Development of the *SANMOTION R 3E Model Safety* Servo Amplifier

Hideki Netsu Yoshiyuki Murata Michio Kitahara Kenichi Fujisawa Haruhiko Kamijo

Yuuki Nakamura Yasuhiro Wakui Mitsuhiro Nishimura Naoki Kubo Yoshiki Okada

1. Introduction

In recent years, Europe in particular has established international safety standards for a variety of industries and equipment, including machine tools, industrial robots, and medical devices. Such standards place a greater emphasis on "functional safety," whereby hazards and risks are reduced to a tolerable level by implementing safety functions using electrical, electronic, and programmable electronic control systems. Even in Japan, there is an increasing demand from the market to support this functional safety standard primarily in the machine tool and industrial robot industries and this has led to initiatives for even higher safety functions.

Components such as servo amplifiers adopted in equipment which are required to have high safety must be equipped with the various safety functions defined in international standards and obtain safety standard certification.

SANYO DENKI already offers the widely-used *SANMOTION R ADVANCED MODEL* and *SANMOTION R 3E Model* which are equipped with STO (Safe Torque Off) as a basic safety function. However, in response to the aforementioned demands, we have expanded our lineup with the addition of the *SANMOTION R 3E Model Safety* servo amplifier which supports a variety of safety functions. This article describes the specifications and features of the new model.

2. Product Overview

2.1 Appearance

Figure 1 shows the 200 VAC input, analog/pulse train interface model (left) and the EtherCAT interface model (right).

Fig. 1: Appearance (10 A)

2.2 General specifications

Table 1 provides the general specifications of the 200 VAC input model, while Figure 2 is a structural drawing. The new safety functioned servo amplifier (hereinafter "new model"), the *SANMOTION R 3E Model Safety*, can be configured by attaching a special-purpose board (hereinafter "safety module") on the side of the existing *SANMOTION R 3E Model* analog/pulse train interface or EtherCAT interface servo amplifier. Moreover, the safety module and side cover are standardized, so all amplifier capacities of each input power specification are compatible with the expansion.

Table 1: General specifications

Input power specifications	100, 200, 400 VAC
Amplifier capacity	All capacities
Compatible motor	*SANMOTION R* series motors
Compatible encoder	Absolute encoder (for incremental systems, battery-backup, battery-less) Wire saving pulse encoder
User interface	Analog/pulse train interface EtherCAT interface

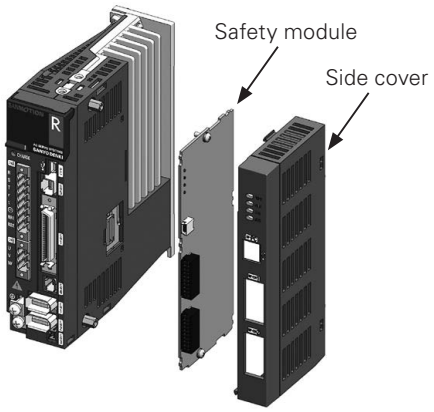


Fig. 2: Structural drawing (10 A model)

The new model is compatible with our standard encoders, and can be used with the *SANMOTION R* servo motors. This means that safety functions can be added by simply replacing the existing servo amplifier with this new, safety function-equipped model, eliminating the need to make changes to the servo motor or equipment itself.

3. Functions and Features

Table 2 shows the safety specifications of the new model. The new model uses software to monitor motor speed and position to deliver a variety of complex safety functions. Furthermore, it also supports a safety output function whereby the circuit has a self-diagnosis function.

Table 2: Functional safety specifications

Item			**Safety performance**	
Safety function	**IEC/EN 61800-5-2**		EN 61508 IEC/EN 62061	ISO 13849-1: 2015 EN ISO13849-1: 2015
	Safe Torque Off (STO)		SIL3 SILCL3	PL=e Category 3
	Safe Stop 1 (SS1)			
	Safe Stop 2 (SS2)			
	Safe Operating Stop (SOS)			
	Safely-Limited Speed (SLS)			
Safety output function	**Safe Brake Control (SBC)**			
	Safe Speed Monitor (SSM)			
Safety I/O	**Configuration**		Redundant configuration (SF-CN1, SF-CN2)	
	Input device	**No. of inputs**	5 points x 2 systems (sink/source)	
		Mismatch detection time	10 s	
		Diagnosis cycle	10 min	
		Off-shot pulse width	Less than 1 ms	
	Output device	**No. of outputs:**	3 points x 2 systems (source)	
		Diagnosis cycle	10 min	

3.1 Safety functions

Table 3 describes the safety functions. The new model is equipped with five safety inputs to execute each of these five functions. Moreover, parameters can be used to determine which safety function is executed by each safety input.

