GE Fanuc Automation

Computer Numerical Control Products

AC Spindle Motor Series (Serial Interface)

Descriptions Manual
(Volume 4 of 4)

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Warning

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CONSTITUTION OF THIS MANUAL

This manual (B-65042E) is composed of the following 4 volumes.

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I. AC SPINDLE MOTOR S series

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CONFIGURATION AND ORDER DRAWING NUMBER/ CONNECTIONS/
ALLOWABLE RADIAL LOAD/ ASSEMBLING ACCURACY/ EXTERNAL DIMENSIONS

II. AC SPINDLE MOTOR P series

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IV. AC SPINDLE MOTOR HV series (380/415 VAC INPUT)

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NON HOLLOW SHAFT AND WITHOUT SPEED RANGE SWITCHING TYPE/
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CABLE ROUTING DIAGRAM/ EXAMPLE OF INSTALLATION/ CONNECTION/ CABLES/
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CONNECTIONS/ DIMENSIONS/
CHECKING OUTPUT WAVEFORM AND ADJUSTING THE PREAMPLIFIER
SENSOR AND PREAMPLIFIER FITTING DIAGRAMS/ SENSOR FITTING PROCEDURE

XIV. HIGH-RESOLUTION POSITION CODER

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SHAPE/ INSTALLATION CONDITION AND CAUTIONS

XV. SPEED RANGE SWITHING CONTROL

GENERAL/ CONFIGURATION AND DRAWING NUMBER/ SPECIFICATIONS/ CONNECTIONS/
INTERFACE SIGNALS/ SEQUENCE/
ALARMS RELATED TO SPEED RANGE SWITCHING CONTROL/ CAUTIONS IN USE

XVI. SPINDEL SWITCHING CONTROL

GENERAL/ FUNCTIONS/ RESTRICTIONS/
CONFIGURATION AND ORDERING DRAWING NUMBERS/
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PARAMETERS/ SPINDLE CONTROL SIGNALS/ SEQUENCE/
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XVII. SWITCHING UNIT

GENERAL/ CONFIGURATION/ ORDER DRAWING NUMBER/ SPECIFICATIONS/
EXTERNAL DIMENSIONS AND DIMENSIONS FOR MOUNTING/ CONNECTION/
CAUTIONS IN USE

PREFACE

The models covered by this manual, and their abbreviations are:

Series name	Model name
FANUC AC SPINDLE MOTOR S series	0.5S, 1S, 1.5S, 2S, 3S, 6S, 8S, 12S, 15S, 18S, 22S, 30S, 40S
FANUC AC SPINDLE MOTOR Power up series	8P, 10P, 12P, 15P, 16P, 18P, 22P, 30P, 40P, 50P, 60P
FANUC AC SPINDLE MOTOR High-speed series	6VH, 8VH, 12VH
FANUC AC SPINDLE MOTOR 380/415V series	30HV, 40HV, 60HV
FANUC AC SPINDLE MOTOR LTQUID-COOLED series	· Non hollow shaft/without speed range switching type L6/12000, L12/6000, L15/6000, L18/6000, L22/6000
	· Hollow shaft/with speed range switching type L12/10000, L15/10000, L22/10000, L26/10000, L40/8000, L50/8000
FANUC AC SPINDLE MOTOR IP65 series	1S, 1.5S, 2S, 3S

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I. FANUC AC SPINDLE MOTOR series

1. FEATURES

The FANUC AC Spindle Motor series, which is a spindle motor series for CNC machine tools, has been used in many machine tool applications and provides the following outstanding features based on technology FANUC has accumulated over the years:

(1) From among a wide variety of motor series, the user can choose the motor ideal for his or her specific requirements. Also, the motors of each series are compatible; that is, they can be freely interchanged.

(2) By employing a unique stator cooling system that directly air-cools the electromagnetic steel sheet (for the S, P, and HV series), the series has easily achieved high power output and high-speed revolution in a compact enclosure.

(3) The series has achieved a vibration within V5 (V10 for some models) at high-speed revolution by accurate rotor balance adjustment.

(4) By reducing the rotor inertia, a shorter acceleration/deceleration time has been achieved.

(5) The user can easily select the air flow direction (either front or rear) of the fan motor to minimize the thermal deformation of the machine.

(6) Motors are available which have a built-in position coder required for synchronizing spindle feed with motion along the Z-axis and for rigid tapping. In addition, some motors have a built-in, high-resolution magnetic pulse coder to allow spindle synchronization control and C-axis contouring.

2. CONFIGURATION OF THE FANUC AC SPINDLE MOTOR series

The FANUC AC Spindle Motor series consists of the series listed below with their features.

(1) S series: This series is the standard series. It has been used in the field successfully for a long time.

(2) P series: This series has a wide constant output range of 1:8. As a result, some of the mechanisms, such as the gear change mechanism, has been eliminated. This has greatly simplified the mechanical structure.

(3) VH series: This series has achieved high-speed revolution by using oil-mist lubrication for the bearings. This series also minimizes the temperature rise by using liquid cooling.

(4) HV series: This series can be connected with a 380/415 VAC power supply directly without using a power transformer.

(5) LIQUID-COOLED series: This series uses liquid cooling to minimize the temperature rise, and has achieved a low-speed large torque with speed range switching. In addition, some models are directly linked with the spindle, and have a shaft with a through-hole to enable the flow of coolant.

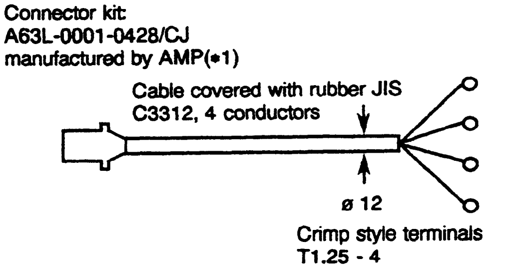
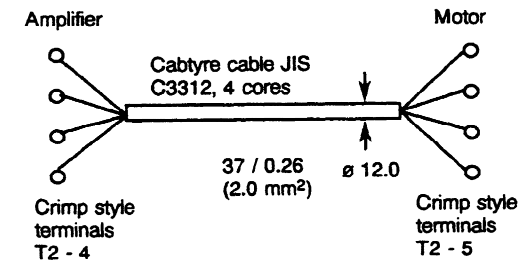
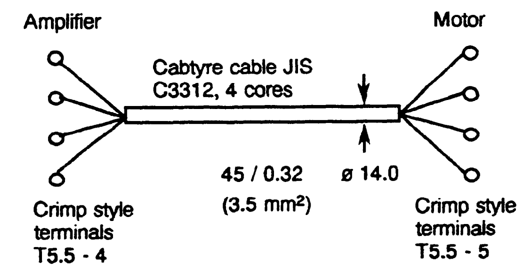
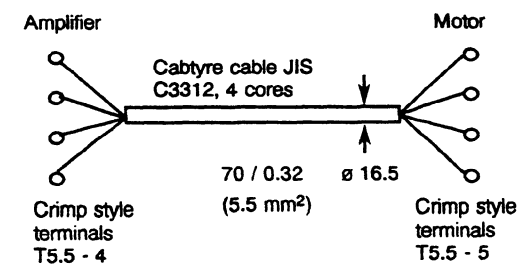
(6) IP65 series: This series has a protection structure grade of IP65. A motor of this series is therefore ideal as the motor for the second spindle or as a motor for tool rotation exposed to spattered coolant.

APPENDIX

APPENDIX 1 CABLE SPECIFICATIONS

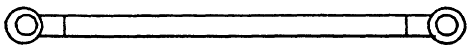
The cable specifications are as shown below.
If specifications are not described here or the cable length are different, prepare them by the MTB.

(1) Power line and motive power line for respective motor models

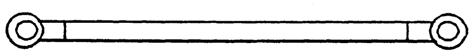
Applications	Symbol	Specifications	FANUC specification (Cable assembly)
Model 0.5S (Lower than 4 kVA)	K2		A06B-6050-K801 14 m A06B-6050-K803 7 m
Model 1S (Lower than 5 kVA)	K1 K2		
Model 1.5S, 2S (Lower than 7 kVA)	K1 K2		
Model 3S (Lower than 12 kVA)	K1 K2		

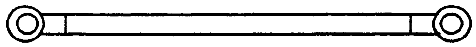
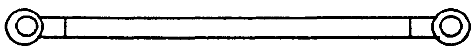
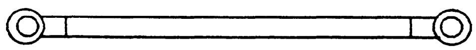
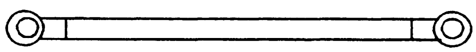
(Note 1) Change crimpe style terminals on the power supply side according to the power supply.
(Note 2) Refer to the chapter of the connection of each motor. This table shows the crimp style terminal on the motor side of the S series spindle motors.

Applications	Symbol	Specifications Amplifier side / Motor side	FANUC specification (Cable assembly)
Model 6S, Small type 6S (Lower than 16 kVA)	K1 K2	Amplifier — Motor Cabtyre cable JIS C3312, 4 conductors 50 / 0.45 (8 mm²) ø 20 Crimp style terminals 6S: T8 - 5, Small type 6S: T8 - 4 Crimp style terminals T8 - 5	
Model 8S, 12S (Lower than 25 kVA)	K1 K2	Amplifier — Motor Cabtyre cable JIS C3312, 4 cores 88 / 0.45 (14 mm²) ø 24.0 Crimp style terminals T14 - 5 Crimp style terminals T14 - 5	
Model 15S, Small type 15S (Lower than 30 kVA)	K1 K2	Amplifier — Motor Heat resisting vinyl cable (Note) 88 / 0.45 (14 mm²) Crimp style terminals 15S: T14 - 8, Small type 15S: T14 - 5 Crimp style terminals T14 - 5	
Model 18S, 22S, 26S, Small type 30S (K1 only) (Lower than 45 kVA)	K1 K2	Amplifier — Motor Heat resisting vinyl cable (*2) 7 / 20 / 0.45 (22 mm²) Crimp style terminals T22- 8 Crimp style terminals T22 - 8	

Applications	Symbol	Specifications	FANUC specification (Cable assembly)
Small type 30S	K2	AC 600V heat-proof cable LMFC made by FURUKAWA Electric Industry or equivalent Single wire connection: (a) × 3 and (b) × 1 (a) Conductor 7/34/0.45 (38mm^2) Crimp style terminals T38-8  (b) Conductor 7/20/0.45 (22mm^2) Crimp style terminals T38-8 	

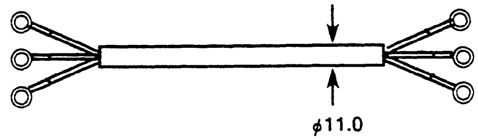
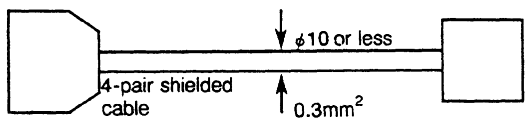
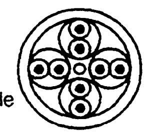
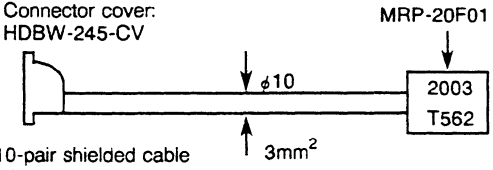
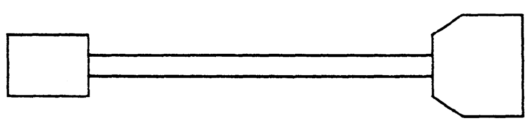
(*) Use the flame retardant poli-flex cable (LMFC). (Maximum temperature of conductor: 105°C)

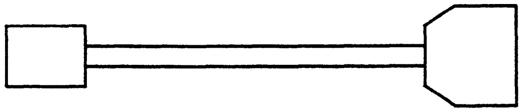
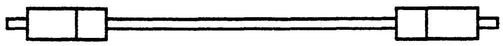
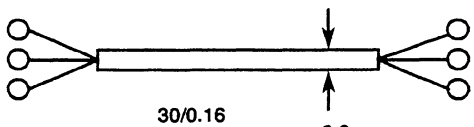
Applications	Symbol	Specifications	FANUC specification (Cable assembly)
Model 30S Model 40HV	K1 K2	AC 600V heat-proof cable LMFC made by FURUKAWA Electric Industry or equivalent Single wire connection: (a) × 3 and (b) × 1 (a) Conductor 7/34/0.45 (38mm^2) Crimp style terminals T38-10  (b) Conductor 7/20/0.45 (22mm^2) Crimp style terminals T38-10 	A06B – 6044 – K202 7 m

Applications	Symbol	Specifications	FANUC specification (Cable assembly)
Model 40S Model 60HV	K1 K2	AC 600V heat-proof cable LMFC made by FURUKAWA Electric Industry or equivalent Single wire connection: (a) × 3 and (b) × 1 (a) Conductor 19/16/0.45 (50mm^2) Crimp style terminals T60-10  (b) Conductor 7/20/0.45 (22mm^2) Crimp style terminals T38-10 	A06B – 6044 – K203 7 m
Model 30HV	K1 K2	Heat-resistant cable for 600 VAC manufactured by LMFC of Furukawa Electric Assembly into a single cable: 3 each of (a) and 1 each of (b) (a) Conductor 7/27/0.45 (30 mm^2) Size of crimp terminal: T38-10  (b) Conductor 7.20/0.45 (22 mm^2) Size of crimp terminal: T38-10 	

(2) Common cables

The following cables are common for each model:

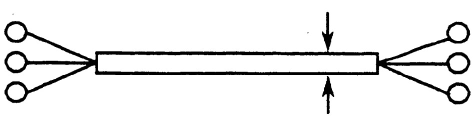
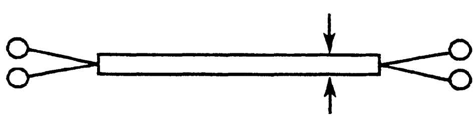
Applications	Symbol	Specifications	FANUC specification (Cable assembly)
Motor cooling fan	K3	Vinyl cabtyre cable: JIS C 3312, 3 cores Conductor: 37/0.26 ($2mm^2$) Outer cover: PVC φ11 Crimp style terminal: T2-4S 	
Spindle servo unit | AC spindle motor (for signal)	K4	Spindle/servo unit connector (basic) CN2 Connector attached to spindle motor  Housing 350720-1 Contact 350689-6  MR-20LFH made by HONDA PVC sheath shielded braided conductor	A06B – 6044– K200 7m
Model 0.5S Spindle servo unit | AC spindle motor (for signal)	K4	Connector: HDBB-25S, manufactured by Hirose (*1) Connector cover: HDBW-245-CV MRP-20F01  10-pair shielded cable (all wires shielded in one braiding) $0.2mm^2$ (7/0.18)	A06B-6064-K800 14 m A06B-6064-K801 7 m
Preamplifier | Detection circuit (for detector built-in motor)	K7	Preamplifier connector CN2 Detection circuit connector CN16  HR22-12WTPA-20S made by HIROSE MR-20LFH made by HONDA	A06B – 6063– K802 7m

Applications	Symbol	Specifications	FANUC specification (Cable assembly)
Preamplifier | Detection circuit (for spindle detector)	K8	Preamplifier connector CN2 / Detection circuit connector CN15  HR22-12WTPA-20S made by HIROSE / MR-20LMH made by HONDA	A06B – 6063– K801 7m
CNC | Spindle servo unit	K5	(*2) 	A66L-6001-0009#L5R003 5m
Speedometer Dynamometer | Spindle servo unit (for measuring instruments)	K7	Vinyl cabtyre cable JIS C 3312, 3 cores  Crimp style terminals / 30/0.16 (0.75 mm²) / ϕ9.2 / Crimp style terminals	A06B – 6044– K201 7m

(*) For specifications of optical fiber cables, see item Ⅶ. 5.7 Optical fiber cable.

