"E-SX Bus" & "SPH3000MM" Promising High-speed, High-precision Motion Control

Eiji Nishimura † **Toshiyuki Nishiwaki** † **Kazuhito Nagatsuka** †

ABSTRACT

In the plant control and machine control fields, further improvements in quality and the stabilization and streamlining of operations are required. Fuji Electric has developed the high-speed/high-precision synchronou s"E-SX Bus", a backbone bus for configuring control system, and the high-speed/high-performance "SPH3000MM" CPU module to execute applications. These enable high-speed and high-precision motion control while also making it possible to flexibly expand applications up to large-scale systems with numerous I/O points. As application examples, high-speed and high-precision motion control has been achieved in multi-color printing machines and steel/iron plant systems.

1. Introduction

In the field of plant control for iron and non-ferrous material production, paper manufacturing and so on, and in the field of machinery control for metal processing, printing, packaging and so on, higher quality and operational efficiency are required. In order to achieve these goals, while maintaining the ease of system construction and engineering based on general-purpose controller, a high-speed and high-precision control system that can be built flexibly according to the control target is needed.

For high performance machinery, for example, applications that combine sequence control for controlling a variety of inputs/outputs and multi-axis motion control (see supplemental explanation 3 on page47) that require high-precision synchronization must be easy to build. Such applications must acquire data from sensors at a period of several hundred microseconds, and control multiple actuators synchronously with precision of 1 microsecond or less. Large plants typically have control periods ranging from several microseconds to several tens of microseconds, and often have more than 10,000 inputs and outputs, and control systems have traditionally been realized by connecting multiple controllers in a networked configuration which increases costs.

Thus, to realize high-speed high-precision motion control functionality based on general-purpose controller technology and to support large systems having numerous inputs and outputs, Fuji Electric has developed the high-speed high-precision synchronous "E-SX" bus as a backbone bus for controllers and the "SPH3000MM" high-speed high-performance CPU module for running applications. This paper describes features and presents application examples of the E-XS bus and the SPH3000MM.

2. Overview of Systems That Use The SPH3000MM

Fuji Electric's "SPH3000MM" CPU module equipped with an E-SX bus is an important component for implementing high-speed high-precision motion control and for realizing large control systems. The SPH3000MM is positioned as the top-level model of Fuji Electric's "MICREX-SX" series and has the following features:

(a) High-speed computations: Top speed of 9 ns per instruction
(b) Capable of synchronous control among 32-axial drive machines with accuracy within ±1 μs
(c) Dual processing engines enable synchronous execution of application programs
(d) High-speed I/O with 25 μs response speed
(e) Large I/O capacity up to 4,096 words×2 systems

An example system configuration for motion control is shown in Fig. 1.

(1) High-speed, high-performance CPU module

The new CPU module can be mounted on an existing baseboard, and used with a conventional SX bus or in a multi-CPU module configuration. Furthermore, because the CPU module has two processing engines and is equipped with a dual-system E-SX bus to which high-speed I/O devices and drive control devices can be connected, application programs can be run simultaneously for sequence control and motion control.

(2) "SX-Programmer" support tool

Support for the creation of application programs for sequence control and motion control of multiple CPU modules, the setting of system definition parameters, fault diagnosis, monitoring operation, and so

† Fuji Electric Co., Ltd.

