Application of Integrated Controller "MICREX-SX" to a Motion Control System

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1. Introduction

A scalable multi-controller SPH [hardware programmable controller (PLC)] of the integrated controller "MICREX-SX" (hereafter referred to as SX) series has the features of high speed and high performance, and is suitable for the motion control of various machines. Historically, in the servo-system of a typical motion control, a high-performance position control module (for example, the electronic-cam module of MICREX-F) was required. However, in an SX system, SPH can perform the functional calculation due to the realization of a high-speed calculation feature. That is, in an SX system, the system is configured such that only actuator interface functions such as a D-A converter, pulse distributor, etc., are on the position-control module side, and the position-control calculation is executed on the SPH side with an extended function block (FB). With this configuration, it is easy to customize position control processing for integrating user "know how" with the combination of extended FB for position control and user FB (various compensation calculations), and to support special machines. Particularly, in machines performing synchronous operation, there is demand for tuning of the machine control such as for predicting the main axis position and compensating the position gap of the control axis. This SX is the most suitable controller for these machines.

In this paper, we will present an overview of synchronous operation processing and the control characteristics during synchronous operation as an example application of the motion control system of the SX system. Further, example application to a special-purpose cutting machine that combines a rotary axis and a linear axis using the floating point calculation function of the SX will be introduced.

2. Position Control Module

2.1 Basic specifications and system configuration

Table 1 lists the basic specifications of the position-control module for the SX, and Fig. 1 shows a system configuration for position-control with the SX. The following three types of signal systems exist for a servo-amplifier in an SX system.

(1) Pulse reference signal system (NP1F-MP2, NP1F-HP2, etc.)

A pulse reference is output on the position-control module side.

This system is combined with the servo-amplifier and stepping motor of the pulse reference signal system.

(2) Analog velocity reference signal system (NP1F-MA2)

An analog voltage is output on the position-control module side.

This system is combined with the servo-amplifier of the analog velocity reference signal system.

(3) Servo-amplifier directly coupled to SX bus (L, R and V type of FALDIC-α)

This system directly signals the amplifier via the SX bus.

When combining with a FALDIC-α directly connected to the SX bus, the position-control module is unnecessary.

2.2 Function block of position-control module

Figure 2 shows a control block diagram for the position-control module.

In the function calculation unit, acceleration, deceleration and interpolation calculations are performed, and a position signal is output. In the position-control module of the pulse reference output, the position signal is the number of actual pulses. Further, in the position-control module of the analog velocity reference output, position regulator calculation (error counter, gain and feedforward control calculation) is performed. In the error counter, the difference between command position and feedback position from the servomotor is counted. The feedforward compensates for the response lag of the position signal, and is an important function in synchronous operation. The sum of the calculated gain value and the feedforward output value is added to the output value of the error counter to become the velocity reference value for the servo-amplifier.

In the conventional MICREX-F system, the function calculation unit and position-controller were en-