(3) Other

Cable materials used for some models:

Applications	Symbol	Specifications	FANUC specification (Cable assembly)
Unit adapter fan motor (models 6S - 26S)	K10	Vinyl cabtyre cable: JIS C 3312, 3 cores Conductor: 37/0.26 (2mm²) Outer cover: PVC ϕ11.0 Crimp style terminal: T2-4S  ϕ11.0	
Fan unit or fan motor (models 30S, 40S, 30HV, 40HV, 60HV)	K10	Vinyl cabtyre cable: JIS C 3312, 2 cores Conductor: 37/0.26 (2mm²) Outer cover: PVC ϕ10.5 Crimp style terminal: T2-5  ϕ10.5	A06B – 6044 – K022 7m

(*1) Connector kit (A06B-6050-K111: K63L-0001-0428/CJ) components

Part name	Quantity
Case	1
Contact housing	1
Contact	6
Nut	1

Part name	Quantity
Cable packing	1
Cable clamp	1
Packing	1
Setscrew	2

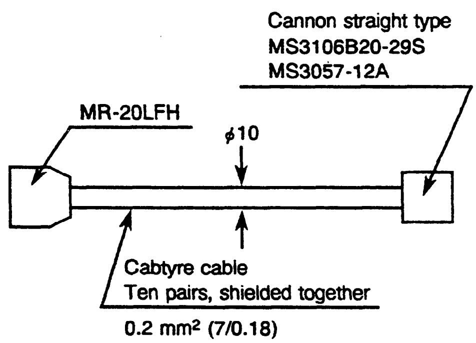
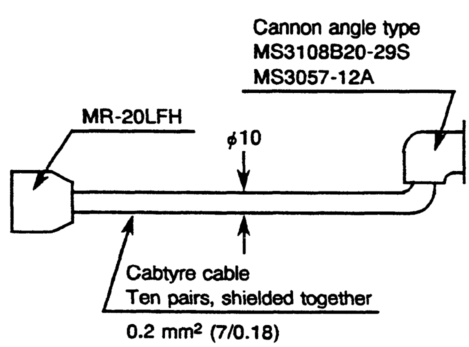
Crimping tool manufactured by AMP	
Crimping tool	914596-2
Extractor	614677-1

(*2) Connector kit (A06B-6050-K110) components

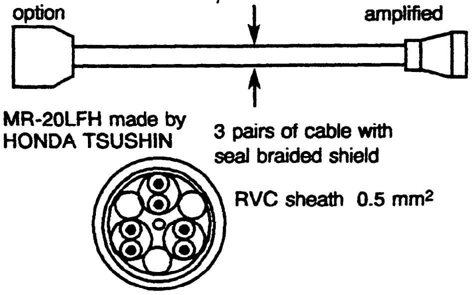
Part name	Quantity
D-SUB 25-pin connector, solder type	1
Water-proof cover for D-SUB connector	1

(4) Cables for spindle orientation

a) For position coder

Applications	Symbol	Specifications	FANUC specification (Cable assembly)
Spindle servo unit | Position coder	K10		A06B – 6041– K201 7m
Spindle servo unit | Position coder	K10		A06B – 6041– K204 7m

b) For magnetic sensor

Applications	Symbol	Specifications	FANUC specification (Cable assembly)
Spindle servo unit | Magnetic sensor	K13	Connector attached to option φ13 or less Connector attached to amplified  MR-20LFH made by HONDA TSUSHIN 3 pairs of cable with seal braided shield RVC sheath 0.5 mm²	A06B – 6041– K203 7m

<Reference cables>

Details of cable specifications

Name	Conductor		Sheath thickness	Finished OD	Electric characteristics		Designation*
	Diameter	Configu-ration			Conductor resistance	Allowable current	
Cable A (10 pairs)	φ1.05 mm	7 / 0.18	1.4 mm	φ10.0 mm	110 Ω/km	1.6 A	A66L-0001-0041
Cable B (50 pairs)	φ1.05 mm	7 / 0.18	1.5 mm	φ12.5 mm	110 Ω/km	1.6 A	A66L-0001-0042
Cable C (3 pairs)	φ0.93 mm	45 / 0.12	1.0 mm	φ10.8 mm	38.7 Ω/km	1.6 A	A66L-0001-0108

* Length is designated separately.

APPENDIX 2 TECHNICAL DATA

2.1 How to Obtain Load Inertia Reflected to Motor Shaft

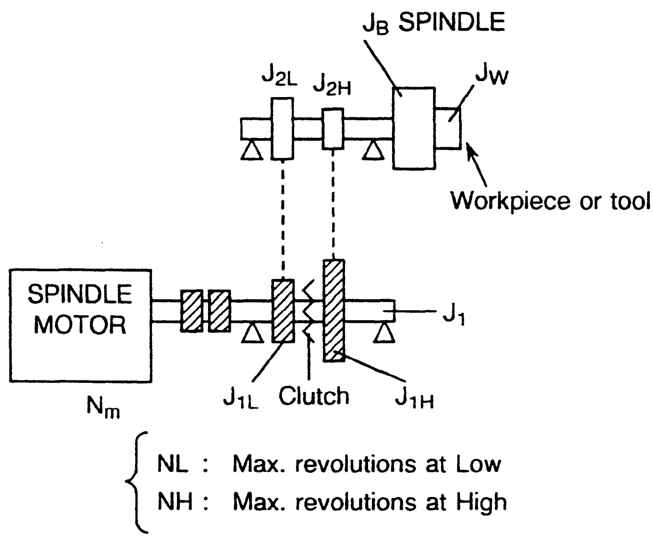
To obtain the load inertia reflected to motor shaft when the spindle holds the maximum tool or maximum work, full the procedure described below.

Spindle speed change gear stage	Inertia reflected to motor shaft
High J_H	——— $kg \cdot cm \cdot s^2$
Low J_L	——— $kg \cdot cm \cdot s^2$

Select the load inertia reflected to motor shaft so that it is less than 3 times the inertia of the spindle motor employed.
As the load inertia is larger, the acceleration/deceleration time becomes longer.

(1) Calculation method of load inertia reflected to motor shaft (Example)

(Model)



Nm : Maximum speed of motor (min^{-1})

N_L : Maximum speed when speed change gear stage is low (min^{-1})

N_H : Maximum speed when speed change gear stage is high (min^{-1})

Ra : Speed ratio between speed change stages $\frac{N_H}{H_L}$

G_L : Ratio of motor revolutions to revolutions when speed change gear stage is low $\frac{N_L}{Nm}$

GH : Ratio of motor revolutions to revolutions when speed change gear stage is high $\frac{N_H}{Nm}$

J_1 : Inertia of shaft directly coupled to motor (kg.cm.s^2)

J_{1L} : Inertia of gear or pulley when the motor side speed change gear stage is low (kg/cm.s^2)

J_{1H} : Inertia of gear or pulley when the motor side speed change gear stage is high (kg/cm.s^2)

J_{2L} : Inertia of gear or pulley when the spindle side speed change gear stage is low (kg/cm.s^2)

J_{2H} : Inertia of gear or pulley when the spindle side speed change gear stage is high (kg/cm.s^2)

L_b : Inertia of spindle (kg.cm.s^2)

L_W : Inertia of work (kg.cm.s^2)

① Calculation formulas when low and high speed change gear stages are switched by clutch

Inertia reflected to motor shaft when the speed change gear stage is low. J_L (kg.cm.s^2)

$$J_L = J_1 + J_{1L} + \left(\frac{1}{Ra}\right)^2 \times J_{1H} + G_L{}^2 \times (J_{2L} + J_{2H} + L_b + L_w) \quad \cdots\cdots \quad (1\text{-}1)$$

Inertia reflected to motor shaft when the speed change gear stage is high. JH (kg.cm.s^2)

$$J_H = J_1 + Ra^2 \times J_{1L} + J_{1H} + G_H{}^2 (J_L + J_H + J_b + J_w) \quad \cdots\cdots \quad (1\text{-}2)$$

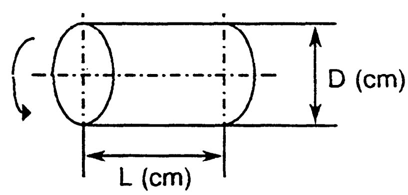
② Calculation formula when low and high speed change gear stages are switched by gear shift.

$$J_L = J_1 + J_{1L} + J_{1H} + G_L{}^2 (J_{1L} + J_{2L} + J_b + J_W) \quad \cdots\cdots \quad (1\text{-}3)$$

$$J_H = J_1 + J_{1L} + J_{1H} + G_H{}^2 (J_{2L} + J_{2H} + J_B + J_W) \quad \cdots\cdots \quad (1\text{-}4)$$

The calculation formulas of respective inertia are given below.

1) Inertia of cylindrical body



The inertia produced when a cylindrical body rotates around its center shaft is calculated by the following formula. Calculate ball screws, gears, etc. by approximating this formula for cylindrical body.

$$J = \frac{\pi\gamma}{32 \times 980} D^4 L \ (\text{kg} \cdot \text{cm} \cdot \text{s}^2) \quad \cdots\cdots \quad (1\text{-}5)$$

This can be approximated in case of steel ($\gamma = 7.8 \times 10^{-3}$kg/cm^3) as follows.

$$J = 0.78 \times 10^{-6} D^4 L \ (\text{kg} \cdot \text{cm} \cdot \text{s}^2) \quad \cdots\cdots \quad (1\text{-}6)$$

where,

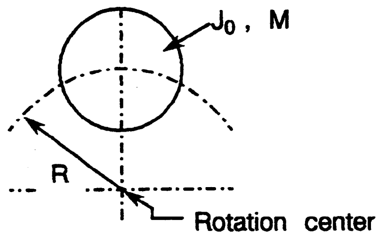
J : Inertia (kg.cm.s^2)

γ : Weight per unit volume (kg/cm^3)

D : Diameter of cylindrical body (cm)

L : Length of cylindrical body (cm)

2) Inertia of cylindrical body having a deviated rotation center



$$J = J_0 + \frac{M}{980} R^2 \text{ (kg} \cdot \text{cm} \cdot \text{s}^2\text{)} \cdots\cdots\cdots \text{ (1-7)}$$

where,

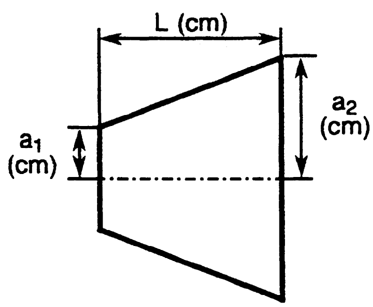
J_0 : Inertia around the center of cylindrical body (kg.cm.s^2)

M : Weight of cylindrical body (kg)

R : Rotation radius (cm)

The above formula applies to calculations of the inertia of large diameter gears when lightening holes were made for reducing their weight.

3) Inertia of tapered cylindrical body



$$J = \frac{\pi \gamma}{10 \times 980} \times \frac{(a_2{}^5 - a_1{}^5)}{a_2 - a_1} \times L \text{ (kg} \cdot \text{cm} \cdot \text{s}^2\text{)} \quad \cdots\cdots \text{ (1-8)}$$

2.2 Load Torque

The friction torque of bearings and viscosity torque of lubrication oil inside the spindle act as the load torque.

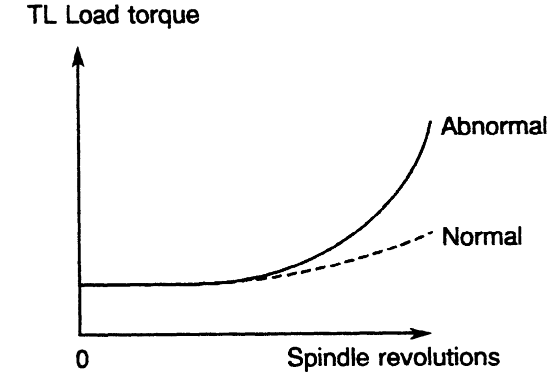
Tl = Tc + Tv (kg · cm)

where,

Tc : Friction torque

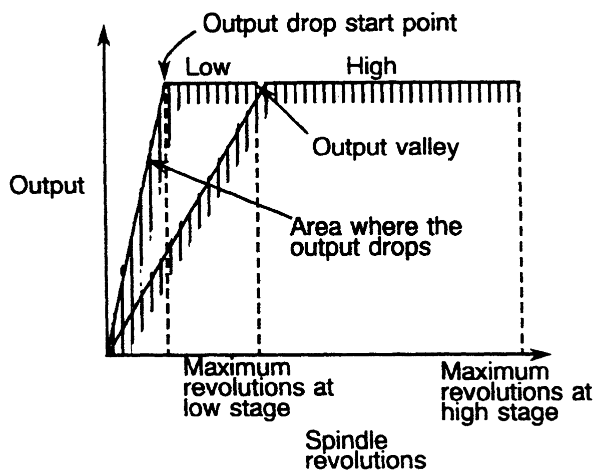
Tv : Viscosity torque

Be careful since the viscosity torque of lubrication oil largely affects the machine when the spindle rotates at high speed.



2.3 Spindle Speed Change Gear Stages

The spindle gear speed change stages are determined according to the specified output of the spindle.



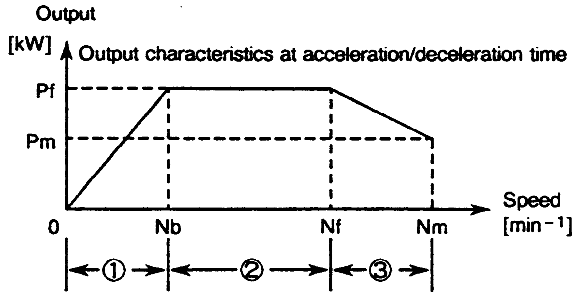
To eliminate the output valley, the ratio of high to low stages of spindle is generally set as follows.

$$\frac{\text{Max. revolutions at low stage}}{\text{Max. revolutions at high stage}} = \frac{\text{Basic speed of motor}}{\text{Max. speed of motor}} = \frac{1}{3} \sim \frac{1}{4}$$

Since the revolutions lower than the output drop start point of low gears cause the cutting power of machine to decrease, the revolutions must be specified clearly.

