Diagnostic Solution for Machinery and Equipment That Uses AI for Real-Time Detection of Defective Products

YUO, Yukiteru* SHIMAMURA, Akio* MUNAKATA, Masaaki*

ABSTRACT

The recent increasing demand for quality from end users has necessitated improving the technology for detecting defective products in machinery and equipment. Fuji Electric has developed a diagnostic solution that can be incorporated into motion systems to detect defective products during machining operations. The diagnostic functionality is provided as a module of the "MICREX-SX" and can detect defective products in real time by interfacing with the control application of the machinery and equipment. In addition, it can detect defective products with high accuracy using the load torque monitoring function of the servo amplifier of the Fuji Electric's "ALPHA7" servo system without adding external sensors.

1. Introduction

Motion systems are used in a variety of machinery and equipment, including metal processing machines, packaging machines, and semiconductor manufacturing equipment.

Conventionally, motion systems focused mainly on improving productivity through increased speeds, but in recent years, they have also been required to improve the quality of manufactured products. Furthermore, they are also being required to detect defective products in real time while machinery is in operation, and prevent defective products from affecting later-stage manufacturing processes.

In order to meet these requirements, Fuji Electric is providing a diagnostic solution for machinery and equipment by applying the Internet of Things (IoT) and artificial intelligence (AI) as core technologies of digital transformation (DX). In this paper, we describe this diagnostic solution.

2. Challenges in Detecting Defective Products in Machinery and Equipment

For end users, the outflow of defective products not only results in huge costs due to product recalls, but also may lead to a decrease in sales for the company as a whole due to the deterioration of the corporate image. As a result, end users are increasingly asking equipment manufacturers to incorporate systems into their equipment to detect product quality in real time without compromising productivity and to prevent the outflow of defective products.

Examples of defects that need to be detected in real time are crimping defects in the packaging film of food packaging machines and crimping defects in the wiring of harness processing machines. While machinery and equipment manufacturers are trying to improve the accuracy of defect detection by installing a variety of sensors, the rising cost of doing so is putting pressure on profits. This has created the challenge of reducing costs, while maintaining and improving the accuracy of defect detection.

In order to respond to this challenge, Fuji Electric has developed a diagnostic solution that equips its controllers with an AI-based "diagnostic module" and corresponding application libraries.

3. Detection of Abnormalities Using the Diagnostic Module

Figure 1 shows the appearance of our MICREX-SX. The diagnostic module is a functional module of MICREX-SX Series products. It performs diagnostics by applying multivariate statistical process control (MSPC) as an analytics and AI technology based on

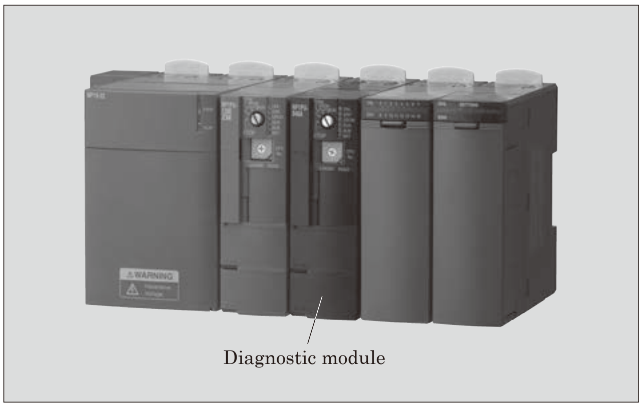

Fig.1 "MICREX-SX"

* Power Electronics Industry Business Group, Fuji Electric Co., Ltd.

data from input modules, response data from servo amplifiers, and calculation data from control applications.

3.1 MSPC

MSPC is a diagnostic method in which a range of typical operating conditions (diagnostic model) are set in a space that represents the correlation between multivariate process data (parameters). An abnormal condition is defined when a set of observed parameters deviates from the range of the diagnostic model. As shown in Fig. 2, the deviation from the correlation between the parameters of the diagnostic model is defined as the Q statistic, and the deviation from the mean value is defined as the T^2 statistic. Detection of abnormalities is based on these two types of evaluation values. This method makes it possible to detect abnormalities that would otherwise be missed by diagnosis methods that use the upper and lower limits of individual parameters.