Table 1 Basic specifications of the position-control module

Item \ Name / Type	Analog velocity reference compound module	Pulse reference compound module	Pulse reference output module	FALDIC-α directly coupled to SX bus
	NP1F-MA2	NP1F-MP2	NP1F-HP2	RYSxxxS3-xSS
Occupied slot	1 slot	1 slot	1 slot	——
Number of occupied words	22 words (Input 14 words, output 8 words)	22 words (Input 14 words, output 8 words)	16 words (Input 8 words, output 8 words)	16 words L, R: Input 8 words, output 8 words V: Input 10 words, output 6 words
Number of control axes	2 axes/module	2 axes/module	2 axes/module	1 axis/unit
Control system	Closed loop control	Open loop control	Open loop control	Closed loop control
Reference signal	◦ Analog velocity reference ◦ 0 to ±10.24 V	◦ Pulse reference (open collector) ◦ CCW pulse+CW pulse ◦ Max. 250 kHz	◦ Pulse reference (open collector) ◦ CCW pulse+CW pulse ◦ Max. 250 kHz	——
Feedback pulse	◦ Line driver/open collector ◦ 90°phase difference signal (ϕA, ϕB signal) ◦ Max. 500 kHz (×1)	◦ Line driver/open collector ◦ 90°phase difference signal (ϕA, ϕB signal) ◦ Max. 500 kHz (×1)	——	◦ 16-bit serial encoder (integrated in motor, compatible with ABS)
Manual pulse generator/ Main axis pulse for synchronous operation	◦ Operation signal/open collector ◦ 90°phase difference signal (ϕA, ϕB signal) or CCW pulse+CW pulse ◦ Max. 500 kHz (×1)	◦ Operation signal/open collector ◦ 90°phase difference signal (ϕA, ϕB signal) or CCW pulse+CW pulse ◦ Max. 500 kHz (×1)	——	◦ Expansion counter for manual pulse generator 1 channel (V type)
Outside input/output signal	◦ Dedicated input 5 points (EMG, ±0T,beginning point LS, external interrupt) ◦ General-purpose output 2 points	◦ Dedicated input 5 points (EMG, ±0T,beginning point LS, external interrupt) ◦ General-purpose output 2 points	◦ Dedicated input 5 points (EMG, ±0T,beginning point LS, external interrupt) ◦ General-purpose output 2 points	◦ Dedicated input 5 points (Control 1 to 5) ◦ Dedicated output 2 points (Output 1 and 2)
Internal function	◦ Linear-curve accel./decel. ◦ Continuous change of frequency ◦ Reading the data for position-control in advance ◦ Feedforward calculation ◦ 2-axis simple linear interpolation	◦ Linear-curve accel./decel. ◦ Continuous change of frequency ◦ Reading the data for position-control in advance ◦ Pulse number control function ◦ 2-axis simple linear interpolation	◦ Linear-curve accel./decel. ◦ Continuous change of frequency ◦ Pulse number control function	◦ Linear position-control function (L type) ◦ Rotation calculation function (R type) ◦ Position reference system (V type)
Actuator	◦ Servo-amplifier of analog velocity reference	◦ Servo-amplifier of pulse reference ◦ Driver for stepping motor	◦ Servo-amplifier of pulse reference ◦ Driver for stepping motor	——

Fig.1 System configuration for position control

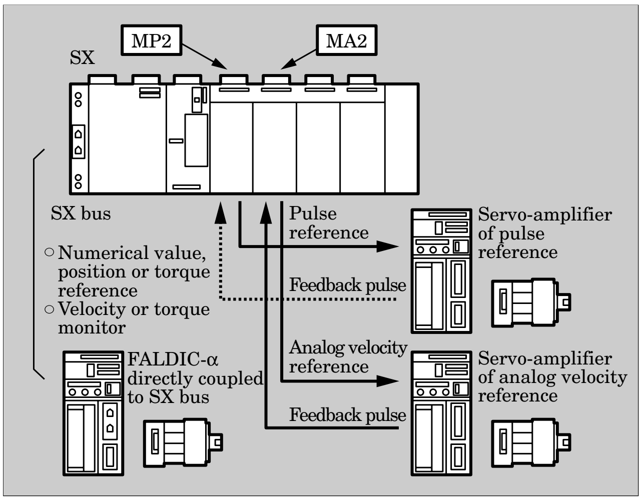
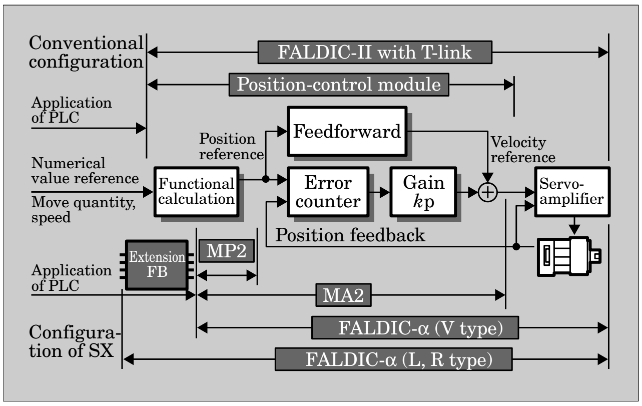