2.4 Determining the Acceleration Time

When the output characteristics shown at the right are used at the acceleration/deceleration time, the acceleration time can be found from the expressions below. Note that the acceleration time thus obtained does not take into account the load torque of the machine, so the actual acceleration time is slightly longer.



J_L : Load inertia converted to motor shaft inertia [kg · m · s^2]
Formula for conversion from GD^2 [kg · m^2]:
1 [kg · m^2] = 0.0255 [kg · m · s^2]

Jm : Motor inertia [kg · m · s^2]
Pf, Pm : Output [kW]
Nb, Nf, Nm : Speed [min^{-1}]

① Acceleration time (t_1) in the constant torque area (0 to Nb)

$$t_1 = 0.10754 \times \frac{(J_L + Jm) \times Nb^2}{Pf \times 1000} \quad [s]$$

② Acceleration time (t_2) in the constant output area (Nb to Nf)

$$t_2 = 0.10754 \times \frac{(J_L + Jm) \times (Nf^2 - Nb^2)}{2 \times Pf \times 1000} \quad [s]$$

③ Acceleration time (t_3) in the decreasing output area (Nf to Nm)

$$t_3 = 0.10754 \times \frac{(J_L + Jm) \times (Nm - Nf)}{(Pm - Pf) \times 1000}$$

$$\times \{(Nm - Nf) - \frac{Pf\,Nm - Pm\,Nf}{Pm - Pf} \times Ln(Pm/Pf)\} \quad [s]$$

Acceleration time (t) from 0 to Nm is: $t = t_1 + t_2 + t_3$ [s]

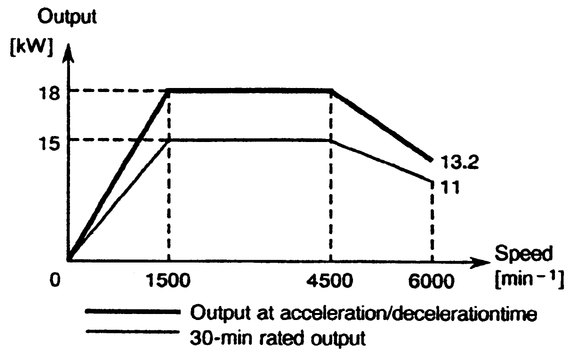
Control can be exercised so that the deceleration time is about the same as the acceleration time. However, this control may be impossible when either the power supply voltage or the power supply impedance is high.

Example of calculation:

Model 12S (6000 min-1) has the output characteristics shown at the right at the acceleration/deceleration time.

The values used are as follows:

- Jm : 0.0093[kg · m · s2]
- Pf : 15×1.2=18 [kW]
- Pm : 11×1.2=13.2 [kW]
- Nb : 1500 [min-1]
- Nf : 4500 [min-1]
- Nm : 6000 [min-1]



When J_L is 0.0186 [kg · m · s2], the following acceleration times are obtained:

① Acceleration time (t_1) in the constant torque area (0 to 1500 min^{-1})

$$t_1 = 0.10754 \times \frac{(0.0186 + 0.0093) \times 1500^2}{18 \times 1000} = 0.3750 \quad [s]$$

② Acceleration time (t_2) in the constant output area (1500 to 4500 min^{-1})

$$t_2 = 0.10754 \times \frac{(0.0186 + 0.0093) \times (4500^2 - 1500^2)}{2 \times 18 \times 1000} = 1.500 \quad [s]$$

③ Acceleration time (t_3) in the decreasing output area (4500 to 6000 min^{-1})

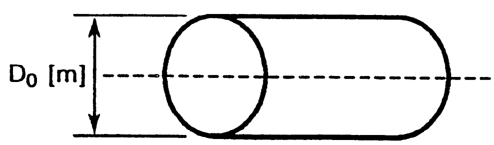
$$t_3 = 0.10754 \times \frac{(0.0186 + 0.0093) \times (6000 - 4500)}{(13.2 - 18) \times 1000}$$

$$\times \{(6000 - 4500) \frac{18 \times 6000 - 13.2 \times 4500}{13.2 - 18} \times Ln(13.2/18)\} = 1.538 \quad [s]$$

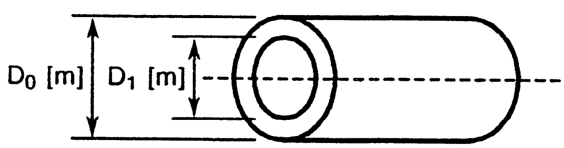
Then, the acceleration time (t) from 0 to 6000 min^{-1} is:
$t = t_1 + t_2 + t_3 = 3.413$ [s]

Reference information: In the case of GD^2 [kg · m2] for a circular cylinder, G represents a weight [kg], and D^2 is as follows:

Solid circular cylinder
$D^2 = D_0^2/2$



Hollow circular cylinder
$D^2 = (D_0^2 + D_1^2)/2$



2.5 Cutting Amount of Machine

The spindle motor output (HP or KW) of machine tools is specified to indicate their cutting amount, in general.

Regarding the lathing, milling, and drilling, the relation between the rate of metal removal and output power will be described by quoting it from the following reference.

Reference:

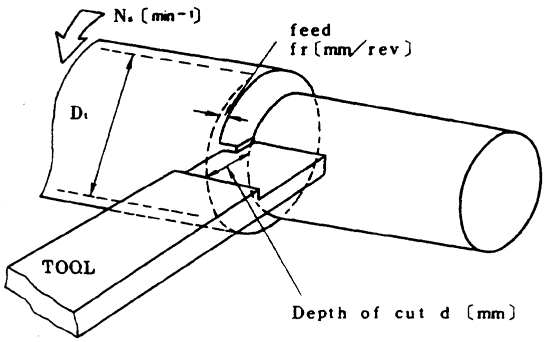
MACHINING DATA HANDBOOK AIR FORCE MATERIAL LABORATORY

(a) Lathe turning

(b) Machining center, milling using milling machine

(c) Machining center, drilling using drilling machine

a) Turning



Cutting conditions:

1) Spindle revolutions Ns (min^{-1})
2) Workpiece diameter Dt (mm)
3) Feed fr (mm/rev)
4) Depth of cut d (mm)

Cutting formulas:

1) Cutting speed

   $Vc = \pi \times Dt \times Ns$ (mm/min)

2) Feed rate

   $fm = fr \times Ns$ (mm/min)

3) Rate of metal removal

   $Q = d \times fr \times Vc/1000$ (cm^3/min)

   $= d \times fr \times \pi / Dt \times Ns/1000$ (cc/min)

$Q = \pi \times Dt \times d \times fm / 1000$ (cc / min)

4) Power required at spindle

   $PS = Q / MRt$ (kW)

   where,

   MRt : Rate of metal removal per kW (cc/min/kW)

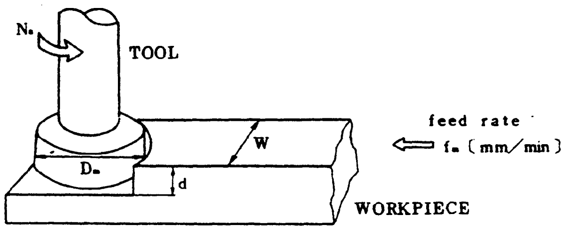
5) Power required at spindle motor

$$PM = \frac{1}{\eta} \times Q / MRt \text{ (kW)}$$

where,

η : Drive efficiency of spindle (%)

b) Milling



Cutting conditions:

1) Spindle revolutions Ns (min^{-1})
2) Diameter of milling cutter Dm (mm)
3) Width of cut w (mm)
4) Depth of cut d (mm)
5) Number of teeth in cutter n (pieces)
6) Feed ft (mm/tooth)

Cutting formulas:

1) Cutting speed
   $Vc = \pi \times Dm \times Ns$ (mm/min)
2) Feed rate
   $fm = ft \times n \times Ns$ (mm/min)
3) Rate of metal removal
   $Q = w \times d \times ft \times n \times Ns/1000$ (cm^3/min)

$Q = w \times d \times fm / 1000$ (cc / min)

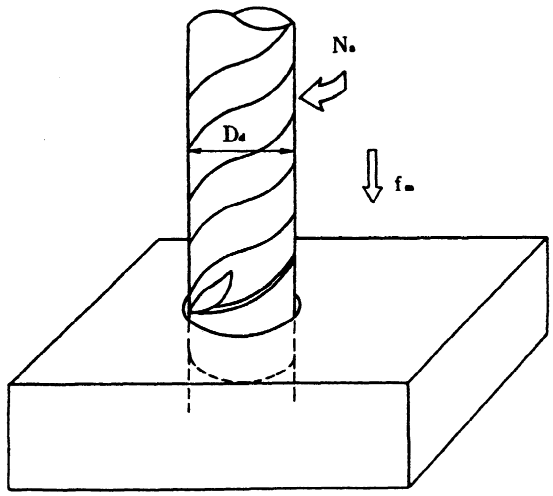
4) Power required at spindle
   $PS = Q/MRm$ (kW)
   where,
   MRm : Rate of metal removal per kW (cc/min/kW)
5) Power required at spindle motor

$$PM = \frac{1}{\eta} \times Q / MRm \text{ (kW)}$$

where,

η : Drive efficiency of spindle (%)

c) Drilling



Cutting conditions:

1) Spindle revolutions Ns (min^{-1})
2) Drill diameter Dd (mm)
3) Feed ft (mm/rev)

Cutting formulas:

1) Cutting speed
   $Vc = \pi \times Dd \times Ns$ (mm/min)
2) Feed rate
   $fm = fr \times Ns$ (mm/min)
3) Rate of metal removal

$$Q = \frac{\pi}{4} \times Dd^2 \times fr \times Ns/1000 \ (cm^3/min)$$

$$\boxed{Q = \frac{\pi}{4} \times Dd^2 \times fm \ / \ 1000 \ (cc \ / \ min)}$$

4) Power required at spindle
   $PS = Q/MRd$ (kW)
   where,
   MRd : Rate of metal removal per kW (cc/min/kW)
5) Power required at spindle motor

$$PM = \frac{1}{\eta} \times Q \ / \ MRd \ (kW)$$

where,
η : Drive efficiency of spindle (%)

Rate of metal removal per kW (cc/min/kW) (average values)
(when the drive efficiency of spindle is 80%)

MATERIAL	HARDNESS (*1) Brinell hardness	MR : Rate of metal removal per kW (cc / min / kW)					
		TURNING MRt HSS AND CARBIDE TOOLS feed 0.127 ~ 0.381 mm / rev		MILLING MRm CARBIDE TOOLS feed 0.127 ~ 0.305 mm / tooth		DRILLING MRd HSS DRILLS feed 0.05 ~ 0.203 mm / rev	
		SHARP TOOL	DULL TOOL	SHARP TOOL	DULL TOOL	SHARP TOOL	DULL TOOL
STEEL - WROUGHT AND CAST	85 - 200 (*2)	20	15.7	20	15.7	21.9	16.8
Plain Carbon	35 - 40 Rc (*3)	15.7	12.9	14.6	11.5	15.7	12.9
Alloy Steels	40 - 50 Rc	14.6	11.5	12.2	10	12.9	10.4
Tool Steels	50 - 55 Rc	10.9	8.7	10.4	8.4	10.4	8.4
	55 - 58 Rc	6.4	5.2	8.4	6.8	8.4	6.8 (*4)
CAST IRONS	110 - 190	31.3	24.4	36.6	27.4	21.9	18.3
Gray, Ductile and Malleable	190 - 320	15.7	12.9	20	15.7	13.7	10.9
STAINLESS STEELS	135 - 275	16.8	13.7	15.7	12.9	20	15.7
Ferritic, Austenitic and Martensitic	30 - 45 Rc	15.7	12.9	14.6	11.5	18.3	14.6
PRECIPITATION HARDENING STAINLESS STEELSS	150 - 450	15.7	12.9	14.6	11.5	18.3	14.6
TITANIUM	250 - 375	18.3	14.6	20	15.7	20	15.7
HIGH TEMPERATURE ALLOYS Nickel and Cobalt Base	200 - 360	8.7	7.0	10.9	8.7	10.9	8.7
Iron Base	180 - 320	13.7	10.9	13.7	10.9	18.3	14.6
REFRACTORY ALLOYS · · · Tungsten	321	7.8	6.2	7.5	6.1	8.4	6.6 (*4)
Molybdenum	229	10.9	8.7	13.7	10.9	13.7	10.9
Columbium	217	12.9	10.4	14.6	11.5	15.7	12.9
Tantalum	210	7.8	6.2	10.9	8.7	10.4	8.4
NICKEL ALLOYS	80 - 360	10.9	8.7	11.5	9.1	12.2	10
ALUMINUM ALLOYS	30 - 150 500 kg	87.8	73.2	68.6	54.9	137.2	109.8
MAGNESIUM ALLOYS	40 - 90 500 kg	137.2	109.8	137.2	109.8	137.2	109.8
COPPER	80Rb (*5)	21.9	18.3	21.9	18.3	24.4	20
COPPER ALLOYS	10-80Rb	34.3	27.4	34.3	27.4	45.7	36.6
	80-100Rb	21.9	18.3	21.9	18.3	27.4	21.9

(*1) Brinell hardness, Standard testing method, Steel ball diameter 10mm, Load: 3000kg, Maximum value about 450