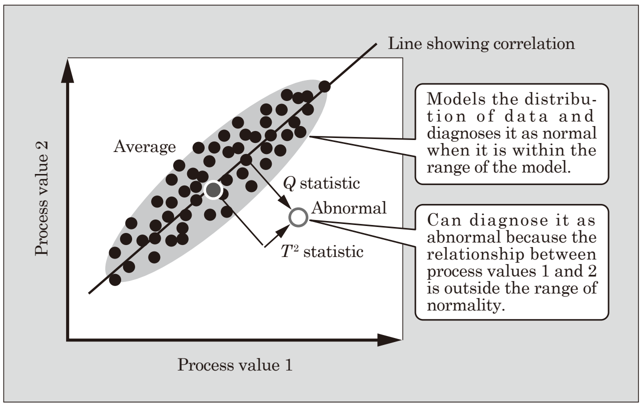

Fig.2 MSPC-based diagnosis

3.2 Diagnostic module

The diagnostic module uses the same controller platform as the MICREX-SX CPU module. Fuji Electric provides users with system function blocks (SFBs) that operate as control functions on the CPU module and as diagnostic functions on the diagnostic module. This allows users to create applications by combining the SFBs.

The CPU module controls the system by utilizing the user-created control applications to perform control operations. On the other hand, the diagnostic module performs diagnosis by utilizing the user-created diagnostic applications to perform diagnosis and model creation operations (see Fig. 3). As input parameters for diagnosis and model creation, users can use inputs from I/O modules connected to the SX bus and actual load torque and feedback speed values for servo amplifier command values. Diagnostic functions are implemented in the diagnostic module using the 10 SFBs shown in Table 1. Users can combine these SFBs to build diagnostic applications.

A diagnostic application running on the diagnostic module can access both the standard memory of the diagnostic module and CPU module on the same base board*1 in order to use the values in calculations. The sequence control application running on the CPU module can also access the standard memory in the diagnostic module and refer to the diagnostic results in real time. The sequence control application can refer to normal and abnormal diagnostic results and execute processes such as rejecting defective products in real time.

The diagnostic results can also be monitored using

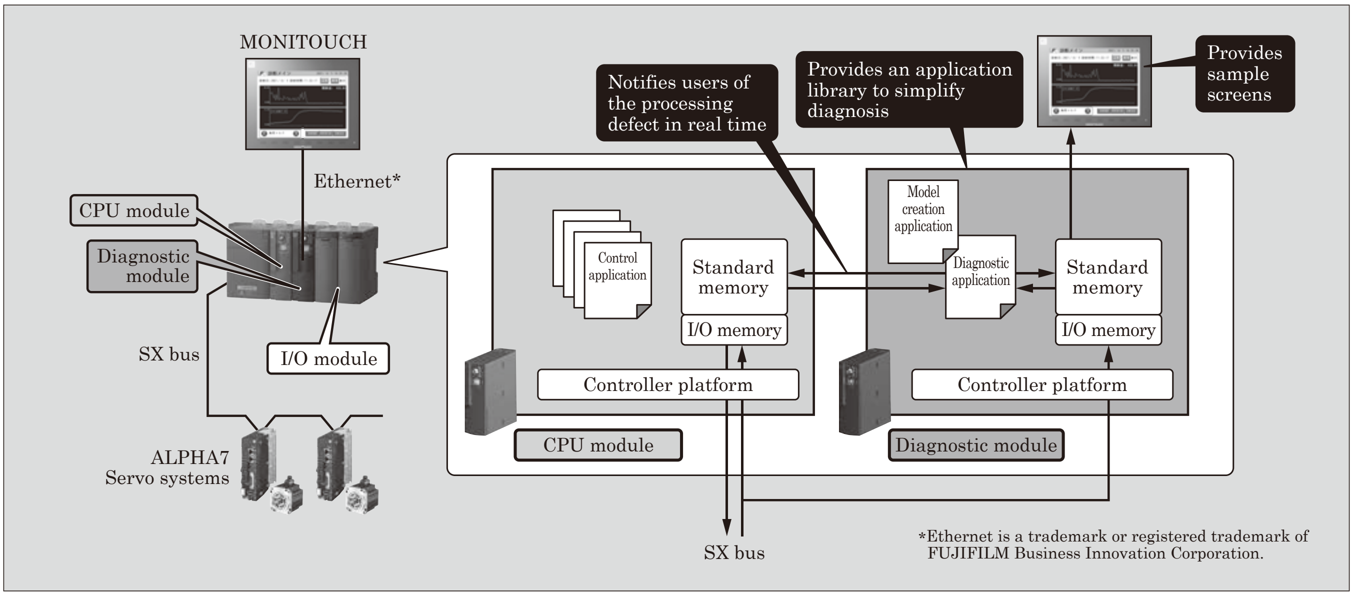

Fig.3 Module configuration

*1 Base board: A board on which power supply modules, CPU modules, and I/O modules are mounted.