Fig.2 Control block diagram for position-control module



tirely integrated into a high-performance position-control module or servo-amplifier on the FALDIC-II side. That is, the functional calculation was performed by the combination of a high-speed microcomputer and an LSI circuit for pulse distribution mounted on the position-control module.

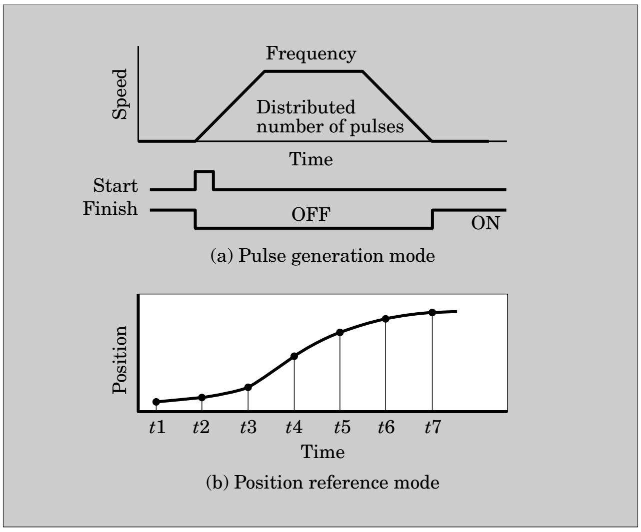
In the SX configuration, among the functional

Table 2 Combination of extended FB for position-control and position-control module

Operating system	Extended FB library name	Function	Objective position-control module			FALDIC-α	Operating CPU	
			NP1F-MA2	NP1F-MP2	NP1F-HP2	RYSxxx S3-VSS	SPH 300	SPH 200
1-axis PTP operation	Compact 1-axis PTP	◦ 1-axis PTP position-control ◦ Linear-curve accl./decel.	○	○	×	×	○	○
	1-axis PTP	◦ 1-axis PTP position-control ◦ 1-axis automatic operation of motion program ◦ Linear-curve accl./decel.	○	○	○	×	○	×
	Multi-function 1-axis PTP	◦ 1-axis PTP position-control ◦ Linear-curve accl./decel./S-form accl./decel ◦ Operation with manual pulse generator	○	○	×	△	○	×
Special synchronous operation	Special synchronous FB + Multi-function 1-axis PTP	◦ Rotary shear ◦ Flying shear ◦ Flying cutter linear operation, rotating operation ◦ Proportional synchronous operation	○	○	×	△	○	×
2- to 4-axis interpola-tion	Compact 1-axis PTP	◦ 2-axis simple linear interpolation in a module	○	○	×	×	○	○
	1-axis PTP	◦ 2- to 4-axis simple linear interpolation	○	○	○	×	○	×
	4-axis interpolation + Multi-function 1-axis PTP	◦ 4-axis linear interpolation ◦ 2-axis circular interpolation ◦ 4-axis automatic operation of motion program	○	○	×	△	○	×

△: An interface FB is required to match the I/O signal with the position-control compound module.
L-type (LSS) and R-type (RSS) FALDIC-α are integrated into an amplifier whose function corresponds to that of an extended FB.

Fig.3 Operation mode for position-control module



calculation components, functions which were conventionally processed on the microcomputer of the position-control module side, are executed on the SPH side as an extended position-control module. (In FALDIC-α, in addition to the V type used in combination with the extended FB, all functional calculation features including the L type and R type are provided, similar to the FALDIC-II.)

Because the functional calculation feature is made into an extended FB, the user FB can be customized.