(*2) Corresponds to hardness of general steel S45C

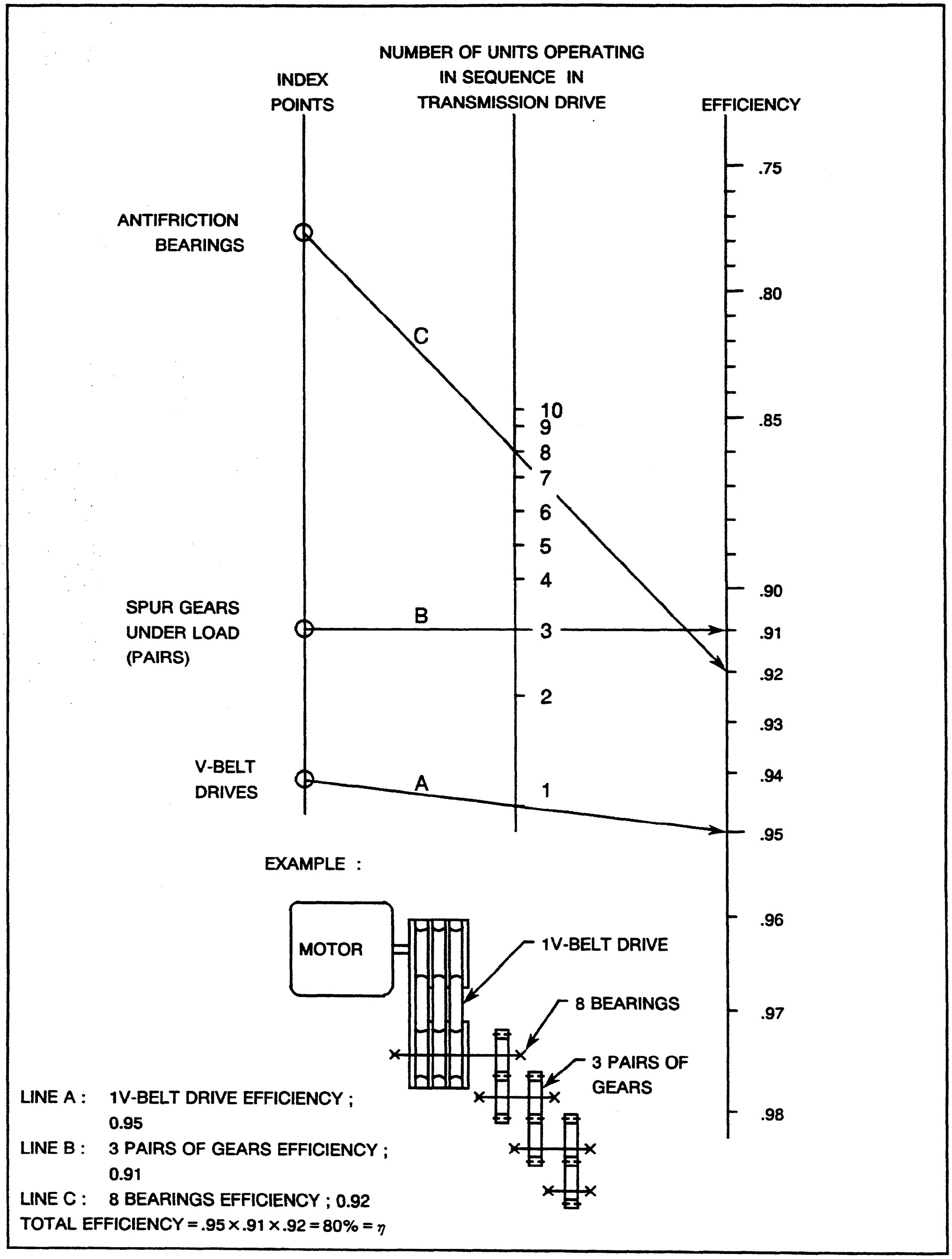
(*3) Rc: Rockwell hardness, C scale, Measurement of hardness of comparatively hard metals

(*4) Carbide

(*5) Rb: Rockwell hardness, B scale, Measurement of hardness of soft metals

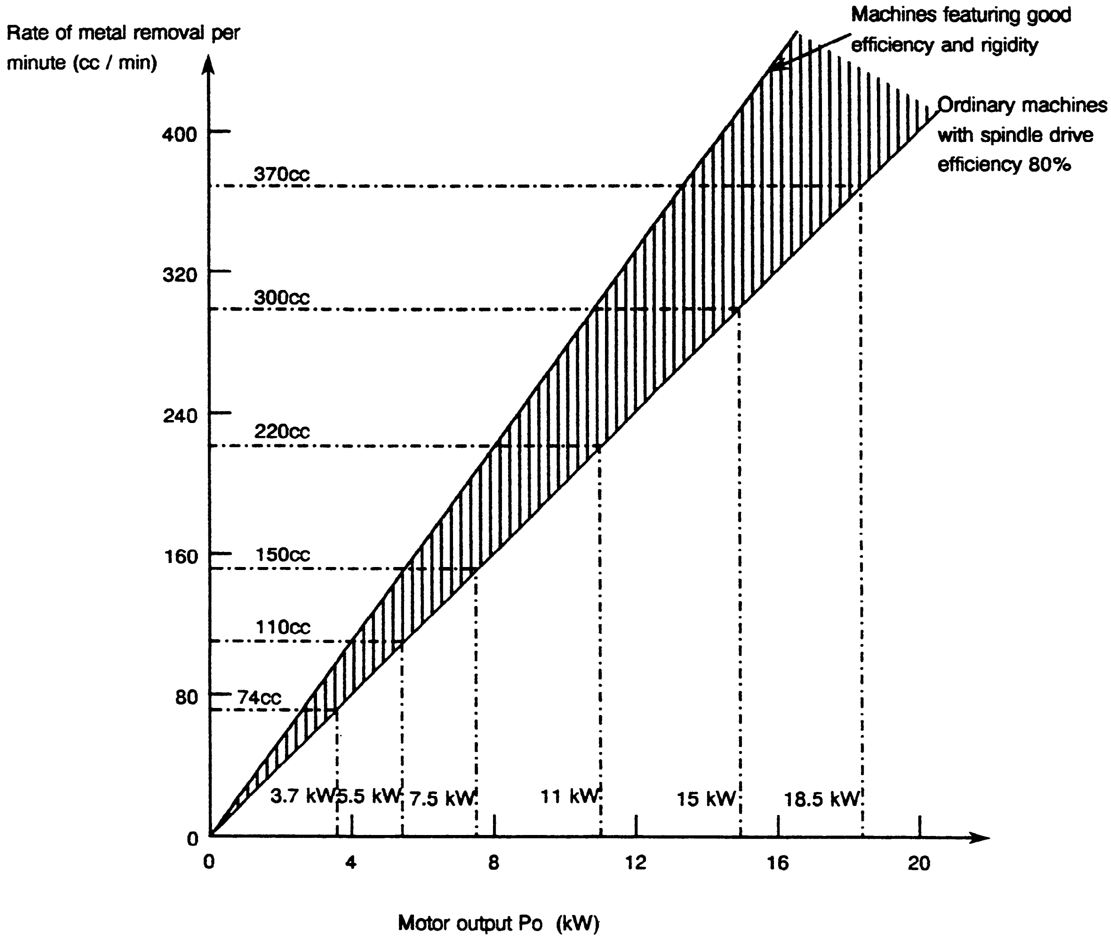
Efficiency of spindle drive system

The efficiency of spindle system can be obtained from the following diagram according to the V belt, number of gear stages, and number of bearings.



Data on rate of metal removal

The rate of metal removal per minute when steel S45C is cut using a new tool on a lathe or machining center is obtained within the shadowed range in the following figure approximately; provided that noload torque such as friction torque, etc. are negligible.



2.6 Constant Surface Speed Control

- Purpose of constant surface speed control in lathe

  (1) Good finish surface

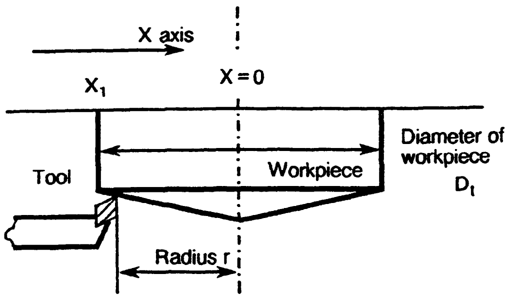
  (2) Reduction of lathing time

  (3) Constant rate of metal removal

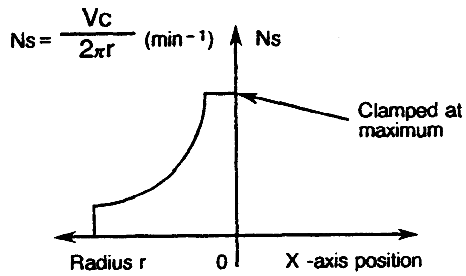
  (4) Prolonged lives of tools by setting the surface speed to a suitable value

- Constant surface speed control operation

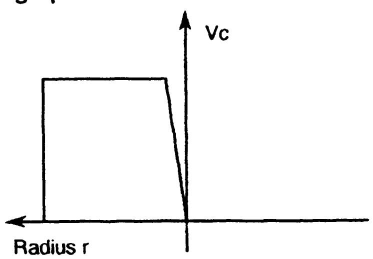
Cutting speed:
Vc (m / min)



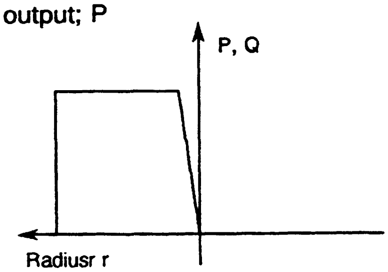
Spindle revolutions Ns



Cutting speed Vc



Rate of metal removal; Q
Cutting output; P



- The cutting output during constant surface speed control, or, the output required for cutting a metal during constant surface speed control under a certain condition is obtained by the following formula:

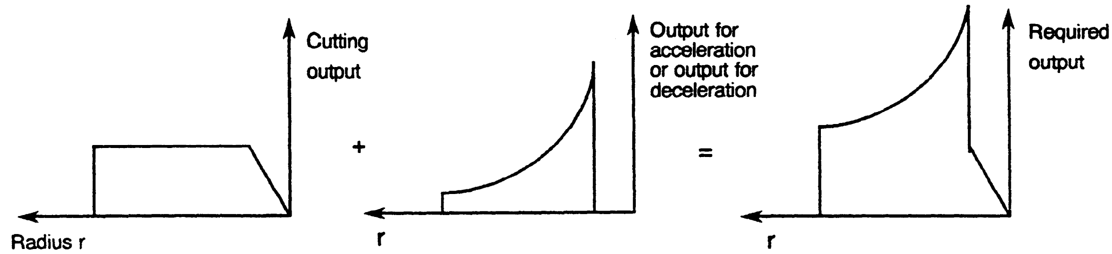
$$Po = \frac{1}{MRt} \times d \times fr \times Vc \ \text{(kW)} \cdots\cdots\cdots \text{(6-1)}$$

where,

Po	:	Cutting output (kW)
MRt	:	Rate of metal removal per kW (20 usually) (cc/min/kW)
d	:	Depth of cut (mm)
fr	:	Feed rate (mm/rev)
Vc	:	Cutting speed (m/min)

- Motor output required for constant surface speed control

  Both required cutting output and the output for acceleration (or deceleration) for increasing (or decreasing) the spindle revolutions are required, and the maximum output is required in the vicinity of the maximum revolutions of the motor.



Since cutting speed Vc is kept constant under the constant surface speed control, the tool position (radius r) on a workpiece is inversely proportional to spindle revolutions Ns.

Thus, the feed rate per minute fm (mm/min) becomes faster, as the tool advances toward the innermost of diameter.

Assume that the tool is displaced by $-\Delta X$ in the X-axis direction during Δt time, and a change rate

$-\frac{\Delta X}{\Delta t}$ represents the feed rate given by the following formula.

$$-\frac{dX}{dt} = fm \frac{fr \times Vc}{2\pi X} \qquad \cdots\cdots (6\text{-}2)$$

From the formula (6-2), the time required for the tool to be displaced from radius $X1 > r1$ to $X_2 = r_2$ is obtained by:

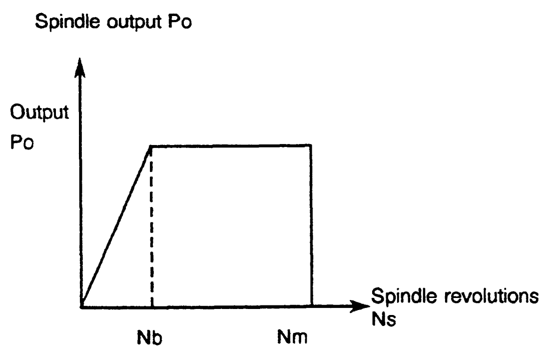
$$\boxed{ta = \frac{\pi}{fr \times Vc}\{r_1{}^2 - r_2{}^2\}} \quad (sec) \qquad \cdots\cdots (6\text{-}3)$$

(where, $r1 > r2$)

This is the formula for obtaining the machining time under the constant surface speed control.

- Extension of constant surface speed control area

  The constant surface speed control area is extended over large diameter workpieces, and the feed rate is reduced by the reduction component of the motor output. In other words, when a large diameter workpiece is machined, the spindle revolutions are lowered, and the motor output is reduced by the reduction component of revolutions in the constant torque area. Accordingly, the feed rate is reduced, as the revolutions decrease, while keeping the circumferential speed constant in cutting machining.

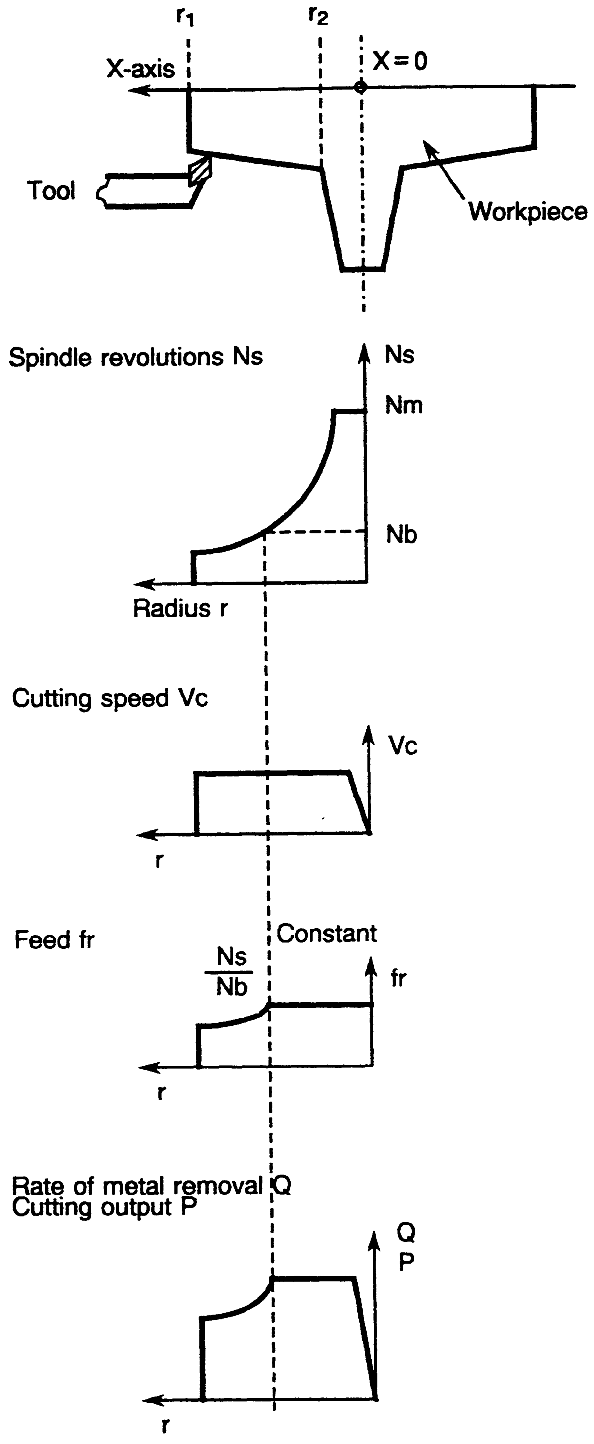


Feed fr (mm/rev) is controlled as follows.

$$\begin{cases} fr' = fr \times 1 & (Ns \geqq Nb) \\ fr' = fr \times \dfrac{Ns}{Nb} & (Ns < Nb) \end{cases} \quad (6\text{-}4)$$

Feedrate fm (mm/min) is controlled as follows.