Table 3: Safety function overview

Safety function	Description
STO	Safely shuts off power supply to the motor.
SS1	Safely reduces motor speed until the motor stops, then shuts off power supply.
SS2	Safely reduces motor speed until the motor stops, then monitors stop position.
SOS	Monitors the motor stop position, and if the safe stop range is exceeded, shuts off power supply to the motor.
SLS	Monitors motor speed, and if the safe speed range is exceeded, shuts off power supply to the motor.

Table 4 lists the safety inputs and corresponding selectable safety functions. Safety inputs SFIA and SFIB support all safety functions and the appropriate function can be selected to suit the purpose.

SFIC through SFIE function as inputs for Safely-Limited Speed (SLS). Seven stages of safe speed range (speed limited levels) can be selected through ON/OFF combinations of the three inputs. Moreover, for fine-tuned control, SFIA and SFIB can be used to expand the safe speed range up to a maximum of 31 stages.

With multiple safety inputs and the freedom to select which safety function to execute, the safety functions can be used flexibly to match the device operating conditions. It is also possible to execute multiple safety functions simultaneously.

Table 4: Safety inputs and selectable safety functions

Safety input	Safety function				
	STO	SS1	SS2	SOS	SLS (SSM)
SFIA	○	○	○	○	○
SFIB	○	○	○	○	○
SFIC	–	–	–	–	○
SFID	–	–	–	–	○
SFIE	–	–	–	–	○

○: Selectable

3.2 Safety output functions

Table 5 provides descriptions of the safety output functions and monitor output functions. The new model supports two types of safety outputs and three types of monitor outputs, which are selectable using parameters.

Table 5: Descriptions of the safety output function and monitor output function

Output function		Description
Safety output function	SBC	Outputs a signal to control the motor's holding brake.
	SSM	Outputs a signal to ensure the motor is within a safe speed range.
Monitor output function	INM	Outputs a signal to notify the safety input status.
	STA	Outputs a signal to notify the safety-function execution status.
	STO	Outputs a signal to notify the motor power shut off status.

Table 6 lists safety outputs and the corresponding selectable safety output functions/monitor output functions.

Table 6: Safety outputs and corresponding selectable safety output functions/monitor output functions

Safety output	Safety output function		Monitor output function		
	SSM	SBC	INM	STA	STO
SFOA	–	○	○	○	○
SFOB	–	○	○	○	○
SFOC	○	○	○	○	○

○: Selectable

Safe Speed Monitor (SSM) can be outputted from SFOC and, in the same way as Safely-Limited Speed, a maximum of 31 stages of safe speed ranges can be selected through different combinations of the safety inputs.

Safe Brake Control (SBC) is a signal for the motor's holding brake control and can be outputted from all safety outputs.

The Safety Input Status Monitor (INM) outputs the statuses of safety inputs SFIA and SFIB to SFOA and SFOB, and the combined statuses of SFIC through SFIE to SFOC. This output function enables equipment failures to be monitored in the path from the safety inputs to the safety outputs of the servo amplifier circuit.

Moreover, by utilizing the Safety Function Operating Monitor (STA) and Safe Torque Off (STO) status monitor,

the new model can monitor consistency between the safety inputs and servo amplifier internal status, as well as assess the amplifier's status.

4. Achieving Required Safety Levels

4.1 Basic structure of safety functions

As Figure 3 shows, the safety module for the new model duplicates the "input devices," "logic," and "output devices" and uses a Cat. 3 (ISO 13849-1) configuration which has a mutual monitoring function.

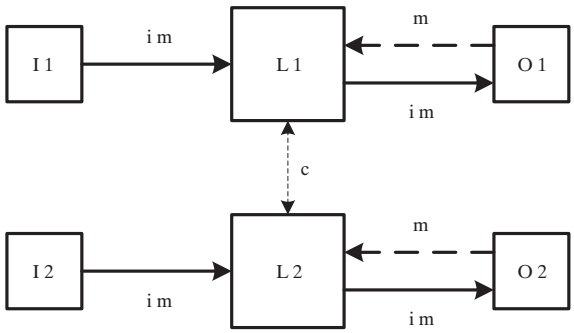
The safety input/output circuit has two I/O connectors (SF-CN1, SF-CN2) and all safety I/O signals have been organized into two systems. As such, when the user executes a safety function, there is a need to simultaneously control both safety input signal systems and this new model can detect a failure if there is a logic mismatch between the two systems. Moreover, the safety I/O circuit has a self-diagnosis function and regularly monitors circuit failures.

The safety module has duplicated voltage generating circuit and it is equipped with a self-diagnosis function. Hazardous movements of equipment are avoided by regularly monitoring mutual voltage faults (excessive voltage, low-voltage), shutting off the power supply to a system if a fault has been detected and transferring into a safe state (in the case of SANYO DENKI, a Safe Torque Off state).

The major components that make up the logic unit have also been duplicated and equipped with a self-diagnosis function. The main diagnosis functions are shown below.

- Processor diagnosis
- Memory diagnosis
- Clock diagnosis
- Program mutual monitoring, etc.