The position-control extended FBs for various operations are provided in the SX system as shown in Table 2, and the position-control modules can be directly signaled from the user FBs. Figure 3 shows two types of operating modes of the position-control modules.

(1) Pulse generation mode

After setting the distribution pulse number and frequency, a start signal is turned ON. At the position-control module side, the position-control-completed signal is turned ON after completing the pulse distribution. (Parameter values such as acceleration/deceleration time and high-speed limiter have been set in advance.)

(2) Position reference mode

Pulse position data are signaled every tact cycle using a constant cycle task. In this mode, special operation is realized by transforming the coordinate system with a user FB. In the position-control extended FB, a multi-function 1-axis PTP FB performs synchronous operation and cam operation movement by referencing this mode. (In a FALDIC-α directly coupled to an SX bus, the V type corresponds to this mode.)

3. Application to Synchronous Operation Machine

A synchronous operation function is contained in various machines such as a running crane and a running cutting machine. In this chapter, we will

Fig.4 Rotary-shear system for running cutting machine

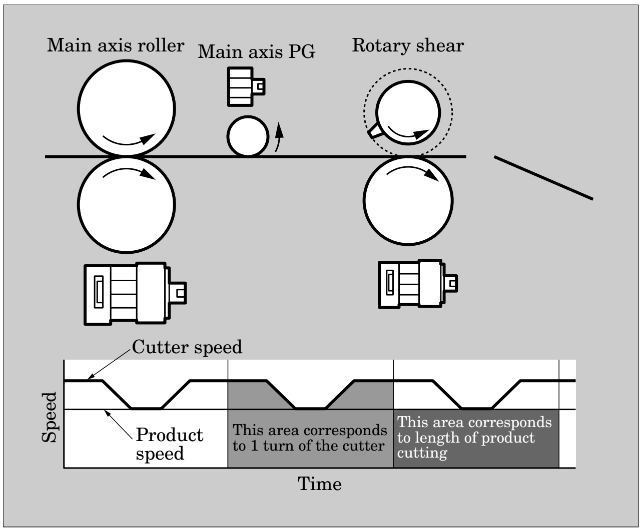
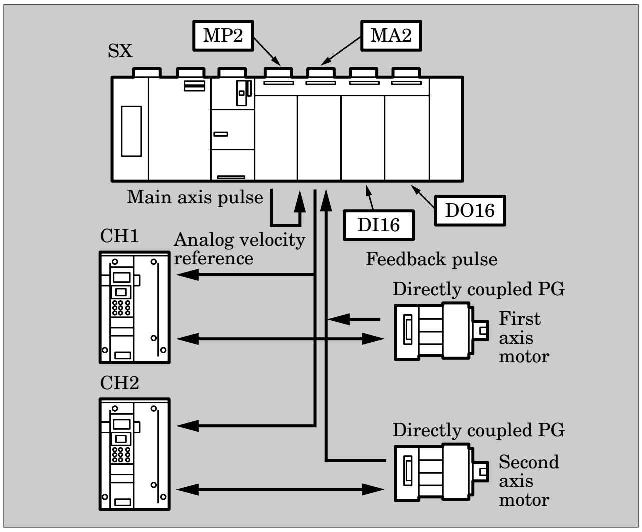


Fig.5 Test system for rotary shear



explain the running cutting machine, assuming that it a rotary shear type.