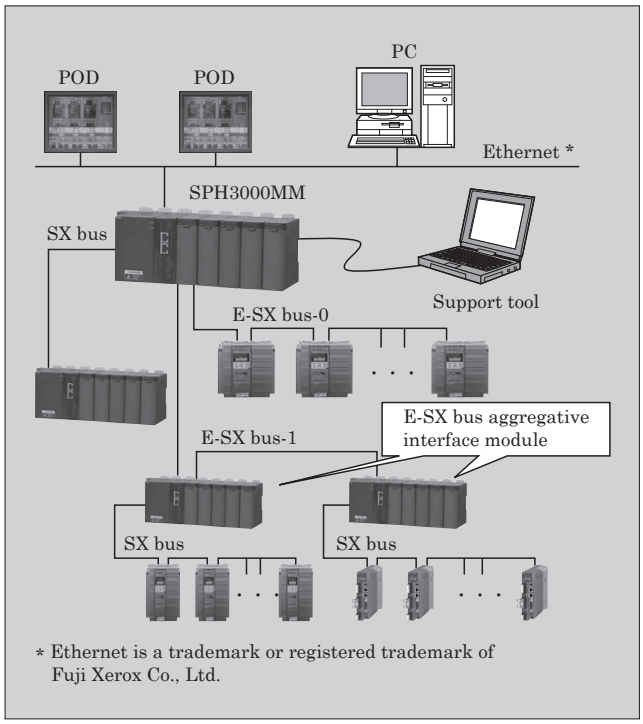

Fig.1 Example system configuration for motion control

on can be provided by a single IEC 61131-3 compliant support tool "SX-Programmer" (2 models: Expert and Standard).

(3) I/O devices and drive control equipment

Having a 25 μs response performance which is faster than before, the E-SX bus supports connections to digital/analog inputs and outputs and other I/O devices such as high-speed counters and encoders, as well as drive control devices such as inverters and servo amplifiers. Furthermore, with an E-SX bus aggregative interface module, the extensive lineup of I/O devices and communication devices for the SX bus can be utilized via the E-SX bus.

3. Features of The "E-SX bus" That Realizes High-Speed, High-Precision Synchronous Communication

The "E-SX bus" utilizes 100 Mbit/s Ethernet*1 technology in its physical layer, and is a hybrid-type motion control bus that realizes a high-speed and high-precision synchronous communication function that are necessary for drive solutions, a large capacity I/O data transfer function, a message communication function and a loopback function. The E-SX bus has the following features.

(1) Scalability

The E-SX bus can flexibly support various systems, ranging in size from small to large, and with a total length of up to 1 km, is capable of connecting up to 238 stations separated by up to 100 m, with a maximum input/output size of 4,096 words (8 times greater than before).

(2) High-speed, high-precision synchronization

When connected to 32 input and output devices, the E-SX bus is capable of high-precision synchronous control with accuracy within ±1 μs.

(3) Large input and output data capacity

In consideration of the runtime required for applications, the data capacity has been increased to 4 times the prior capacity, and at the fastest control period of 0.25 ms, 67 words of input and output data can be processed, or in the case of a control period of 1 ms, 512 words can be processed. Up to 4,096 words can be processed at a control period of 3 ms, and the E-SX bus is well-suited for application to large plants having many inputs and outputs.

(4) Highly efficient transmission protocols

The transmission protocols have evolved from Fuji Electric's proprietary SX bus and have been greatly improved. In addition to the cyclic I/O refresh communication protocol and message communication protocol, a system management protocol for control commands, initial processing and the like is also provided.

These transmission protocols are realized with a high-density integrated circuit (LSI) developed by Fuji Electric, and achieve an effective data transmission efficiency of greater than 70%.

(5) Degenerate continuous operation and wire breakage detection

The E-SX bus uses a configuration (daisy chain connection) that does not require a hub or the like. Other features of the E-SX bus include a function for supplying power from the bus to other stations and a loopback function for times when there is a broken wire. As a result, even if devices are powered-off, wires break, or other bus errors occur, degenerate continuous system operation will be possible whereby, by excepting some system functions, the system will continue to operate. The E-SX bus is also provided with a RAS function for identifying broken wire locations, which improves the ease of maintenance when replacing equipment.

4. Characteristics of The "SPH3000MM" High-Speed High-Performance CPU Module

(1) High-speed high-precision control and large capacity memory

The new CPU module employs a multi-engine architecture as shown in Fig. 2. A system manager and two processing engines are connected through a synchronous bus equipped with a distributed shared memory access function. The processing engine, in combination with high compression compiler technology, realizes a maximum execution performance of 9 ns/instruction. Control period error is less than ±1 μs, and control can be realized with less fluctuation than

*1: Ethernet is a trademark or registered trademark of Fuji Xerox Co., Ltd.

