Development of the Induction Motor for Machine Tool Spindles and Servo Amplifier "SANMOTION S"

Takashi Sekiguchi Masahiro Kidou Yuusuke Shimura Yuji Ide

Masahisa Koyama Michio Kitahara Hiroaki Koike Haruhiko Chino

Shunichi Miyazaki Noriaki Kasuga Satoshi Yamazaki Hiroyuki Fukuchi

1. Introduction

Spindles for machine tools require servo systems with a wide range of rated output characteristics, so induction motors have long been used as they can easily achieve these characteristics. Recent machine tools have developed even higher productivity, so there are demands for spindle servo systems with both higher torque and higher speeds.

This document describes the features and technologies from the development of high-speed operation induction motors and servo amplifiers based on these demands.

2. Product Overview

2.1 Induction motor

Induction motors are made with a simple and robust construction that does not require costly magnets, making them suitable for lower costs.

Furthermore, compared to synchronous motors, which require magnets, the flux in field weakening area can be controlled more easily. By optimizing the winding specifications, wider rated output characteristics can be obtained, making it suitable for spindle motors on machine tools.

The developed spindle induction motor "SANMOTION S" series makes use of these features, and by raising the maximum torque and reducing the rotor inertia, the maximum acceleration is improved, making this a motor suitable for high speed operations. Fig. 1 shows the appearance of the spindle induction motor (4.5 kW). Table 1 shows the specifications of the spindle induction motor.

2.2 Servo amplifier

The developed AC servo amplifier "SANMOTION S" series is a single axis, self-powered amplifier requires external regenerative resistor. There are two models with different command formats. One uses analog pulse train interface that handles pulse train input and analog voltage input, while the other uses EtherCAT interface that handles EtherCAT communications. It supports a pulse encoder as the applicable encoder.

The servo amplifier has the compatible mounting and dimensions as the AC servo amplifier "SANMOTION R" series Advanced Model. By using miniature chip parts and a next-generation power semiconductor, it achieves dramatically smaller size compared to the conventional servo amplifier for induction motor SZ series.

The connectors emphasize ease of use, so the connectors - connected to the host controller, the encoder connector, monitor connector, and setup software connection connector - are compatible with the AC servo amplifier "SANMOTION R" series Advanced Model, and the encoder connector signal is just for the induction motor drive.

Fig. 2 shows the appearance the 150 A output capacity model. Table 2 shows the servo amplifier specifications.

Fig. 1: Appearance of the spindle induction motor "SANMOTION S" series

Fig. 2: Appearance of the 150 A AC servo amplifier "SANMOTION S" series

Table 1: Specifications of the spindle induction motor" SANMOTION S" series

	4.5 kW	3.2 kW
Motor size (mm)	□160 × 367L	□160 × 432L
Mass (kg)	31	36
Rated output (kW)	4.5	3.2
Max. output (kW)	13.5	9.6
Base speed (min^{-1})	3000	1500
Max. speed (min^{-1})	15000	12000
Rated torque (N·m)	14.3	20.4
Max. torque (N·m)	43.0	61.1
Protection class	IP55	IP55
Rotor inertia ($kg \cdot m^2$)	0.00483	0.00686

Table 2: Specifications of the AC servo amplifier "SANMOTION S" series

Power voltage	200 V AC
Amplifier output	150 A
Applicable motor capacity	3.2 kW, 4.5 kW
Applicable encoder	500 to 65,535 x 4 P/R (A, B, Z pulse)
Control functions	Position, speed, torque control, orientation control
Control method Sine	wave PWM control
Speed control range	1:5000 (internal command)
Frequency characteristic	200 Hz
Sequence signal	Analog pulse train amplifier: Input 8 ch., output 8 ch. EtherCAT amplifier: Input 6 ch., output 2 ch.
Operating ambient temperature	0 to 55˚C
Structure	Tray type
Conforming standards	UL, CE, and RoHS directive

3. Product Features

The spindle motor uses large torque to realize heavy cutting at low speed, synchronous machining at mid-speed, and machining at high speed, so the following characteristics are demanded:

(1) Large torque at low speed
(2) Capability for high-speed rotation
(3) Capability for short response time
(4) Short acceleration and deceleration time