As shown above, by duplicating all circuits and equipping them with a self-diagnosis feature, the safety function is not lost and safety can be maintained when a failure occurs on single system.



i m	Internal connection
c	Mutual monitoring
I 1, I 2	Input unit
L 1, L 2	Logic
m	Monitoring
O 1, O 2	Output unit

Fig. 3: Basic configuration

4.2 Encoder diagnosis

With a Cat. 3 configuration, the encoder is also included as an input device. As such, the encoders should have been made redundant and able to detect encoder failures from the positional information of these encoders. Or, the encoder adopted should have obtained functional safety certification and be able to detect failures from the encoder's self-diagnosis. However, these methods would require significant changes to the equipment configuration, thus increase the customer's burden.

As such, SANYO DENKI has newly developed and embedded a diagnosis function in the safety module for the new model that regularly detects encoder failures. As a result, a high-level safety function has been achieved simply with our standard encoder, which has not obtained any functional safety certification.

4.3 Parameter settings

The safety module has parameters specifically for safety functions (hereinafter "safety parameters") separate from the servo amplifier. Just as servo parameters, safety parameters can be edited using our setup program, the *SANMOTION MOTOR SETUP* tool. The following special-purpose functions have been added for safety parameters.

- Requires a password to authorize parameter changing.
- Displays final confirmation notification at parameter updating.
- Displays "power re-boot" notification after parameter changes.
- Records history of additional information such as when parameters were changed and which tool versions were used.
- Prohibits input of values if parameter changing has not been authorized.

The above special-purpose functions prevent unintended parameter changes and secure parameter safety.

4.4 Safety level

By adopting the above-described redundant configuration with self-diagnosis and mutual monitoring in addition to a diagnosis function for the encoder, the new model achieves SIL3 for EN 61508, SILCL3 for IEC 62061, and PL=e for ISO 13849-1 which is the highest level of safety in the industry (as of April 2017 according to SANYO DENKI's investigation) even when combined with a standard encoder.

5. Conclusion

This article has presented an overview and features of the *SANMOTION R 3E Model Safety* servo amplifier that has been newly added to the AC servo amplifier *SANMOTION R 3E Model* lineup.

(1) Features five safety functions to suit the specific application of equipment, including "decelerating and stopping the motor safely then shutting off motor power" and "monitoring the motor to ensure rotation at a safe speed."
(2) Enables selection of up to 31 stages by using a maximum of five safety inputs for Safely-Limited Speed and Safe Speed Monitor.
(3) Equipped not only with the safety output functions of Safe Brake Control and Safe Speed Monitor, but also three types of status monitoring output functions so that the equipment can monitor the servo amplifier to ensure operation of safety functions.
(4) By developing a new encoder failure diagnosis function, we have realized safety functions with one of the industry's highest safety levels, and by combining the new model with our standard *SANMOTION R* series servo motors and encoders.

We believe this new model will greatly contribute to enhancing equipment safety and obtaining functional safety certification.

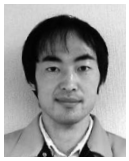
Moving forward, SANYO DENKI wishes to continue development of products that can contribute to the creation of safety systems by our customers with our focus on obtaining both communication and safety certification and enhancing safety levels.

Hideki Netsu
Joined SANYO DENKI in 1989.
Servo Systems Div., Design Dept. 2
Works on the design and development of servo amplifiers.

Yoshiyuki Murata
Joined SANYO DENKI in 1995.
Servo Systems Div., Design Dept. 2
Works on the design and development of servo amplifiers.

Michio Kitahara
Joined SANYO DENKI in 1991.
Servo Systems Div., Design Dept. 2
Works on the design and development of servo amplifiers.

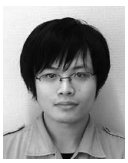
Kenichi Fujisawa
Joined SANYO DENKI in 1992.
Servo Systems Div., Design Dept. 2
Works on the design and development of servo amplifiers.



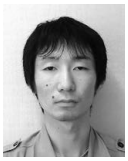
Haruhiko Kamijyo
Joined SANYO DENKI in 2005.
Servo Systems Div., Design Dept. 2
Works on the design and development of servo amplifiers.

Yuuki Nakamura
Joined SANYO DENKI in 2010.
Servo Systems Div., Design Dept. 2
Works on the design and development of servo amplifiers.

Yasuhiro Wakui
Joined SANYO DENKI in 2012.
Servo Systems Div., Design Dept. 2
Works on the design and development of servo amplifiers.



Mitsuhiro Nishimura
Joined SANYO DENKI in 2014.
Servo Systems Div., Design Dept. 2
Works on the design and development of servo amplifiers.



Naoki Kubo
Joined SANYO DENKI in 2015.
Servo Systems Div., Design Dept. 2
Works on the design and development of servo amplifiers.

Yoshiki Okada
Joined SANYO DENKI in 2015.
Servo Systems Div., Design Dept. 2
Works on the design and development of servo amplifiers.