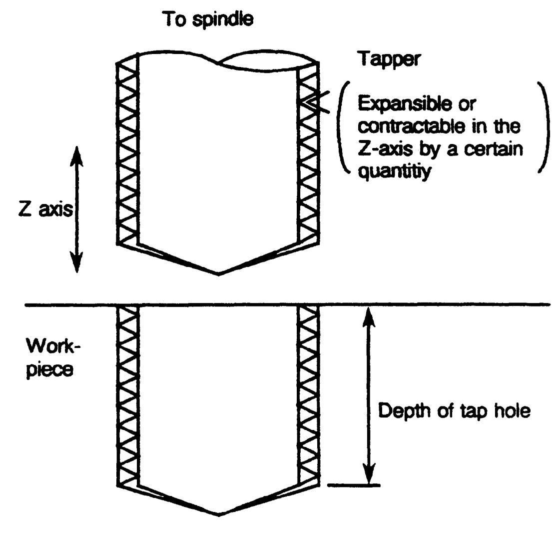
$$\begin{cases} fm' = fr \times Ns \times 1 \\ (Ns \geqq Nb) \\ fm' = fr \times Ns \times \dfrac{Ns}{Nb} \\ (Ns < Nb) \end{cases} \quad (6\text{-}5)$$


r1
r2
X-axis
X=0
Tool
Workpiece
Spindle revolutions Ns
Ns
Nm
Nb
Radius r
Cutting speed Vc
Vc
r
Feed fr
Constant
Ns/Nb
fr
r
Rate of metal removal Q
Cutting output P
Q
P
r

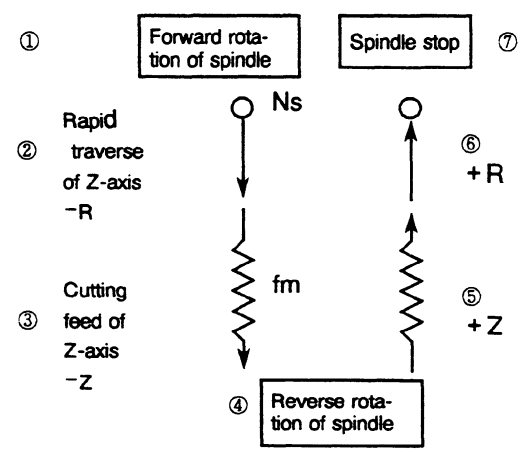
2.7 Tapping

(1) Tapping operation

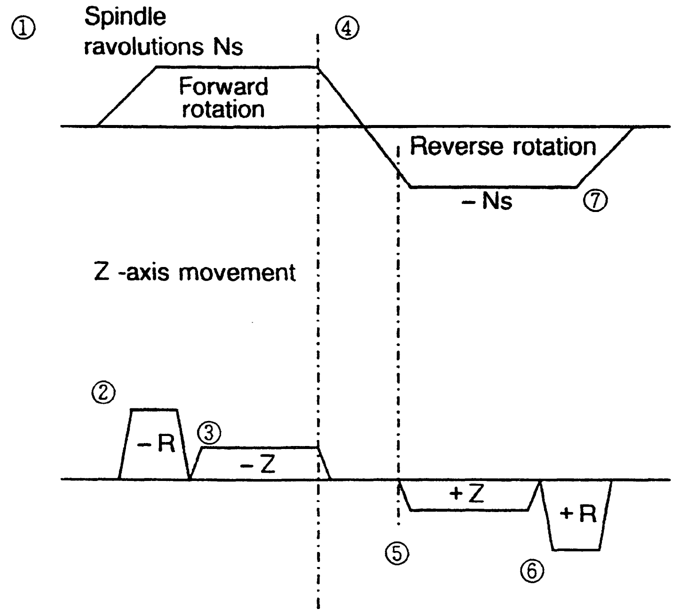
The tapping means a work of threading a female screw on a workpiece in machining center.



Tapping is made by controlling the spindle and Z-axis movement as follows.



Spindle movement



Examine the following items for tapping.

a) Depth of tap hole:
   Check if the depth is finished as specified.
b) Expansion or contraction of tapper: This will affect the threading accuracy.

(2) Tapping and cutting speed

In tapping work, the cutting speed is generally limited according to the kinds of workpieces and tools.

$$Vc = \pi \times d \times Ns / 1000 \quad (m / min) \cdots\cdots (7\text{-}1)$$

where,

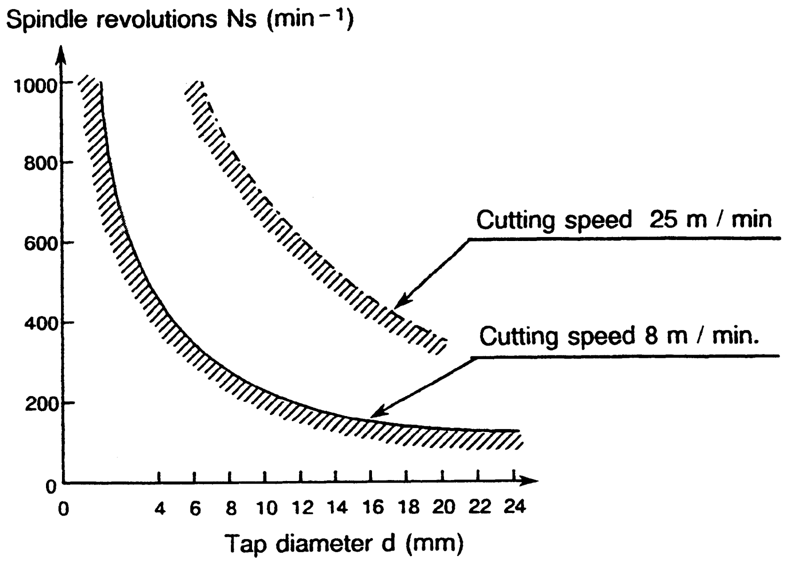
d : Tap diameter (mm)

Ns : Spindle revolutions (min^{-1})

Example of tapping conditions

- When a steel casting workpiece is tapped by an ordinary tapper:
  Lower than 8 m/min
- When a light alloy workpiece is tapped by an ordinary tapper or when a cemented carbide tapper is employed: Lower than 25 m/min

The relation between the tap diameter and spindle revolutions is as illustrated below.



(3) Feedrate during tapping work

Set the cutting feed rate fm (mm/min) during tapping as follows.

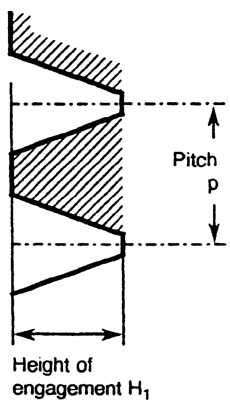
$$fm = Ns \times p \quad \text{(mm / min)} \cdots\cdots\cdots (7\text{-}2)$$

where,

p : Pitch of screw

The relation between the tap diameter (nominal diameter of screw) and pitch is as shown below.

Normal diameter of screw (d)	Pitch (p)	Height of engagemnt (H1)
M2	0.4 mm	0.217 mm
M2.6	0.45	0.244
M3	0.5	0.271
M4	0.7	0.379
M5	0.8	0.433
M6	1.0	0.541
M8	1.25	0.677
M10	1.5	0.812
M12	1.75	0.947
M16	2	1.083
M20	2.5	1.353
M24	3	1.624
M30	3.5	1.894
M36	4	2.165



(4) Tap hole depth control

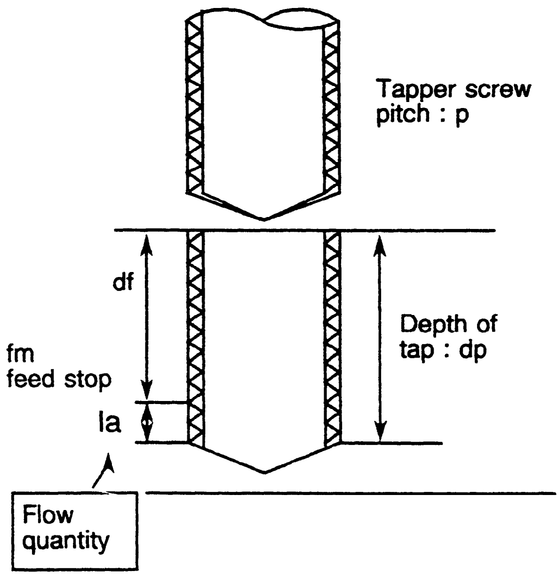
The hole depth dp (mm) is given by the following formula.

$$\boxed{dp = df + la} \quad \text{(mm)} \quad \cdots\cdots\cdots\cdots \text{(7-3)}$$

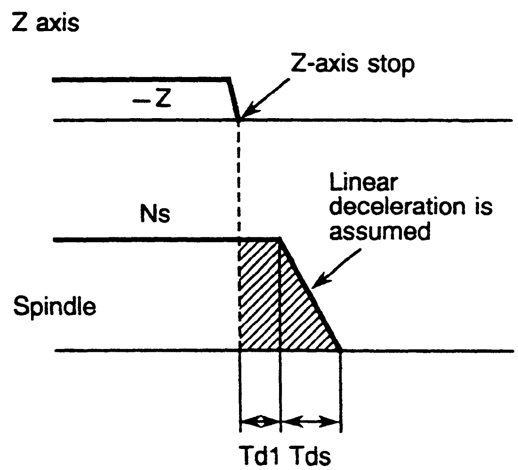
where,

df : Moving distance commanded from a workpiece surface to Z-axis

la : Machining distance of tapper by means of self-propulsion until the spindle is stopped after being decelerated (This is called flow quantity)



How to obtain flow qunatitiy ℓa



Td1: Operation delay time by the time the spindle starts deceleration (sec)

Tds: Deceleration time of spindle (sec)

$$\boxed{la = (Td_1 + \frac{1}{2} Tds) \times \frac{Ns}{60} \times P} \quad \text{(mm)} \quad \cdots\cdots\cdots\cdots \text{(7-4)}$$

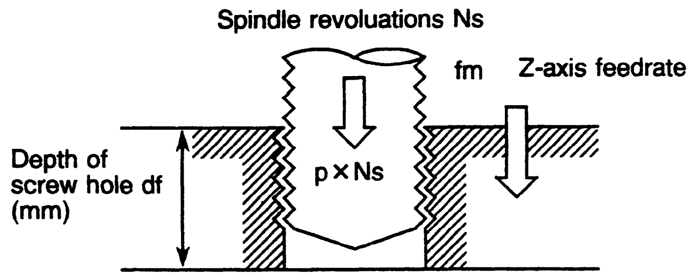
To decrease the flow quantity, the operation delay time and deceleration time must be reduced. This flow quantity corresponds to the expansion of the tapper. It must be controlled to obtain the depth of holes accurately.

(5) Expansion and contraction of tapper

For the expansion and contraction of tapper, refer to tools maker's catalogues. Contraction is generally less than expansion, and the spring pressure increases during contraction.
Accordingly, the finish accuracy of screws is said to be better when threading is made in the expansion direction of the tapper rather than in the contraction direction.
The causes of expansion and contraction of the tapper are as described below.
Please examine the motor selection and power magnetic sequence design, so that tapping can be done with minimized expansion and contraction.

(a) Expansion and contraction caused by the difference between the feed rate and actual spindle revolutions Ns

Expansion and contraction quantity e1 of tapper caused by asynchronism between the feed rate and spindle revolutions



pNs - fm = positive (expansion of tapper)

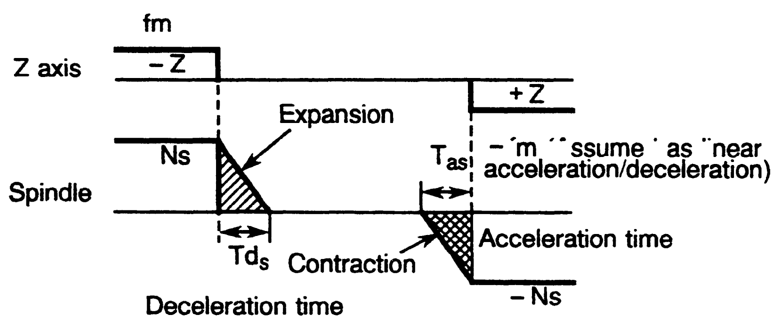
pNs - fm = negative (contraction of tapper)

$$\varepsilon_1 = \frac{pNs - fm}{fm} \times df \quad \text{(mm)} \cdots\cdots (7-5)$$

The above relation is contrary when the tapper is lifted.
Particularly be careful with this relation when a hole is deep.

(b) Expansion and contraction ε2 caused by the forward/reverse rotation of spindle and Z-axis feed timing

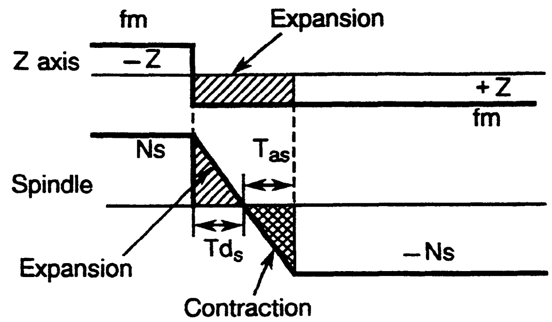
① Pattern A



$$\varepsilon_{2a} = \frac{1}{2} \times \frac{Ns}{60} \times p \times (Td_s - Tas) \quad \text{(mm)} \cdots\cdots (7-6)$$

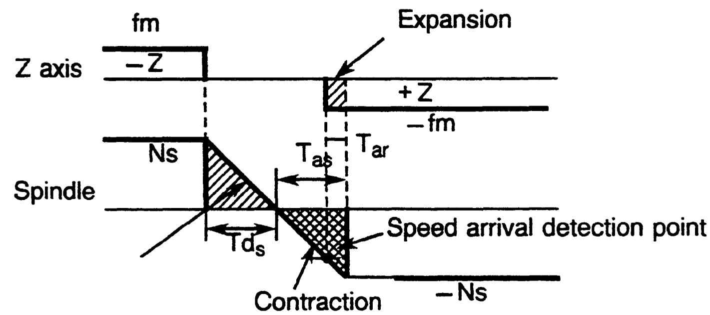
$Td_s \leqq Tas$ usually.

