way showed the height of each pixel as intensity (3D image), we detected cracks by calculating the height profile of every line in the image and comparing the result with the profile of a non-defective product obtained beforehand, as shown in **Fig. 20**.

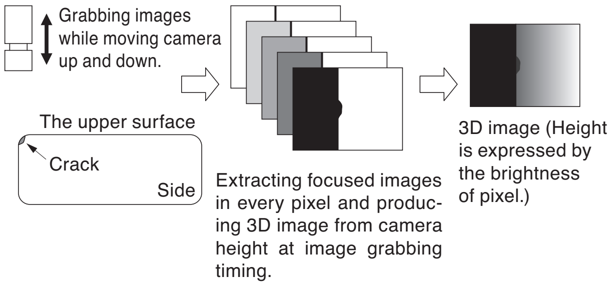

Fig. 19. 3D measurement by all-focusing image processing method

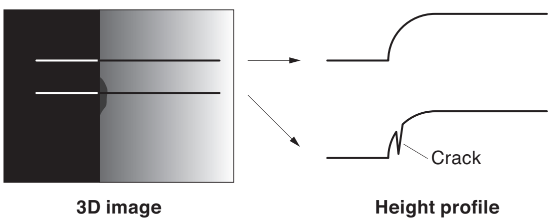

Fig. 20. Detecting process for each line of image

As a result of evaluating the crack detection ability of the equipment that was produced using this method, it turned out that the equipment could detect cracks of the initially targeted size. But cracks that can be detected at present are limited to ones generated on a monotonous surface. Therefore, we are proactively working on the development of a new technology that can be applied to detection on the arbitrary shaped structure, aiming to expand the application area of this technology.

5. Conclusion

In this paper, I introduced the measurement technology that we have developed. To improve the quality assurance level of products manufactured by the Sumitomo Electric Group, our development efforts will need to be concentrated on the following fields:

(1) Visualization through the development of in-line monitoring technology

Thus far, we have focused on technology development for the automation of inspection processes. Currently, there is also a growing need for the use of this technology in monitoring production processes to promote product quality improvement. However, in many cases, monitoring is not conducted due mainly to the fact that the objects are processed in a closed space and at high temperature, preventing cameras from entering the site; and the processing speed is too fast to be followed by cameras.

To overcome these problems, we must develop technology that enables the visualization of production process even in the above-mentioned production environments.

(2) Quick response through the development of analog processing technology

Some C-type products are processed at a high line speed exceeding 1000 m per minute. Continuous observation of the entire length of these products is impossible with the human eye or normal cameras. Image processing and other complex digital processing technologies cannot deal with this high speed, and therefore simplified analog processing technologies are expected to offer solutions.

(3) Direct shape measurement by 3D measurement technology

To assure the quality of B-type products which have advanced with high accuracy and sophistication, it is necessary to acquire the precise size to measure its shape directly in 3D, not to measure indirectly similar to silhouette measurement. Therefore, it is necessary to develop 3D measurement technology, such as crack detection described in Chapter 4, and to make it practical.

We are determined to advance technical development, including the above-mentioned technology, and raise the quality assurance level in the Sumitomo Electric Group.

Contributor

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