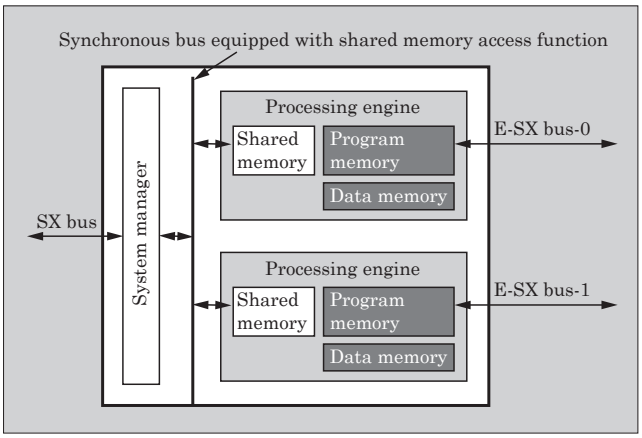

Fig.2 SPH3000MM multi-engine architecture

with prior models.

Additionally, the memories for programs and user data are separate for each processing engine, and substantial applications can be constructed with a large program memory (max. 512 K steps with 2 systems) and a large data memory (max. 4,096 words with 2 systems).

(2) Separation of processing engines and functions between the 2 systems

The processing engines are connected to an internal synchronous bus, and the execution period is synchronized to within ±1 μs among the processing engines. Accordingly, even in cases where 32 I/O devices are connected to the E-SX bus of each system, the output timing among systems can be synchronized within ±3 μs. Furthermore, in the case of the maximum control rate of 0.25 ms, multi-axial motion control can be implemented for up to 8 axes (4 axes×2 systems).

The exchange of data among processing engines is carried out in the background via a shared memory space in order to maintain synchronization. Thus, the exchange of data among the two engines, which is typically performed frequently, can be accomplished with great ease and users are able to create distributed applications without regard to process synchronization. In addition, by distributing the sequence control and motion control functions and running them on two processing engines in parallel, the processing time can be reduced easily.

Furthermore, with two systems of processing engines, by setting one processing engine to a period that is an integer multiple of the other engine, a high-speed motion control application program as well as an equipment control application program, which handles large amounts of data and has a slower control cycle, can be run on a single CPU module.

Thus, flexible systems can be constructed by utilizing the distributed processing function in accordance with the control object.