3.1 Low inertia

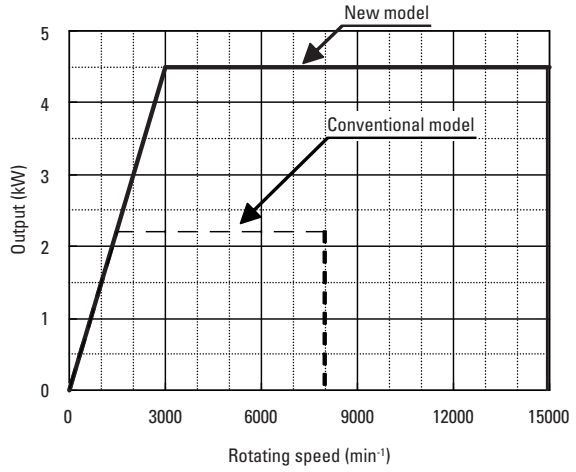
By optimizing the rotor external dimension, changing the rotor slot, and making the rotor conductor out of aluminum, the spindle induction motor "SANMOTION S" series greatly reduced the rotor inertia compared to the conventional motor. Furthermore, by die-casting the rotor out of aluminum, the cost can also be reduced.

3.2 Wide range rated output area

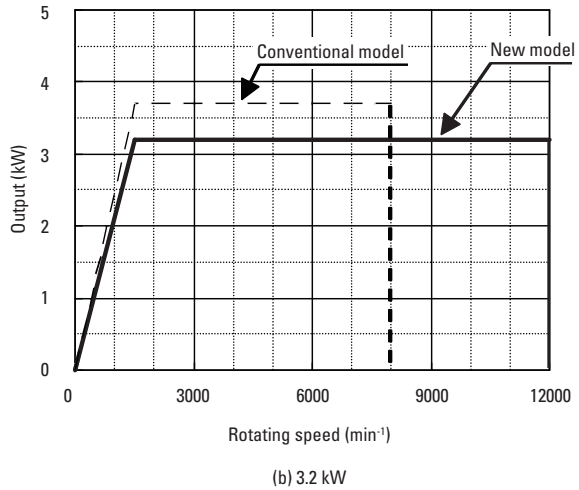
By optimizing the winding specifications, the spindle induction motor “SANMOTION S” series realized a wide range rated output region. With this, the max. rotating speed was increased 1.5 times to 1.9 times higher than the conventional model. Fig. 3 shows an example of output versus rotation speed characteristics in the continuous region.

3.3 High torque

The spindle induction motor “SANMOTION S” series uses the maximum current for the servo amplifier, improving the instantaneous torque 1.5 times compared to the conventional model. Fig. 4 shows a comparison of torque versus rotation speed characteristics in the instantaneous region.

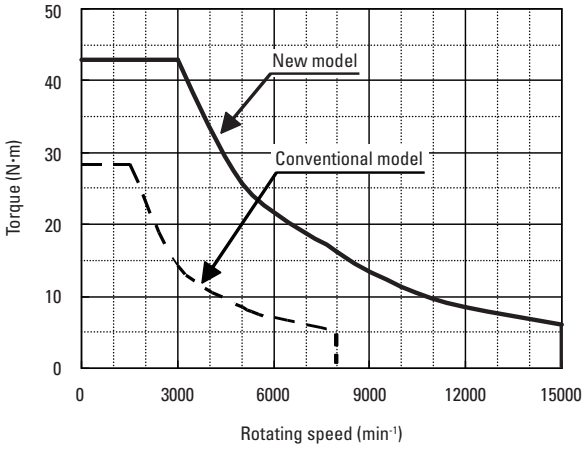


(a) 4.5 kW

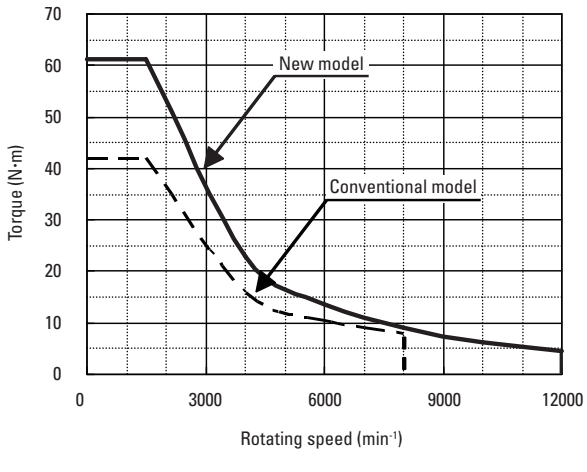


(b) 3.2 kW

Fig. 3: Output vs. rotation speed characteristics in the continuous region



(a) 4.5 kW



(b) 3.2 kW

Fig. 4: Torque versus rotating speed characteristics in the instantaneous region

3.4 High maximum angular acceleration

The spindle induction motor "SANMOTION S" series reduces the rotor inertia and uses a wide range, high torque to greatly improve the maximum acceleration compared to the conventional model. Fig. 5 shows a comparison of the maximum angular acceleration to the conventional model.