Table 1 List of diagnostic module SFBs

Category	Name	Function overview
Shared	MSPC_INIT	Initializes used memory
Model creation	MSPC_MODEL_STACK	Data collection for model creation
	MSPC_MODEL_CREATE	Creates the model
	MSPC_MODEL_UPDATE	Updates the diagnostic model
	MSPC_MODEL_READ	Reads the model (SD card)
Diagnosis	MSPC_DATA_STACK	Collects diagnostic parameters
	MSPC_PREPROCESS	Preprocesses collection parameters
	MSPC_ANALYSIS	Processes MSPC diagnostics
	MSPC_EVALUATION	Evaluates MSPC diagnostic results
	MSPC_OUTPUT	Outputs MSPC diagnostic results

Fuji Electric's MONITOUCH programmable operator interface, which can be connected to the Ethernet*2 port on the front of the diagnostic module.

The high degree of freedom in building diagnostic applications using diagnostic SFBs allows users to build optimal diagnostic applications for various types of machinery and equipment. On the other hand, it is to be expected that users who are not familiar with diagnostic functions will have a high degree of difficulty in deploying such applications. Therefore, we have prepared a library of standard diagnostic applications, as well as samples of MONITOUCH operation screens for using these diagnostic applications. This enables users to customize the applications and facilitates the deployment of easy-to-build diagnostic applications.

3.3 Description of diagnostic functions

As described in Section 3.2, the diagnostic module comes with model creation functions and diagnostic functions.

The model creation functions can be used to create a diagnostic model that represents the state of normal equipment operations when performing diagnosis.

The diagnostic functions compare the diagnostic model created by the model creation functions with the input parameters during actual manufacturing to determine the quality of products. As shown in Fig. 4, the series of equipment processing cycles to be diagnosed is represented by cycles. The timing of capturing the input parameters for the diagnostic functions is called the sampling point, and the interval between the sampling points is called the sampling cycle.

As shown below, the diagnostic functions determine the cycle's processing normality or abnormality in the following order: parameter collection, diagnostic processing, and results evaluation.

(1) Parameter collection

○ Collects the parameter values at every sampling cycle for each cycle using diagnostic parameter collection SFBs.

○ Processes the parameters collected using parameter preprocessing SFBs.

(2) Diagnostic processing

Diagnoses the parameters processed using MSPC diagnostic process SFBs.

(3) Results evaluation

The Q statistic and T^2 statistic thresholds, which represent deviation from the diagnostic model, are input in advance to the MSPC diagnostic results evaluation SFBs to determine the cycle's processing normality or abnormality.

Table 2 shows the specifications of the diagnostic functions of the diagnostic module. The module's diagnostic performance and diagnostic cycle make it possible to detect defective products during machinery and equipment processing operations.