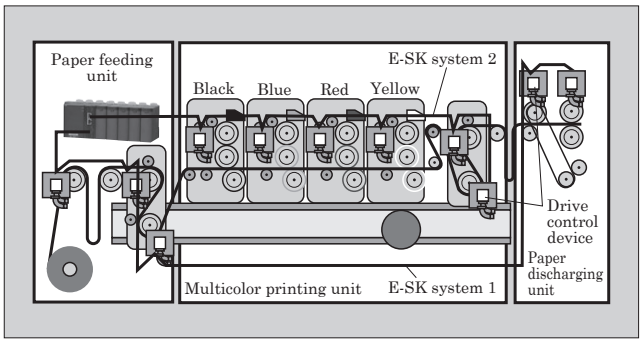

Fig.3 Example of multicolor printer

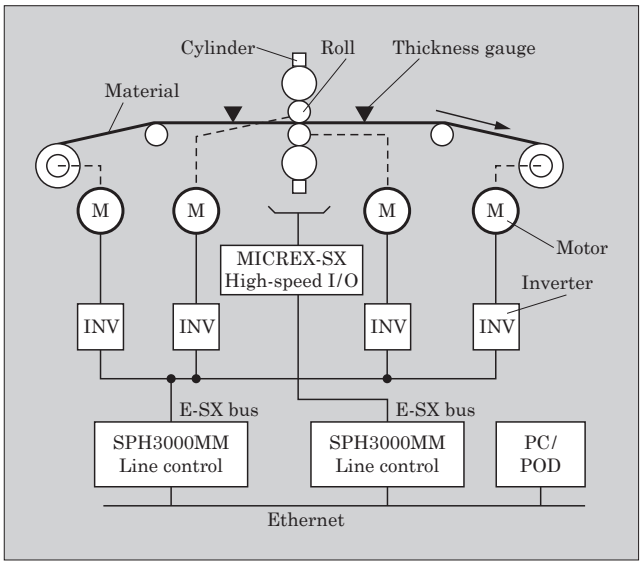

Fig.4 Example of mill pressure control system

5. Application Examples

(1) Application to a high-speed high-precision motion control system

Multi-color printing is an example of an application in which high-speed high-precision synchronous motion control is required. With a minimum configuration of the motion control system, an 8-axial synchronous system can be realized with 4 axes per system and a control period of 0.25 ms, and with a general-purpose controller, motion control can be realized with the maximum speed and precision. During the 0.25 ms control period, 0.12 ms of run time can be ensured for the application program, and high-precision positioning control such as interpolation control can be implemented.

Figure 3 shows an example of a multi-color printer. By performing high-precision synchronization of a vertical axis that controls paper feeding, multi-color printing, paper discharging and other processes with respect to a virtual main axis, high-resolution color printing without print unevenness can be processed quickly. To realize the required printing accuracy (within 0.015 mm) at a printing speed of 300 m/min, the synchronization accuracy must be within 3 μs.