② Pattern B (Z-axis instantaneous reverse rotation)



$$\varepsilon_{2b} = \frac{1}{2} \times \frac{Ns}{60} \times p \times (Td_S - Tas) + \frac{fm}{60} \times (Td_S + Tas) \quad \text{(mm)} \cdots\cdots\cdots\cdots (7\text{-}7)$$

③ Pattern C



Tar : Tome required until the spindle reaches steady-state revolution after generation of speed arrival signal

$$\varepsilon_{2b} = \frac{1}{2} \times \frac{Ns}{60} \times p \times (Td_S - Tas) + \frac{fm}{60} \times Tas \quad \cdots\cdots\cdots\cdots (7\text{-}8)$$

(6) Examination to minimize the expansion and contraction of tapper

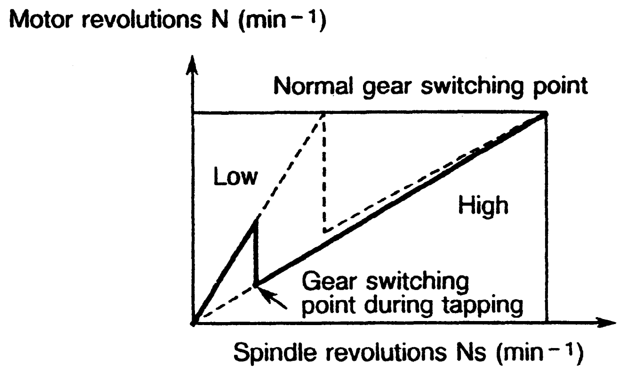
① Synchronize the commanded spindle speed with actual spindle speed.

② Control the reverse rotation start time of the Z-axis feed motor as shown in pattern C until expansion/contraction ε2c Z 0.

Adjust the detection level of the speed arrival signal from the spindle servo unit as a method.

③ Shorten the acceleration and deceleration time of spindle.

Switch gears from low gear to high gear at revolutions lower than normal gear switching point for the purpose of shortening the acceleration and deceleration time of the spindle during tapping work only.

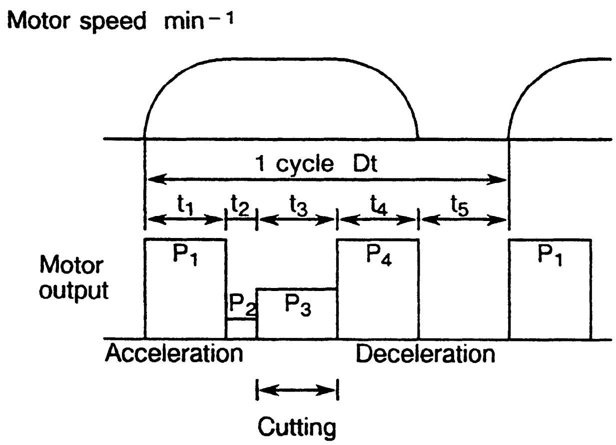


2.8 How to Find Allowable Duty Cycle

When the spindle accelerates and decelerates frequently for machining, the motor should be used so that the average output value of one cycle of operation does not exceed the continuous rated output.

Following is the description of the method of calculating its allowable duty cycle for a typical AC spindle motor.

(1) Duty cycle and average output



P_1, P_4 : Output at acceleration and deceleration (kW) = 30-minute rated output × 1.2

P_2 : Output at no-load rotation (P = 0)

P_3 : Output during cutting (kW)

$$\text{Average output Pav} = \sqrt{\frac{P_1{}^2t_1 + P_2{}^2t_2 + P_3{}^2t_3 + P_4{}^2t_4}{Dt}} \cdots\cdots\cdots\cdots\cdots (8\text{-}1)$$

(Note) As to output P_3 during cutting at motor speed N which is less than base speed Nb, assuming actual cutting output to be Pc (kW), the value is obtained by the following equation.

$$P3 \fallingdotseq \frac{Nb}{N} \times Pc \quad (kW) \cdots\cdots\cdots\cdots\cdots (8\text{-}2)$$

(2) How to find allowable duty cycle time Dt:

From eq. (8-1) above, Dt is determined by:

$$Dt = \frac{1}{Pav^2} \times (P_1{}^2t_1 + P_2{}^2t_2 + P_3{}^2t_3 + P_4{}^2t_4) \quad \cdots\cdots\cdots (8\text{-}3)$$

Substitute the continuous rated output value of AC spindle motor used for Pav (kW).

Ex:

Find the allowable duty cycle time when acceleration and deceleration are repeated at no load ($P_2 = P_3 = 0$) for model 3.

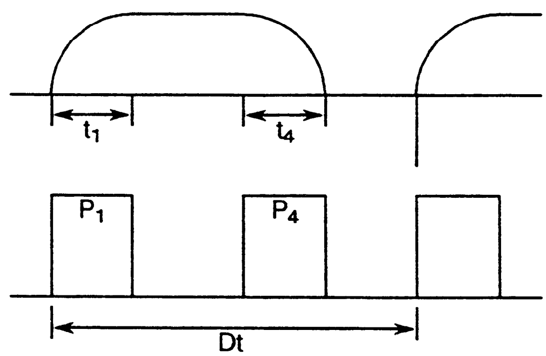
- o Continuous rated output:
  Pav = Pcont = 3.7 kW
- o Output at acceleration/deceleration:
  P1 = P4 = 5.5 kW x 1.2 = 6.6 kW
- o Acceleration time t1 = 3 sec
  Deceleration time t4 = 3 sec

Under the aforementioned conditions, Dt is found as follows.

$$Dt = \frac{1}{3.7^2} \times (6.6^2 \times 3 + 6.6^2 \times 3) = \frac{6.6^2}{3.7^2} \times (2 \times 3) = 19.08 \text{ seconds}$$

In other words, the allowable duty time when acceleration and deceleration are repeated at no load for model 3 corresponds to 3.18 times the summation of the acceleration and deceleration times.

(3) Allowable duty cycle time Dt for repeated acceleration and deceleration



$$Dt = \frac{1}{P^2cont} \times \{P_2 30min \times 1.2^2 \times (t_1 + t_4)\} \quad \cdots\cdots\cdots (8\text{-}3)$$

where,

Pcont : Continuous rated output

$P_2$30 min : 30-minute rated output

$t_1 + t_4$: Summation of acceleration time and deceleration time

$$Dt = \frac{(P_2 30min \times 1.2)^2}{Pcont} \times (t_1 + t_4) = Km \times (t_1 + t_4) \text{ (seconds)} \cdots\cdots\cdots (8\text{-}4)$$

The Km value of each motor model is shown in the table below.

Model	Value of Km
1S	3.10
1.5S	16.29
2S	4.07
3S	3.18
6S	2.68
8S	3.10
12S	2.68
15S	2.19
18S	2.04
22S	2.01

2.9 The Calculating Method of the Orientation Time

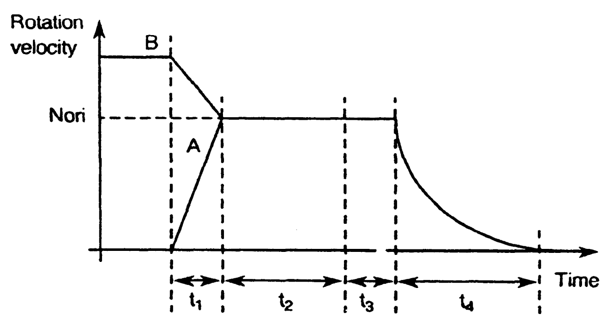
The serial spindle has two kinds of the orientation methods. One is a position coder method, and the other is a magnetic sensor method. The calculating method of the orientation time in each method is shown as follows.

(1) Position coder methoa

In the position coder method, the orientation time is different when the one-rotation signal has not been detected yet and the one-rotation signal has been detected already.

(i) The case that the one-rotation signal has not been detected yet (the first orientation after power on).

The time for the orientation is devided into 4 areas, as shown in a right drawing. Two ways of reaching the velocity 'Nori' from the state of stop (A) and from the state of rotation (B) are shown.



t_1 : time to reaching the orientation velocity 'Nori [min^{-1}]'.

Usually, 't_1' is measured for the machine actually used.

By using the position gain 'PG [sec^{-1}]' and the motor velocity limitation value at the orientation 'Rori', the orientation velocity 'Nori [min^{-1}]' is shown as follows.

$$Nori = PG \times 60 \times Rori \ [min^{-1}] \qquad (1)$$

t_2 : time until the one-rotation signal is detected and the pulse number to the following one-rotation signal is checked, after reaching the velocity 'Nori'.
't_2' is the time necessary for 1-2 rotations at the velocity of 'Nori'.

$$\frac{60}{Nori} \times 1 \leqq t_2 \leqq \frac{60}{Nori} \times 2$$

from the expression (1),

$$\frac{1}{PG \times Rori} \leqq t_2 \leqq \frac{2}{PG \times Rori} \qquad (2)$$

t_3 : time from the end of checking the pulse number to starting the deceleration.
't_3' is the time necessary for 0-1 rotations at the velocity of 'Nori'.

$$\frac{60}{Nori} \times 0 \leqq t_3 \leqq \frac{60}{Nori} \times 1$$

from the expression (1),

$$0 \leqq t_3 \leqq \frac{1}{PG \times Rori} \qquad (3)$$

t_4 : time from starting the deceleration to the completion of the orientation (width of the completion: within ± 10 pulses)

$$t_4 = \frac{1}{PG} \ln \frac{4096 \times Rori}{10} \text{ [sec]} \qquad (4)$$

Therefore, the orientation time is as follows. ($t = t_1 + t_2 + t_3 + t_4$)

$$t_1 + \frac{1}{PG \times Rori} + \frac{1}{PG} \ln \frac{4096 \times Rori}{10} \leqq t \leqq t_1 + \frac{3}{PG \times Rori} + \frac{1}{PG} \ln \frac{4096 \times Rori}{10} \qquad (5)$$

[Calculating example]

When the time to reaching the orientation velocity is 0.5 ($t_1 = 0.5$ [sec]), the position is 20 ($PG = 20$ [sec^{-1}]) and the motor velocity limitation value at orientation is 0.33 ($Rori = 0.33$ [33%]), the orientation time is calculated.

from the expression (5),

$$0.5 + \frac{1}{20 \times 0.33} + \frac{1}{20} \ln \frac{4096 \times 0.33}{10} = 0.896 \text{ [sec]}$$

$$0.5 + \frac{3}{20 \times 0.33} + \frac{1}{20} \ln \frac{4096 \times 0.33}{10} = 1.196 \text{ [sec]}$$

Therefore, the orientation time 't' is as follows.

$\underline{0.896 \leqq t \leqq 1.196}$

※ $t_1 = 0.5$ [sec] is used in this example, but in the actual calculation, please use the time which is measured in the real machine.

ii) The case that the one-rotation signal has been detected (the orientation since the second time)

When the one-rotation signal has been detected, the time to detect the one-rotation signal is not necessary. Therefore, the orientation time is as follows. ($t = t_1 + t_3 + t_4$)

$$t_1 + \frac{1}{PG} \ln \frac{4096 \times Rori}{10} \leqq t \leqq t_1 + \frac{1}{PG \times Rori} + \frac{1}{PG} \ln \frac{4096 \times Rori}{10} \qquad (6)$$

In the case of starting the orientation from the state of stop, the orientation is completed within one rotation. The orientation time is as follows.

$$0 \leqq t \leqq \frac{1}{PG \times Rori} (1 - Rori) + \frac{1}{PG} \ln \frac{4096 \times Rori}{10} \qquad (7)$$

[Calculating example]

When the time to reaching the orientation velocity is 0.5 ($t_1 = 0.5$ [sec]), the position is 20 ($PG = 20$ [sec^{-1}]) and the motor velocity limitation value at orientation is 0.33 ($Rori = 0.33$ [33%]), the orientation time is calculated.

In the orientation from the state of rotation.
from the expression (6),

$$0.5 + \frac{1}{20} \ln \frac{4096 \times 0.33}{10} = 0.746 \text{ [sec]}$$

$$0.5 + \frac{1}{20 \times 0.33} + \frac{1}{20} \ln \frac{4096 \times 0.33}{10} = 0.896 \text{ [sec]}$$

Therefore, the orientation time 't' is as follows.

$\underline{0.746 \leqq t \leqq 0.896}$

In the orientation from the state of stop.
from the expression (7),

$$\frac{1}{20 \times 0.33} \cdot (1 - 0.33) + \frac{1}{20} \ln \frac{4096 \times 0.33}{10} = 0.346 \text{ [sec]}$$

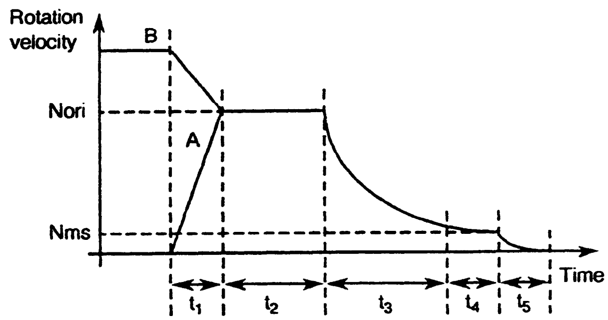
Therefore, the orientation time 't' is as follows.

$\underline{0 \leqq t \leqq 0.346}$

※ $t_1 = 0.5$ [sec] is used in this example, but in the actual calculation, please use the time which is measured in the real machine.

(2) Magnetic sensor method

As shown in a right drawing, the orientation time is devided into 5 areas.



t_1 : time to reaching the orientation velocity 'Nori [min^{-1}]'.
't_1' is measured for the machine actually used.

t_2 : time until the one-rotation signal is detected and the deceleration is started, after reaching the velocity 'Nori'.

$$\frac{60}{Nori} \times (1 - Rori) \leqq t_2 \leqq \frac{60}{Nori} \times (2 - Rori)$$

from the expression (1),

$$\frac{1}{PG \times Rori} - \frac{1}{PG} \leqq t_2 \leqq \frac{2}{PG \times Rori} - \frac{1}{PG} \qquad (8)$$

t_3 : time from starting the deceleration to reaching the velocity 'Nms'.