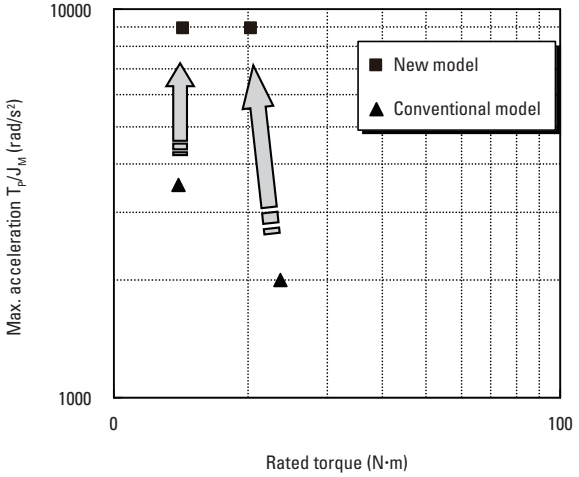


Fig. 5: Max. angular acceleration vs. rated torque characteristics

3.5 High speed flux control

Induction motor requires excitation current for flux. At high speeds, field weakening controls are performed to suppress inverter output voltage saturation by reducing the excitation current, it also reduce the flux. However, flux operates with a delay compared to the excitation current, so in applications with sudden acceleration and deceleration, the changes in flux will come after the changes in rotating speed, and stable torque controls cannot be performed. As the weak field control method, the AC servo amplifier "SANMOTION S" series developed a method of directly controlling the flux, change from controlling the excitation current. Using the motor parameters to estimate flux, a flux control loop is constructed. With this, the flux response becomes faster and the flux can follow field weakening from sudden motor acceleration and deceleration.

3.6 Torque up control

Induction motors must control torque current and excitation current. In conventional models, the excitation current and torque current were controlled independently, and the maximum output current of the inverter was not used effectively.

In the "SANMOTION S" series, to effectively use the maximum output current of the inverter, torque controls are performed with excitation current taken into consideration. In the conventional model, the maximum current supplied to the motor fell due to field weakening, but with this method in the "SANMOTION S" series, the maximum current supplied to the motor does not fall, even with field weakening. Therefore, the torque in the high-speed region is improved about 20%.

3.7 Torque constant compensation control

With general purpose induction motor controls, the torque constant falls due to field weakening at mid and high speed ranges. A lower torque constant leads to lower response speed, so synchronous machining accuracy with the feed shaft also fell.

For the "SANMOTION S" series, a control was developed that compensates the torque constant at mid-speed range to prevent the synchronous machining accuracy with the feed shaft from falling.

3.8 High speed vector control

With the flux control loop applied to the high speed flux controls, torque up controls that take into consideration excitation current, and the torque constant compensation controls, the vector controls, that is essential to torque controls for the induction motor, have become faster. Fig. 6 shows velocity loop frequency response with this control, and it shows high speed response of 200 Hz fc. With a higher resolution encoder, the response is raised up to 500 Hz fc.

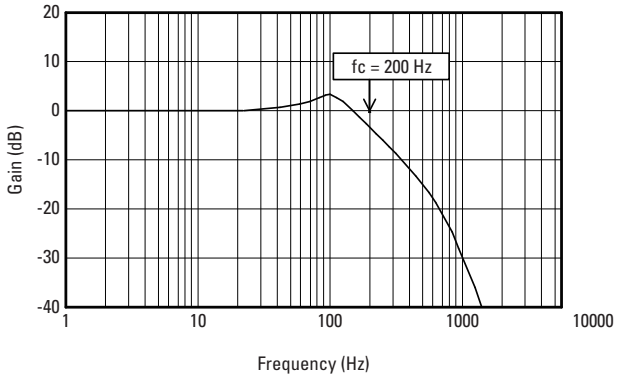


Fig. 6: Velocity loop frequency response

Furthermore, this high speed vector control and low inertia, high torque induction motor achieves an acceleration and deceleration time to the maximum rotation speed of 300 to 500 ms, a great reduction compared to the conventional model time of 2 to 3 seconds. Fig. 7 shows the acceleration and deceleration characteristics for the 4.5 kW motor up to 15,000 min^{-1}.