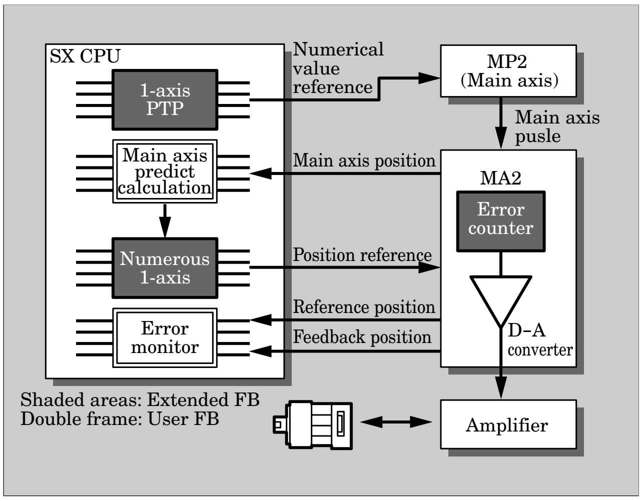
The rotary shear is equipment that cuts with a rotating blade a product which is fed continuously as shown in Fig. 4. The rotary shear is utilized in packing machines and printing machines. During operation of the rotary shear, the peripheral speed of the cutter is synchronized with the speed of the product. Further, since the cutter must rotate one turn when the product is fed by a cutting length (in the case of a single blade), the cutter shaft operates synchronously while adjusting the speed. If the motor that drives the main axis of product feeding is independent of the controller for the rotary shear control, the operation is externally synchronized, and the controller for the cutter unit performs the cutting operation while calculating the feed length of the product and feeding speed from pulses of the main axis pulse generator (PG). The following three types of errors influence cutting accuracy in the running cutting machine.

(1) Control error of the controller
(2) Control error of the actuator
(3) Control error on the machine side

We evaluated the synchronous characteristics of the SX and actuator on the assumption of rotary shear operation, and will introduce the results of that evaluation. The configuration of the evaluation system is shown in Fig. 5, and a function block diagram is shown in Fig. 6.

In this system, externally synchronized operation is assumed, and the cutter is synchronously operated, utilizing the output pulses of the position-control module of the pulse reference output [NP1F-MP2 (hereafter called MP2)] as pulses from the main axis PG. As shown in Fig. 6, processing on the SPH side is commanded from 1-axis PTP extended FB to MP2, but this is independent of the synchronous calculation. Synchronized processing is performed with a combination of the “Prediction calculation FB of main axis position” (user FB) created for this evaluation system and the “Multi-function 1-axis PTP FB” (extended PTP FB). This time, error pulses of the position-control module of the analog velocity reference [NP1F-MA2 (hereafter called MA2)] are sampled every tact cycle, and unevenness is evaluated. Further, this characteristic evaluation is performed with a combination of SX and a vector inverter (unloaded motor).

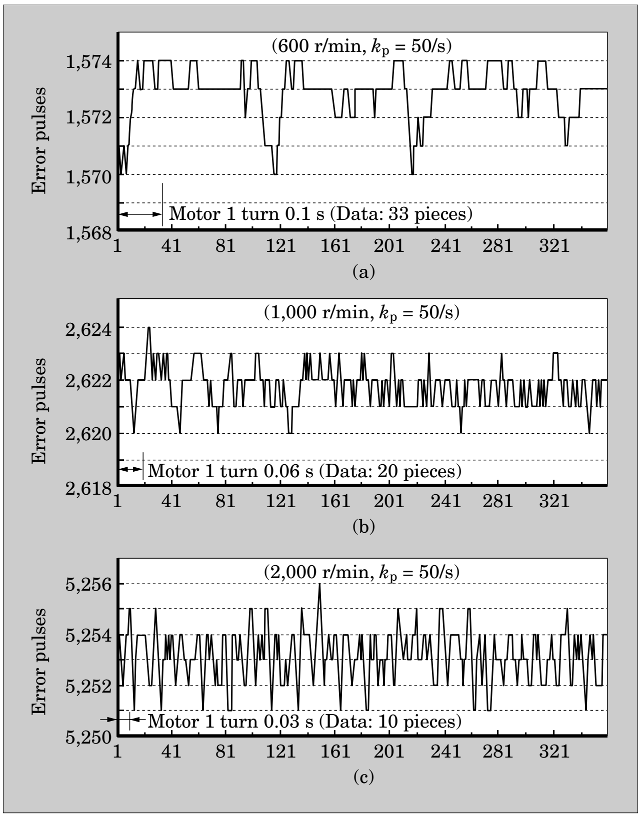
Fig.6 Rotary-shear control block diagram for test system