By using the length of the magnetizing element 'L' and the distance form the center of the spindle to the magnetizing element 'H', the velocity 'Nms' is shown as follows.

$$Nms = \{(L/2) / 2\pi H\} \times 60 \times PG \ [min^{-1}] \qquad (9)$$

It is easier to calculate the sum of t_3 and t_5 than to calculate t_3 and t_5 respectively.
Therefore, t_3 is calculated with t_5 later.

t_4 : time from reaching the velocity 'Nms' to detecting the LS signal.
't4' is the time necessary for $(L/2)/2\pi H$ rotation at the velocity of Nms.

$$t_4 = \frac{(L/2) / 2\pi H}{\{(L/2) / 2\pi H\} \times 60 \times PG} \times 60 = \frac{1}{PG} \ [sec] \qquad (10)$$

t_5 : time from entering the LS signal area to the completion of the orientation (within ±one degree).

The sum of t_5 and t_3 is as follows.

$$t_3 + t_5 = \frac{1}{PG} \ 1n \ (360 \times Rori) \ [sec] \qquad (11)$$

Therefore, the orientation time 't' is as follows. ($t = t_1 + t_2 + t_3 + t_4 + t_5$)

$$t_1 + \frac{1}{PG \times Rori} + \frac{1}{PG} \ 1n \ (360 \times Rori) \leqq t \leqq t_1 + \frac{2}{PG \times Rori} + \frac{1}{PG} \ 1n \ (360 \times Rori) \qquad (12)$$

[Calculating example]

When the time to reaching the orientation velocity is 0.5 ($t_1 = 0.5$ [sec]), the position is 20 (PG = 20 [sec^{-1}]) and the motor velocity limitation value at orientation is 0.33 (Rori = 0.33 [33%]), the orientation time is calculated.

from the expression (12),

$$0.5 + \frac{1}{20 \times 0.33} + \frac{1}{20} \ln (360 \times 0.33) = 0.889 \text{ [sec]}$$

$$0.5 + \frac{2}{20 \times 0.33} + \frac{1}{20} \ln (360 \times 0.33) = 1.039 \text{ [sec]}$$

Therefore, the orientation time 't' is as follows.

$\underline{0.889 \leqq t \leqq 1.039}$

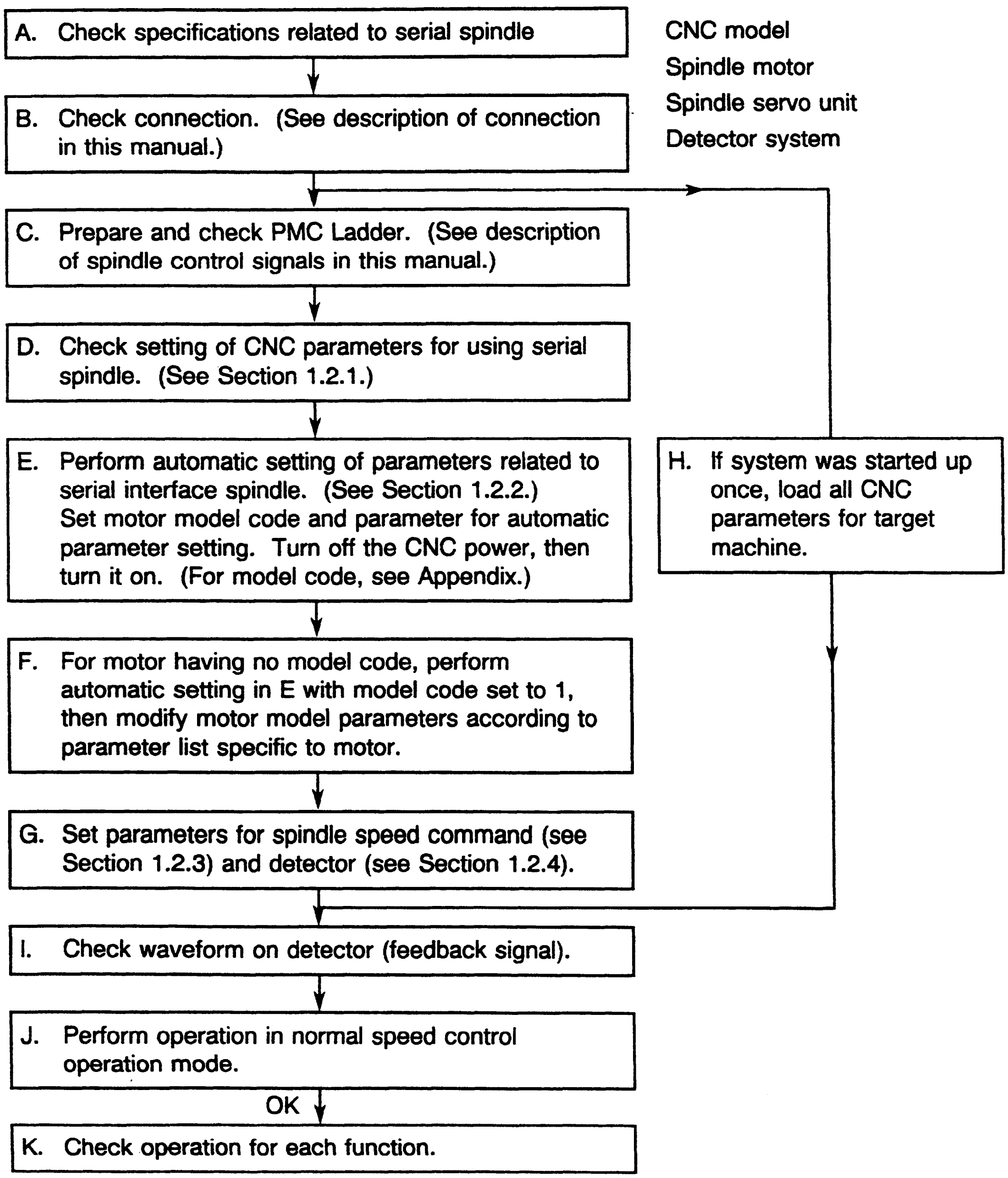
※ $t_1 = 0.5$ [sec] is used in this example, but in the actual calculation, please use the time which is measured in the real machine.

APPENDIX 3 SERIAL SPINDLE START-UP PROCEDURE

Appendix 3 explains the procedure for starting up the serial interface spindle amplifier.
First, start the amplifier in the normal operation mode.
Then, start individual functions including Cs contour control, spindle synchronization control, rigid tapping, and spindle orientation.
For the method of starting up a specific function, see the description of the start-up procedure for the function.

1. START-UP PROCEDURE FOR NORMAL OPERATION

1.1 Start-up Procedure for Normal Operation (Flowchart)



1.2 Parameters for Normal Start of the Serial Spindle

For details on the parameters, refer to the operator's manual of the CNC used, and the appendix in this manual.

1.2.1 Parameters for the serial spindle system

Parameter No.				Description
PM	OC	15	16	
0025 #0	(*1)	5606 #0	(*1)	Specifies whether to use the serial spindle amplifier (first spindle).
–		5606 #1		Specifies whether to use the serial spindle amplifier (second spindle).
–	0071 #4	5604 #0(*2)	3701 #4	Specifies the number of serial spindle amplifiers connected.

(*1) Optional parameter
(*2) For Series 15TT only

1.2.2 Parameters for automatic parameter setting

Parameter No.				Description
PM	OC	15	16	
3019 #7	6519 #7	5607 #0	4019 #7	Specifies whether to set serial spindle parameters automatically (first spindle).
3133	6633	3133	4133	Motor model code (first spindle)
–	6659 #7	5607 #1	4019 #7	Specifies whether to set serial spindle parameters automatically (second spindle).
–	6773	3273	4133	Motor model code (second spindle)

If a spindle switch function is provided to control the switching of two motors with one spindle amplifier, refer to the description of the spindle switch function for automatic parameter setting for the secondary motor.

1.2.3 Parameters related to the spindle speed command

Parameter No.					Description
PM	0TC	0MC	15	16	
0011	0013		–	3706	Polarity of spindle speed command (valid when SSIN = 0) (bits 7 and 6)
0236	–	0543 (*1)	5618	3735	Minimum clamp speed of the spindle motor
0237 0238 0239	–	0542 (*1)	5619	3736	Maximum clamp speed of the spindle motor
3120	6520		3020	4020	Maximum speed of the spindle motor
0242	0539	0577	5613	–	Spindle speed command offset (always set to 0)
0243	0516		5614	–	Spindle speed command gain adjustment (always set to 1000)
0233 ~ 0235	0540 ~ 0543	0541 0539 0555 (*2)	5621 ~ 5628	3741 ~ 3744	Maximum spindle speed corresponding to the gear

(*1) Valid only for the M system. These parameters are invalid when the constant surface speed control option is used.

(*2) If the constant surface speed control option is used for the M system, the same parameters as the T system are used (0540 to 0543).

1.2.4 Parameters related to the detector

Digits following # indicate bit numbers.

Parameter No.					Description
PM	0TC	0MC	15	16	
3000	6500		3000	4000	Direction of rotation of the spindle and motor (#0)
3011	6511		3011	4011	Number of motor speed detector pulses (#2 to #0) (*1)
3001	6501		3001	4001	Specifies whether to use the position coder signal (#2) (*2)
3000	6500		3000	4000	Mounting direction of the position coder (#2)
3003	6503		3003	4003	Position coder type (number of pulses) (#7, #6, #4)
0026 #7, 6	0003 #7, 6	0028 #7, 6	5610	3706 #1, 0	Spindle-position coder gear ratio For ×1, ×2, ×4, or ×8
3001	6501		3001	4001	Specifies whether to use the detector for Cs contour control (#5)
3001	6501		3001	4001	Setting of a detector when the Cs contour control function is provided and a built-in motor is used (#6)
3001	6501		3001	4001	Mounting direction of the detector for Cs contour control (#7)
3007	6507		3007	4007	Specifies whether to check the position coder signal of the Cs contour control detector for disconnection (#5)
3056 ~ 3059	6556 ~ 6559		3056 ~ 3059	4056 ~ 4059	Spindle-motor gear ratio data This data is selected by PMC DI signals CTH1A and CTH2A.

(*1) If a motor included in the Cs contour control detector (90000p/revx4) is used, the number of speed detector pulses must be set to 128 pulses/rev.

If the Cs contour control detector is used with the built-in motor, the setting differs according to the shape of the drum of the detector used.

(*2) If one of the following functions is used, the parameter must be set so as to use the position coder signal:

- Spindle orientation with a position coder
- Spindle synchronization control function
- Spindle indexing with a position coder
- SACT indication (for indicating spindle speed)
- Rigid tapping
- Feeding for each rotation (such as normal threading and constant surface-speed control)

1.2.5 Outline of serial spindle speed command processing

(1) Series 0C

In both the T and M systems, actual output is not performed until the direction of rotation is determined by the parameters (No. 13#7 and 13#6 TCW CWM) or by the PMC signals(SSIN, SSGN) and the M03 or M04 command.
If SSIN is 1, the direction of rotation is determined from SSGN. If SSIN is 0 and parameters TCW and CWM are set so as to determine the direction of rotation by M03 or M04, actual output is not performed unless M03 or M04 is specified even once after the NC power is turned on.
If plus or minus setting is made, instead of M03 and M04, actual output is performed only by an S code. In this case, it is not necessary to specify M03 or M04.

(1) - 1 T system (lathe)

(a) Sxxxxx is specified in min^{-1} by the program or with the MDI.

(b) Speed command data is calculated using the maximum spindle speed (4096 min^{-1}) set in a parameter selected according to the gear selection signal (one of four: GR1 and GR2 combinations at DI).
Set spindle speed command offset compensation parameter No. 539 to 0, and spindle speed command gain parameter No. 516 to 1000.

GR1	GR2	Maximum spindle speed (Spindle speed when the maximum motor speed is specified)
0	0	Parameter No. 540
0	1	Parameter No. 541
1	0	Parameter No. 542
1	1	Parameter No. 543

(c) The data calculated in (b) is output to DO:F172 (R08O to R01O) and F173 (R12O to R09O).

(d) The spindle speed data is transferred to the serial spindle according to the SIND (DI signal) state.
0: The maximum spindle speed is converted to ±16384 according to the data calculated in (b), then the result is transferred to the serial spindle.
1: The maximum spindle speed is converted to ±16384 according to the data (±4095) in DI:G124 (R08I to R01I) and G125 (R12I to R09I), then the result is transferred to the serial spindle.

(e) The polarity of the speed command can be specified according to the SSIN (DI) signal as follows:
0: The polarity is determined by parameter Nos. 13#7 and 13#6, and M03 and M04.
1: The polarity is determined by SGN (DI) signal.

(f) For constant surface-speed control, the spindle speed (in min^{-1}) is calculated from G96, Sxxxxx (m/min.) and the position on the X axis, then steps (b) to (d) are performed.

(g) *SSTP (DI): Spindle stop signal

0: S0 is output to F172 and F173 regardless of the command.

1: Normal steps (b) and (c) are performed.

*SSTP works on the value S on the command. It exists between (a) and (b), and functions in a portion where the S code value specified by program or with the MDI is recognized in the CNC.

If *SSTP is 0, the resulting output to F172 and F173 is set to 0. If SIND is 1 and values are set in G124 and G125, however, the spindle is rotated.

(1) - 2 M system (machining center)

(a) In the T system, the gear selection signals are input signals. In the M system, they are output signals (DO). With the T system, one of four gear stages is selected by two bits. With the M system, one of three gear signals GR10, GR20, and GR30, and the SF signal (to indicate the change of the gear signal) are output.

Set spindle speed command offset compensation parameter No. 577 to 0, and spindle speed command gain parameter No. 516 to 1000.

Gear	Maximum spindle speed (spindle speed when the maximum motor speed is specified)		
GR10	Parameter No. 541	:	Low
GR20	Parameter No. 539	:	Middle
GR30	Parameter No. 555	:	High

To clamp the maximum spindle speed command, set parameter No. 542.

In normal operation, set 4095 (to output up to 10 V).

To clamp the minimum spindle speed command, set parameter No. 543.

In normal operation, set 0.

For type B gear change, the motor speed at gear change must be set in the following parameters:

Parameter No. 585 (For the maximum motor speed with the low gear)

Parameter No. 586 (For the maximum motor speed with the middle gear)

(b) Sxxxxx (in min^{-1}) is specified by the program or with the MDI.

(c) In reply to the S command, the CNC outputs SF and either GR10, GR20, or GR30. At the same time, by using the maximum spindle speed (in min^{-1}) set in the corresponding parameter to the set gear, the CNC calculates speed command data. The maximum spindle speed is assumed to be 4096. The calculated data is then output to DO: F172 (R08O to R01O) and F173 (R12O to R09O).

(d) According to the SIND (DI) state, the spindle speed data is transferred to the serial spindle.
   0: Based on the data calculated in (c), the maximum spindle speed is converted to ±16384, then it is transferred to the serial spindle.
   1: Based on the data (±4095) in DI: G124 (R08I to R01I) and G125 (R12I to R09I), the maximum spindle speed is converted to ±16384, then it is transferred to the serial spindle.