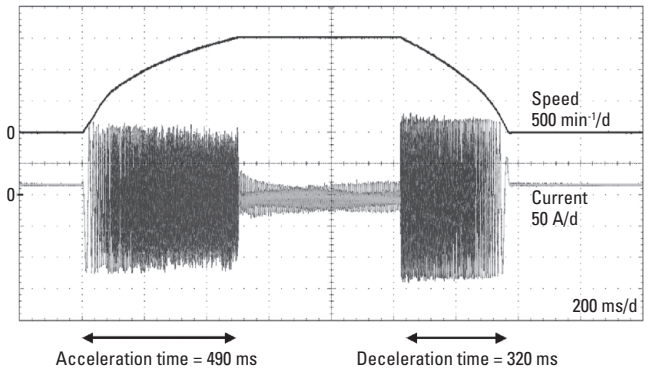


Fig. 7: Acceleration and deceleration characteristics up to max. rotating speed

3.9 High speed orientation

In order to position the spindle servo motor at the desired position, there is a built-in orientation function that runs speed controls until a fixed speed (orientation speed), switches the control mode from speed control to position control, and performs position stop controls based on the command stop position. Fig. 8 shows these operations.

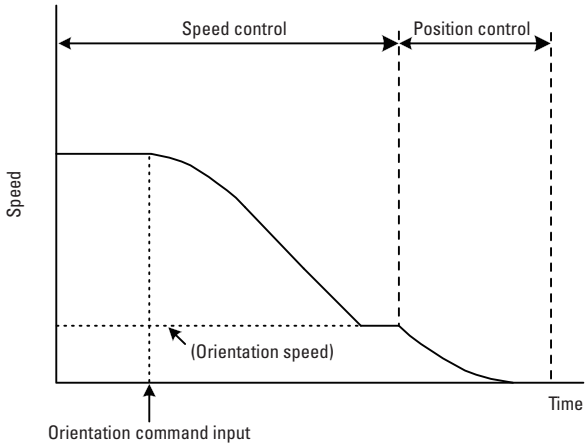


Fig. 8: Orientation operations

4. Conclusion

This document described the spindle induction motor "SANMOTION S" series and the AC servo amplifier "SANMOTION S" series.

Using this induction motor or servo amplifier provides the following effects.

(1) With a low inertia, high torque induction motor and high speed vector controls, the acceleration and deceleration time for the spindle can be reduced, thus shortening the cycle time.

(2) This newly developed model has a wide rated output region, enabling both heavy cutting at low speed and machining at high speed.

(3) With high speed vector controls and torque constant compensation controls, high accuracy synchronous control with the feed shaft can be realized.

(4) When the induction motor is mounted to a machine and when the servo amplifier is mounted to a control panel, the machine or control panel can be made smaller, leading to resource conservation for machines.

As described above, the AC servo system "SANMOTION S" series is suitable for machine tools that require high speed operations, and it will lead to significant improvements to machine performance over conventional models.

In the future, we plan to expand the capacity lineup and extend the induction motor drive function. We will continue to actively advance technological developments to improve convenience, quality, and productivity.

Takashi Sekiguchi
Joined Sanyo Denki in 1990.
Servo Systems Division, 1st Design Dept.
Worked on the development and design of servo motors.

Masahiro Kidou
Joined Sanyo Denki in 2004.
Servo Systems Division, 1st Design Dept.
Worked on the development and design of servo motors.

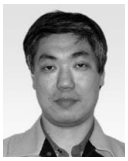
Yuusuke Shimura
Joined Sanyo Denki in 2010.
Servo Systems Division, 1st Design Dept.
Worked on the development and design of servo motors.

Yuji Ide
Joined Sanyo Denki in 1984.
Servo Systems Division, 2nd Design Dept.
Worked on the development and design of servo amplifiers.

Masahisa Koyama
Joined Sanyo Denki in 1990.
Servo Systems Division, 2nd Design Dept.
Worked on the development and design of servo amplifiers.

Michio Kitahara
Joined Sanyo Denki in 1991.
Servo Systems Division, 2nd Design Dept.
Worked on the development and design of servo amplifiers.

Hiroaki Koike
Joined Sanyo Denki in 1988.
Servo Systems Division, 2nd Design Dept.
Worked on the development and design of servo amplifiers.



Haruhiko Chino
Joined Sanyo Denki in 1983.
Servo Systems Division, 2nd Design Dept.
Worked on the development and design of servo amplifiers.

Shunichi Miyazaki
Joined Sanyo Denki in 1990.
Servo Systems Division, 2nd Design Dept.
Worked on the development and design of servo amplifiers.

Noriaki Kasuga
Joined Sanyo Denki in 2007.
Servo Systems Division, 2nd Design Dept.
Worked on the development and design of servo amplifiers.

Satoshi Yamazaki
Joined Sanyo Denki in 2001.
Servo Systems Division, 2nd Design Dept.
Worked on the development and design of servo amplifiers.

Hiroyuki Fukuchi
Joined Sanyo Denki in 2010.
Servo Systems Division, 2nd Design Dept.
Worked on the development and design of servo amplifiers.