3.1 Evaluation system

(1) Motor: 5.5 kW synchronous motor (trial sample)
(2) Amplifier: Vector inverter FRENIC5000VG5
(3) Cutter axis PG: 2,000 P/R × 4
(4) Tact cycle: 3 ms
(5) Position regulator (MA2) calculation cycle: 0.8 ms
(6) Position regulator gain: k_p = 50/s
(7) Number of sampling points and cycle: 360 and 3 ms interval
(8) Number of control axis: 2

Fig.7 Unevenness for error pulse (evaluation result of test system)



3.2 Evaluation results

(1) Unevenness is within 5 pulses (refer to Fig. 7)

The ordinate in Fig. 7 shows error pulses, and the calculated error Ep is calculated with the following formulae:

Ep = (Rotating speed/min) × (2,000 pulses × 4) ÷ (60s × k_p) .... (1)

○ Fig. 7(a): 600 r/min

Ep = (600 × 2,000 × 4) ÷ (60 × 50) = 1,600 pulses

○ Fig. 7(b): 1,000 r/min

Ep = (1,000 × 2,000 × 4) ÷ (60 × 50) = 2,666 pulses

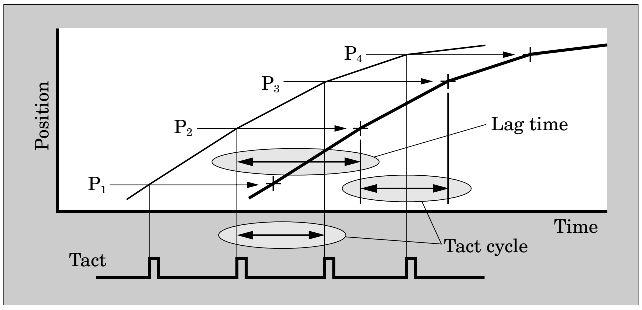
○ Fig. 7(c): 2,000 r/min

Ep = (2,000 × 2,000 × 4) ÷ (60 × 50) = 5,333 pulses

There are differences between the calculated error pulses and the measured values in Fig. 7, but this is unrelated to stability of the synchronous speed because gain adjustments of the analog velocity reference signals between MA2 and the amplifier are somewhat out of alignment.

In the synchronous operation function of the SX, by means of the position reference signal mode (refer to paragraph 2.2), target position reference signaling is performed from the “Multi-function 1-axis FB” to the MA2 side every tact cycle. As shown in Fig. 8, the reference position data P_n calculated with SPH are sent via the SX bus to the MA2 every tact cycle. On the MA2 side, after receiving the data, a distributed calculation of the reference pulses is performed so as to reach the target position after the setting time (lag time). Further, the data-receiving intervals (tact cycles) are automatically measured, and a frequency calculation is performed so as to distribute the pulses at the receiving intervals. By means of this system, even if the calculations of MA2 are performed with a 0.8 ms cycle compared to the 3 ms tact cycle, the velocity reference signal has no ripple and the motor can rotate with a stable velocity. Since the signal to MA2 is the position data, the compensation of data detected with pulses such as the length of phase compensation for synchronous operation, lag compensation, etc., is simply realized by incorporating addition and subtraction of the position data into the user FB.

Fig.8 Operation timing for position control mode



4. Application to Special-Purpose Cutting Machine

Figure 9 shows an example of a 2-axis cutting system combining a rotary axis and linear axis. A product is turned by motor M1 and a torch moves linearly with a motor M2 and ball screw. As shown in Fig. 10, many machines have 2-axis orthogonal configurations and cut with linear interpolation and arc interpolation functions of position-control modules, but machines whose configuration combines a rotary axis and linear axis can be made smaller. Conventionally, the control of a machine configured as in Fig. 9 required a dedicated controller. Otherwise, the linear axis was made to synchronize with the rotary axis using a cam pattern registered to an electronic cam module (NC1F-EC1 of MICREX-F).