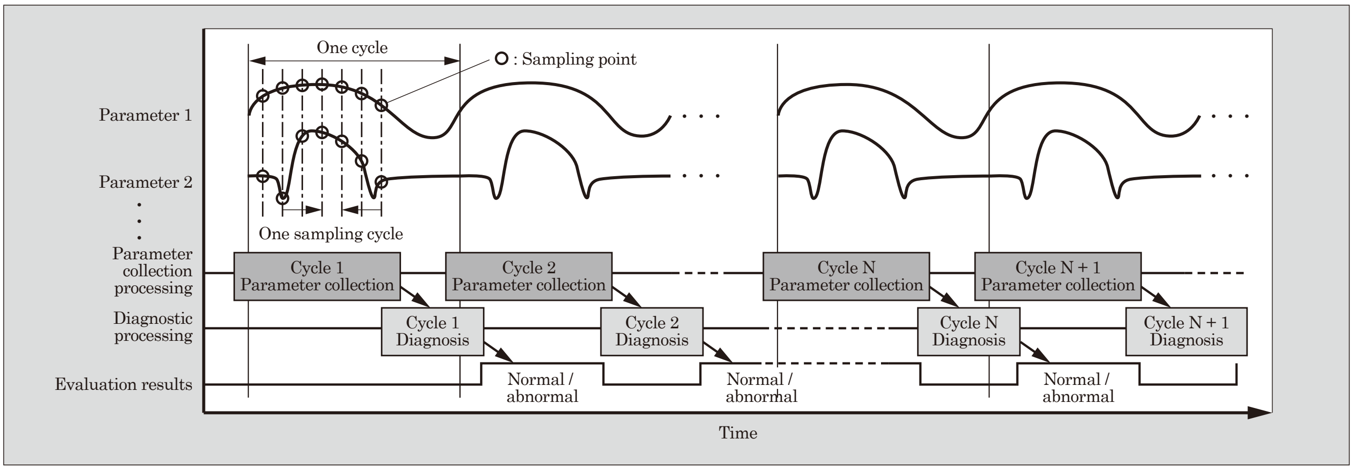

Fig.4 Diagnostic function timing chart

*2 Ethernet is a trademark or registered trademark of FUJIFILM Business Innovation Corporation.

Table 2 Specifications of diagnostic module diagnostic functions

Item	Specification
No. of parameters	2 to 5
No. of samplings	11 to 200
Sampling cycle	Max. of 2 ms
Diagnostic cycle	Max. of 200 ms
Diagnostic performance (diagnostic time per cycle)	Within 70 ms

4. Systems Using Diagnostic Modules

4.1 Configuration of a motion system using the ALPHA7 servo system

Fuji Electric's "ALPHA7[(1)]" servo system comes with a load torque monitoring function. By combining the diagnostic module with the ALPHA7, it is possible to improve the diagnostic accuracy (see Fig. 3).

The ALPHA7's new load torque monitoring function exclusively extracts and monitors load torque, excluding acceleration and deceleration torque, gravitational torque, and frictional force, from the motor torque fed back from the servo amplifier.

By utilizing this load torque and feedback speed as one of the types of input data for the diagnostic module, abnormal behavior in equipment can be detected. For example, it can detect the application of a higher-than-expected load or non-application of a required load.

For equipment and machines that utilize our MICREX-SX and ALPHA7, even if there are no defect detection sensors, the diagnostic function can still be used by adding a diagnostic module to the system. This makes it possible to detect defective products.

4.2 Diagnostic module application examples

In the food industry, the outflow of defective products can immediately impact consumers in an adverse manner, leading to health hazards and a significant reduction in product sales.

One of the most important pieces of equipment in ensuring the safe delivery of products to consumers is the food packaging machine. There are various types of food packaging machines. For example, in the horizontal pillow packaging machine shown in Fig. 5, the rolled packaging film is supplied to make the film cylindrical. After this, the product on the conveyor belt is wrapped and the back-to-back portions of the film are thermo-compressed. Next, the film portions in the front and back of the product are thermo-compressed by the cutter sealer mechanism and finally cut to wrap the product.

In these types of food packaging machines, the thickness of the film at the time of sealing is measured using a proximity sensor to detect defects, and an infrared sensor is used in a separate process to check for foreign matter contamination.