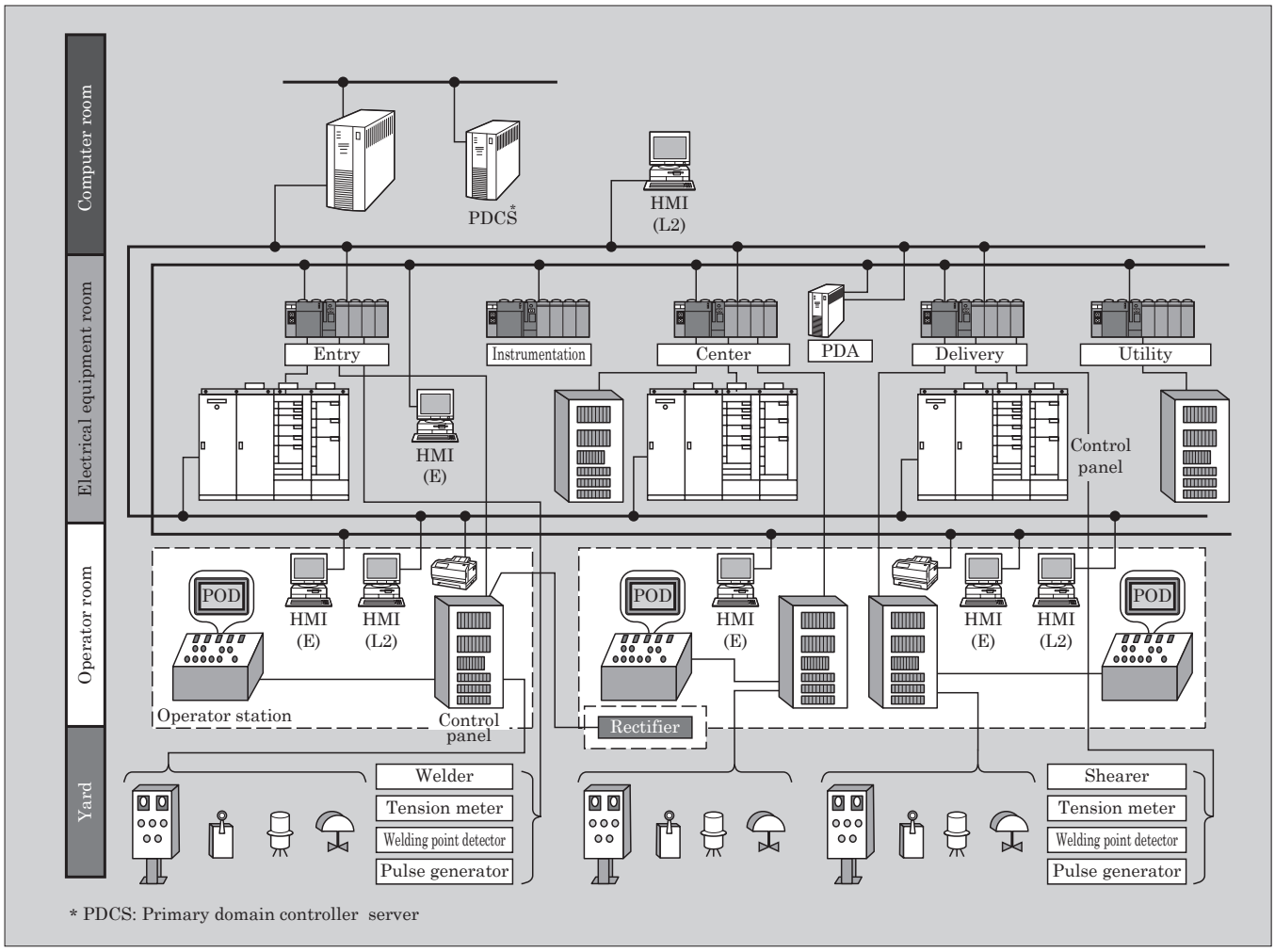

Fig.5 Example of control system for iron process line

With the SPH3000MM, by using one system for the virtual main axis and the paper feeding and discharging units, and another system for the multi-color printing unit and so on, application programs that flexibly separate the functions of customers' equipment and that realize high-speed high-performance synchronization can be constructed easily.

(2) Application to a steel plant system

A steel plant control system is a large-scale system configured from many detectors and actuators, as well as equipment for their control, operation and monitoring. Of these component parts, high-speed performance is especially required of the electric control system, which includes electric motors and solenoid valves.

(a) Application to mill rolling force controller

A mill rolling force controller is a device that uses an apparatus known as a mill (a rolling mill), consisting of multiple rollers, to control materials such as steel, copper or aluminum to a predetermined thickness (Fig. 4).

Material discharged from the upstream side is rolled according to the position of the rollers and the tension applied to the material as it passes through the mill. Because the state of the material passing through the mill changes from moment to moment, controlling the material to a predetermined thickness requires that the state of the material and the equipment be measured with various sensors, and that the mill be controlled to an optimal state. Various control methods have been proposed, and the extent to which information from the sensors can be accurately incorporated is critical to the realization of these methods. Requirements for control equipment are as follows.

(i) High-speed and reliable input from detector (Magnescale, absolute encoder, etc.)
(ii) High-speed processing, high-speed period
(iii) High-speed synchronous output of instructions to actuator

Previously, these requirements were met by using a dedicated control device, narrowing down the control functions and increasing the processing speed.

The SPH3000MM, with its high-speed processing performance, coupled with the high-speed high-precision synchronization function as well as the high-speed input/output capability for detectors and actuators provided by the E-SX bus, enables advanced control functions to be realized easily while maintaining high-

speed performance with few restrictions.

(b) Application to the control system for a process line

A process line is a facility for processing iron and nonferrous materials such as by heating, acid washing, plating, coating and so on. In the case of a large-scale system, a process line may consist of drive units for driving several hundred electric motors, numerous solenoid valves, detectors and monitoring devices; and the control system may have a control period of several tens of milliseconds, and the number of inputs and outputs may exceed 10,000 points (Fig. 5).

Requirements for such a system are as follows.

(i) Scalability according to system size

(ii) High-speed connectivity with distributed equipment

(iii) Easy connectivity with third-party equipment

With the SPH3000MM, an optimal configuration can be assembled for the required control performance of systems ranging in size from small to large. Furthermore, in addition to the E-SX bus, conventional buses (P/PE link, T link) and open buses (FL-net, PROFIBUS-DP*2, etc.) are also supported, and thus, systems that mix older model devices and third-party equipment can be easily connected.

6. Postscript

Controllers equipped with the SPH3000MM CPU module and the E-SX bus can be used to construct various types of high-speed, high-precision and large capacity motion control systems. It is the authors' hope that the content described in this paper will contribute to the manufacture of high quality products required by various plant systems and machinery and to the realization of stable and efficient operation.

To resolve the challenges facing manufacturing sites, the authors intend to continue to expand the range of applications of controllers.

*2: PROFIBUS-DP is a trademark or registered trademark of PROFIBUS User Organization