The SX performs a coordinate calculation with a high-speed floating-point calculation instruction, and operates with position reference every tact cycle. Operation with the electronic cam module causes the response of the cam axis side to lag the main axis operation at the time of acceleration and deceleration of the main axis because of the following action of the cam axis, even if a prediction calculation treatment of the main axis position is added. In contrast, in an SX system, there is no response lag at acceleration and deceleration due to the calculation of commanded position because positions are calculated for both axes.

The contents of the calculation will be explained

Fig.9 Combination of rotary axis and linear axis

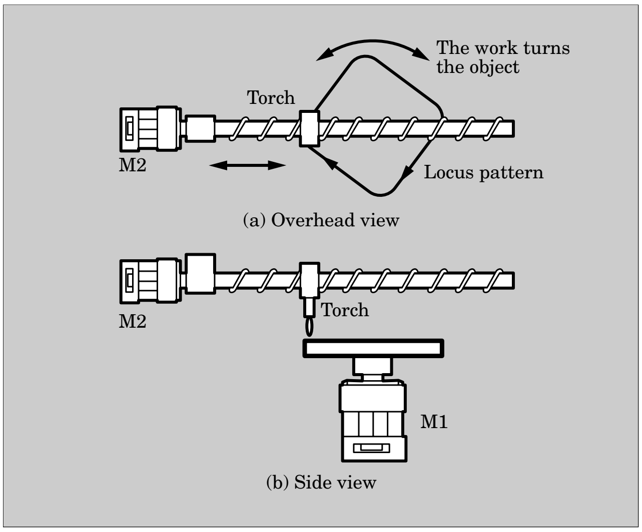


Fig.10 System configuration for 2 orthogonal axes

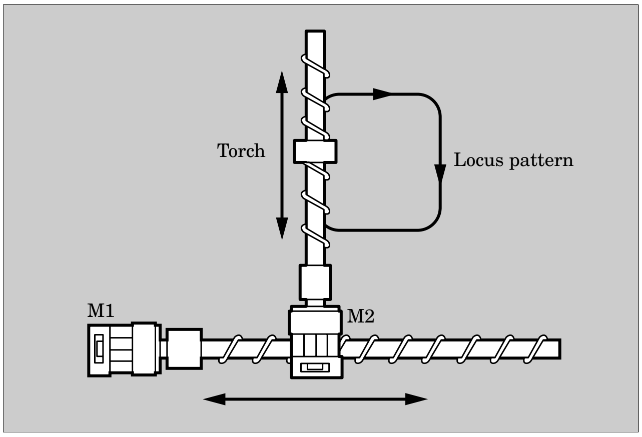


Fig.11 Operation pattern

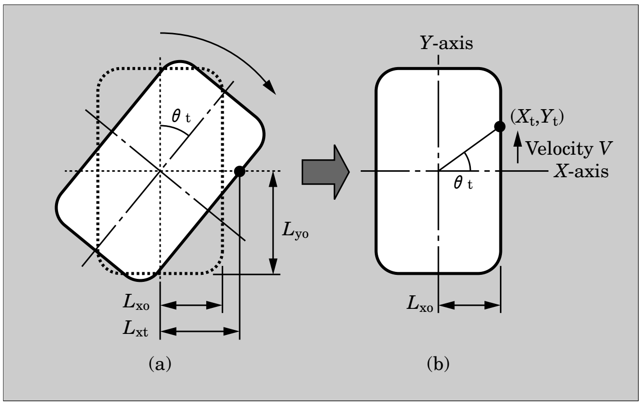
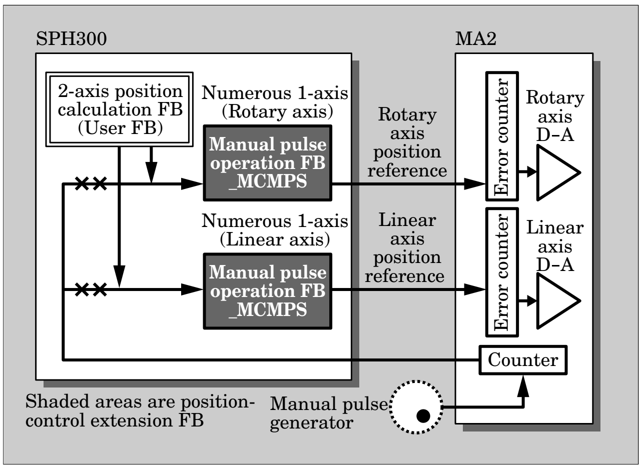