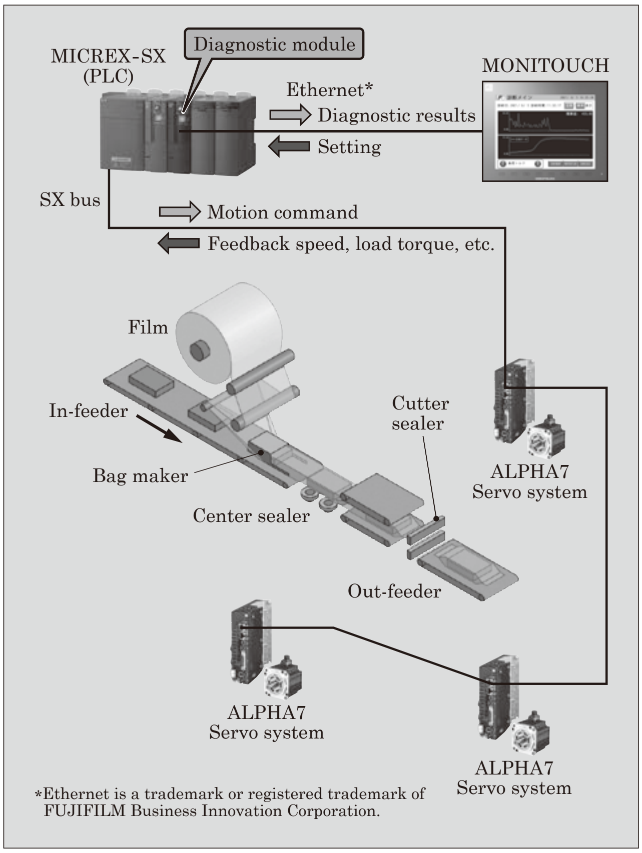

Fig.5 Diagnostic solution system configuration for a food packaging machine

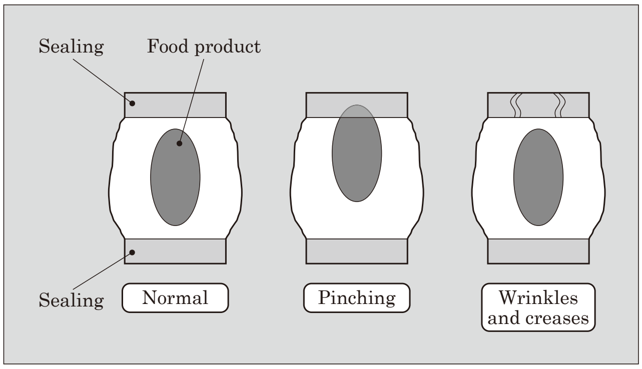

Fig.6 Examples of defects in food packaging

As shown in Fig. 6, most of the defects in food packaging are seal defects caused by wrinkles in the film or food scraps that get caught when sealing the packaging film. As a result, there is strong demand for accurate detection of these defects. To meet this demand, we developed a diagnostic solution system with the configuration shown in Fig. 5.

The cutter-sealer unit and various other mechanical parts of the food packaging machine are operated by a servo system that is motion controlled by a programmable logic controller (PLC). The diagnostic module can detect seal defects using the load torque and other data obtained from this servo system.

Figure 7 shows the results of a simulated test in which a 70 μm thick paper was pinched in the sealing

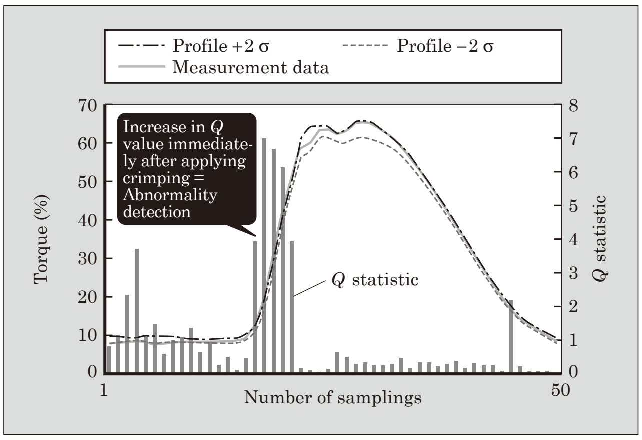

Fig.7 Simulation test results for detecting sealing defects (load torque)

to simulate wrinkles and food scraps in the packaging film. The diagnostic model is shown with profile $+2\sigma$ and profile -2σ. The area where the load torque measurement data rises corresponds to the crimping of the film. The rise timing of the load torque was slightly faster than the diagnostic model. This slight difference created a sharp increase in the Q statistic. This made it possible to detect the crimp defect and improved the detection accuracy compared to conventional methods.

By applying the diagnostic solution to food packaging machines, it became possible to detect abnormalities and signs of equipment failure that could not be detected previously. It also made it possible to improve the detection accuracy of defective products, minimize the number of external devices such as sensors, and reduce the total cost by reducing the number of human-involved checking processes. These enhancements have increased the added value of machinery and equipment. This real-time detection of defects can prevent unwanted effects on subsequent manufacturing processes and stop the outflow of defective products.

5. Postscript

In this paper, we described a diagnostic solution for machinery and equipment that applies AI to detect defective products in real time.

We are contributing to the development of machinery and equipment that achieve higher detection of defective products by incorporating a diagnostic module into the controller system as a separate module that helps the CPU module perform equipment sequence control, and by combining the module with the ALPHA7 servo system that has a load torque monitoring function.

In the future, we plan to expand our line-up of modules that apply MSPC diagnostic functions and advance the application of IoT systems at the core of Fuji Electric's DX in order to improve the quality and operational efficiency of user products.

References

(1) Yamashita, S. et al. "ALPHA7 Series" Servo System: New Functions and Application Examples. FUJI ELECTRIC REVIEW. 2021, vol.67, no.1, p.54-59.

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