Fig.12 Control block diagram for special-purpose cutting machine



with Fig. 11. Figure 11(a) shows the fed quantity of the linear axis when the product turns by θ_t. L_{x0} is the length from the reference point at the start of operation (center of a rectangular) to the cutting start point. If the position of the torch L_{xt} when the product turns by θ_t, the length moved ΔL_t is:

$$\Delta L_t = L_{xt} - L_{x0} \quad (2)$$

Actually, the coordinate calculation is performed from the reference point as the product is fixed as shown in Fig. 11(b).

If the cutting velocity setting value is V, the X-axis and Y-axis coordinate positions (X_t and Y_t) are:

$$X_t = L_{x0} \quad (3)$$

$$Y_t = V \times t \quad (4)$$

[Calculation formula while moving toward vertical direction in the example of Fig. 11(b)]

The turning angle θ_t from the X-axis and Y-axis coordinates (X_t and Y_t) is:

$$\theta_t = \mathrm{atan}\,(Y_t / X_t) \quad (5)$$

The length from the center to (X_t and Y_t) is:

$$L_t = L_{x0} / \cos\,(\theta_t) \quad (6)$$

or

$$L_t = \sqrt{(X_t^2 + Y_t^2)} \quad (7)$$

In Fig. 11(b), the calculation formulae for X-axis and Y-axis coordinates at corners and feeding along the horizontal direction are different from formulae (3) and (4). However, the coordinate positions are calculated first, next, the rotary axis angle and linear axis position are calculated and then position control is performed.

The FB configuration that was used in this cutting machine is shown in Fig. 12. The coordinate calculations and position calculations of formulae (3) to (7) were performed with a user FB. The calculated 2-axis position results become an input of the manual pulse operation multi-function 1-axis PTP FB. In manual pulse operation, normally, a manual pulse generator is connected to MA2, and position control is performed according to the number of the input pulses counted with a counter in MA2. The application example in this chapter utilizes high-speed floating-point calculation, and replaces the pulse counter of the manual pulse generator with an SPH calculator (user FB) to execute the special operation.

5. Conclusion

This paper introduced the unevenness in the accuracy of an SX system when applied to a synchronous operation machine. The synchronous accuracy required for running a cutting machine such as a flying shear differs depending on the product, but the accuracy proved in this system could be applied to many machines. However, there are machines such as printers for multi-color poster printing that require higher accuracy and higher speed response for position detection resolution, stability of error unevenness, etc. In the future, we intend to respond to the requirements of high accuracy and high speed by enriching the compensation processing FBs that are matched to various machines in an SX position-control system.

Further, in application to special cutting machine, we described an overview of the position-control operation which was conventionally difficult in PLC position-control module. The SX system has a function that performs position-control by means of position reference to MA2 and MP2. When integrating operation pattern calculation with the user FB on the SPH side (similar to drawing a picture of the operation pattern on the screen of a personal computer), special operations can be realized easily.

The authors will be glad if this paper is useful for applying these functions to actual machines that require synchronous operation and rotary axis operation, such as packing machines and various manufacturing machines in addition to printing machine.