(e) The polarity of the speed command can be specified according to the SSIN (DI signal) state as follows:
   0: The polarity is determined by parameter Nos. 13#7 and 13#6, and M03 or M04.
   1: The polarity is determined by the SGN (DI) signal.

(f) *SSTP functions in the same way as the T system.

(g) The SOR (DI) signal is provided for gear change.
   If SOR is 1 and *SSTP is 0, the spindle rotates at a constant speed specified by the speed command set in the parameter.
   In the M system, either the spindle or spindle motor can be turned at constant speed. One of them can be selected by parameter No. 3#5 GST.
   The T system also provides SOR. Unlike from SOR in the M system, SOR in the T system always causes the spindle to rotate at constant speed.
   In addition to the gear change point mentioned above, other switch points can be provided in G84 and G74 (tapping mode).(Set parameter No. 12#6 G84S, and Nos. 540 and 556).
   The M system can have the constant surface-speed control option. This allows the M system to function as the same gear shift type as the T system.
   The M system, when provided with the constant surface-speed control option, is compatible with the T system, except for two features. One of the differences is that in the M system, the reference axis for calculating the surface speed can be set to either the X, Y, Z, or 4th axis by the program or parameters. The other difference is that in the T system, the maximum speed is clamped by the program at G50SXXXXX. In the M system, it is clamped at G92SXXXXX. (Gear shift of the M system type is not permitted when constant surface-speed control is provided.)

(2) Series 15 (common to the T and M systems)

The serial spindle allows the BMI interface only. Basically, the PMC calculates and sends the contents of the spindle motor speed command to the CNC. In general, spindle control SPCNT (machine instruction) of the PMC is used.

(a) Sxxxxx (in min^{-1}) is specified by the program or with the MDI.

(b) Sxxxxx (in min^{-1}) is output to DO:F20 to F23 (32 bits) without modification.

(c) The PMC sets data, which is calculated with the maximum motor speed assumed to be ±8192, in RI (DI): G24 and G25 by using a machine instruction.
Parameters such as maximum spindle speed for the set gear stage (one of four stages) and spindle override must be set in the machine instruction.

(d) Based on the RI data (±8192), the CNC performs processing related to the following two parameters, converts the maximum motor speed into 16384, then transfers it to the serial spindle.
Spindle speed command offset compensation parameter No. 5613 = 0
Spindle speed command gain parameter No. 5614 = 1000

(e) When functions such as spindle change detection and constant surface speed control are used, the following parameters are also used:
Gear Maximum spindle speed (spindle speed when the maximum motor speed is specified)
Gear 1 : Parameter No. 5621
Gear 2 : Parameter No. 5622
Gear 3 : Parameter No. 5623
Gear 4 : Parameter No. 5624

(3) Series 16

The spindle control flow for Series 16 is almost the same as that for Series 0C. Note that the parameter Nos. indicated above for the T and M systems of Series 0C are different for Series 16.

A major difference in Series 16 is spindle override. The conditions for spindle override are the same as in Series 0C. Spindle override is enabled where *SSTP and the command S code are recognized in the CNC.
The PMC signal, however, is treated in a different way.
In Series 0C, override is done in 10% steps by a 3-bit signal. If all bits are set to 0, 100% override is achieved. In Series 16, the amount of override applied in steps of 1% is set in binary representation by using the eight bits of G30 (0% to 255%). With Series 0C, 100% override can be applied automatically without special operation. With Series 16, 0% spindle override is always applied unless the override is set by the PMC.
If SIND is 1, spindle override is disabled.

(3) - 1 T system (lathe)

(a) Sxxxxx is specified in min^{-1} by the program or with the MDI.

(b) Sxxxxx is output in min^{-1} to DO: F22 to F25 (32 bits) without modification.

(c) By using the maximum spindle speed (min^{-1}) set in the parameter corresponding to the gear selection signals (one of four stages is selected by DI: GR1 and GR2), the speed command data is calculated. The maximum spindle speed is assumed to be 4096.
Spindle speed command offset compensation parameter No. 3731 = 0
Spindle speed command gain parameter No. 3730 = 1000

GR1	GR2	Maximum spindle speed (spindle speed when the maximum motor speed is specified)
0	0	Parameter No. 3741
0	1	Parameter No. 3742
1	0	Parameter No. 3743
1	1	Parameter No. 3744

(d) The data calculated in (c) is output to DO: 36 (R08O to R01O) and F37 (R12O to R09O).

(e) The spindle speed data is transferred to the serial spindle according to the SIND (DI) state as follows:
- 0: The maximum spindle speed is converted to ±16384 according to the data calculated in (c), then the result is transferred to the serial spindle.
- 1: The maximum spindle speed is converted to ±16384 according to the data (±4095) in DI: G32 (R08I to R01I) and G33 (R12I to R09I), then the result is transferred to the serial spindle.

(f) The polarity of the speed command can be specified by SSIN (DI signal) as follows:
- 0: The polarity is determined by parameter Nos. 3706#7 and 3706#6, and M03 and M04.
- 1: The polarity is determined by the SGN (DI) signal.

(g) For constant surface-speed control, the spindle speed is calculated in min^{-1} from G96, Sxxxxx (m/min.) and the position on the X axis, then steps (c) to (e) are performed.

(h) *SSTP (DI): Spindle stop signal
- 0: S0 is always output regardless of the command.
- 1: Normal processing steps (c) and (d) are performed.

(3) - 2 M system (machining center)

In the T system, the gear selection signals are input signals. In the M system, they are output signals (DO). In the T system, one of four gear stages is selected by two bits. In the M system, one of three gear signals GR10, GR20, and GR30, and the SF signal (to indicate the change of the gear signal) are output.
Spindle speed command offset compensation parameter No. 3731 = 0
Spindle speed command gain parameter No. 3730 = 1000

Gear	Maximum spindle speed (spindle speed when the maximum motor speed is specified)
GR10	Parameter No. 3741
GR20	Parameter No. 3742
GR30	Parameter No. 3743
——	Parameter No. 3744

When M system gear shift is used, parameter No. 3744 becomes valid.

The parameter is valid when the constant surface speed control function is used in the M system.

To clamp the maximum spindle speed command, normally set parameter No. 3736 to 4095 (to output up to 10 V).

To clamp the minimum spindle speed command, normally set parameter No. 3735 to 0.

For type B gear change, the motor speed at gear change must be set in the following parameters:

Parameter No. 3751 (for the maximum motor speed with gear 1)

Parameter No. 3752 (for the maximum motor speed with gear 2)

(a) Sxxxxx is specified in min^{-1} by the program or with the MDI.

(b) Sxxxxx specified in min^{-1} is output to DO: F20 to F23 (32 bits).

(c) In reply to the S command, the CNC outputs SF and either GR10, GR20, or GR30. At the same time, by using the maximum spindle speed (min^{-1}) set in the corresponding parameter to the set gear, the CNC calculates speed command data. The maximum spindle speed is assumed to be 4096. The calculated data is then output to DO: F36 (R08O to R01O) and F37 (R12O to R09O).

(d) According to the SIND (DI) state, the spindle speed data is transferred to the serial spindle.
- 0: Based on the data calculated in (c), the maximum spindle speed is converted to ±16384, then it is transferred to the serial spindle.
- 1: Based on the data (±4095) in DI: G32 (R08I to R01I) and G33 (R12I to R09I), the maximum spindle speed is converted to ±16384, then it is transferred to the serial spindle.

(e) The polarity of the speed command can be specified according to the SSIN (DI signal) state as follows:
- 0: The polarity is determined by parameter Nos. 3706#7 and 3706#6, and M03 or M04.
- 1: The polarity is determined by the SGN (DI) signal.

(f) The SOR (DI) signal is provided for gear change.
If SOR is 1, the spindle rotates at a constant speed specified by the speed command set in the parameter.

2. Cs CONTOUR CONTROL FUNCTION START-UP PROCEDURE

2.1 Start-up Procedure of the Cs Contour Control Function (Flowchart)

A. Check that the system is ready for normal operation (Start-up of normal operation mentioned in Chapter 1 is completed.)

↓

B. Prepare and check the ladder program for Cs contour control function. (See Sections 2.2 and 2.3.)

↓

C. Set Cs contour control parameters. (See Section 2.4.)

↓

D. Check and adjust the waveform on the Cs contour control detector.

↓

E. Check the reference position return operation

- Maximum speed in the Cs contour control mode (speed at which the machine returns to the reference position)
- Parameter of the change rate of the position gain when returning to the reference position in the Cs contour control mode

↓

F. Check the stop position when the machine returns to the reference position

↓

G. Check the direction of spindle rotation in the Cs contour control mode

- Grid shift in the Cs contour control mode

↓

H. Adjust and check the Cs contour control servo

- Rotation direction parameter for the positive move command

↓

I. Check then terminate operation in the Cs contour control mode

- Check the operation during jog, rapid traverse, and handle operation.

2.2 DI and DO Signals for Cs Contour Control

2.2.1 DI signal (PMC→CNC)

(1) Cs contour control mode switching signal

This signal switches between the spindle rotation control mode and Cs contour control mode. Before switching from the Cs contour control mode to the spindle rotation control mode, check that the spindle move command has terminated.
Switching from the spindle rotation control mode to the Cs contour control mode is enabled even when the spindle is rotating.
In this case, spindle rotation is decelerated then stopped, and the modes are changed. For safe operation, be sure to reset the spindle speed command (S command).

COFF (0TC) 0: Cs contour control mode
1: Spindle rotation control mode
CON (0MC) 0: Spindle rotation control mode
(16) 1: Cs contour control mode
SCNTR1, 2, ... 0: Spindle rotation control mode
(15) 1: Cs contour control mode

0C	15	16	7	6	5	4	3	2	1	0
G123			CON(M)							COFF(T)
		G027	CON(T/M)							
	G67, G71 . .		SCNTR1, 2 . .							
G229	G227	G070	MRDYA	ORCMA	SFRA	SRVA	CTH1A	CTH2A	TLMHA	TLMLA
G230	G226	G071	RCHA	RSLA	INTGA	SOCNA	MCFNA	SPSLA	*ESPA	ARSTA

2.2.2 DO signal (CNC→PMC)

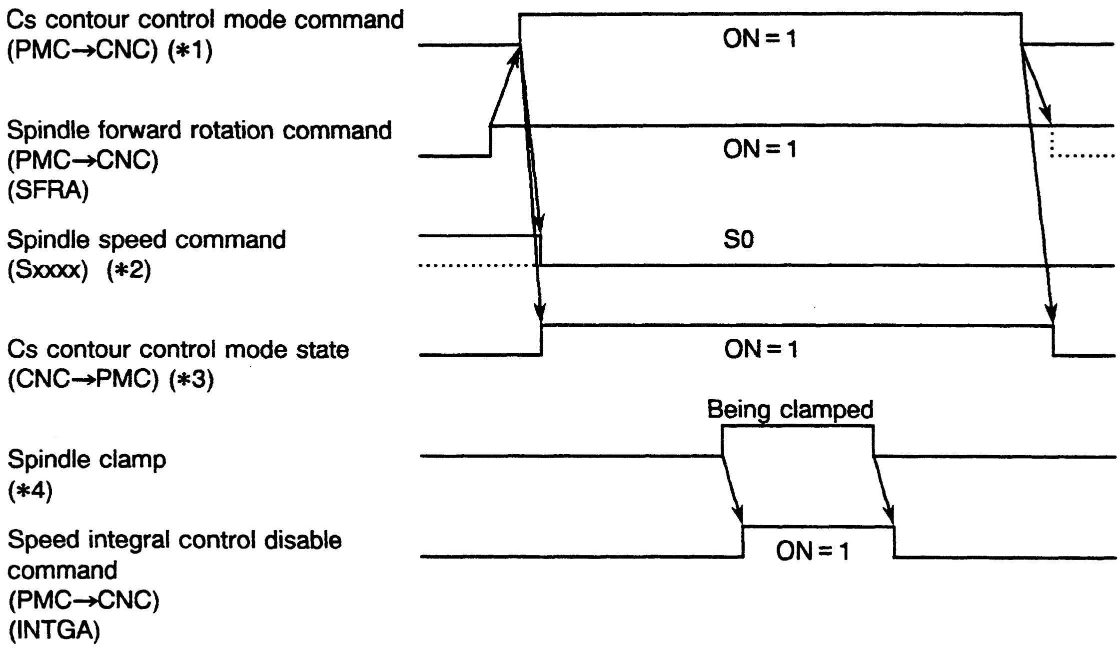
(1) Cs contour control mode switching confirmation signal

This signal posts the completion of switching between the spindle rotation control mode and Cs contour control mode.

FSCSL (0C) 0: Spindle rotation control mode
(16) 1: Cs contour control mode
MCNTR1, 2, ... 0: Spindle rotation control mode
(15) 1: Cs contour control mode

0C	15	16	7	6	5	4	3	2	1	0
F178		F004							FSCSL	
	F67, F71 . .		MCNTR1, 2 . .							
F281	F229	F045	ORARA	TLMA	LDT2A	LDT1A	SARA	SDTA	SSTA	ALMA
F282	F228	F046					RCFNA	RCHPA	CFINA	CHPA

2.3 Sample Sequence in the Cs Contour Control Mode



(*1) For Series 0TC : Setting COFF to 0 enters the Cs contour control mode.
For Series 0MC: Setting CON to 1 enters the Cs contour control mode.
For series 15 : Setting SCNTR to 1 enters the Cs contour control mode.
For Series 16 : Setting CON to 1 enters the Cs contour control mode.

(*2) When specifying the Cs contour control mode, reset the spindle speed command (S0 command) for safe operation.

(*3) For Series 0C : Setting FSCSL to 1 enters the Cs contour control mode.
For Series 15 : Setting MCNTR to 1 enters the Cs contour control mode.
For Series 16 : Setting FSCSL to 1 enters the Cs contour control mode.

(*4) When the spindle is clamped after it is positioned to perform machining such as drilling in the Cs contour control mode, the clamp position of the spindle may deviate a little from a specified position. If it deviates, the speed integral function works. The function attempts to move the spindle to the specified position. As a result, excessive current may flow in the motor. To prevent this, the speed integral function must be disabled while the spindle is being clamped.

2.4 Cs Contour Control Parameters

Parameter No.				Description
0TC	0MC	15	16	
3rd axis	4th axis	1804	1023	Sets an axis for which Cs contour control is performed.
0037 #7		1804 #0	–	Specify that the high resolution pulse coder is not used.
0037 #3, 2		1815 #1	1815 #1	Specify that a separate pulse coder is not used.
0021 #3, 2		1815 #5	1815 #5	Specify other than absolute-position detector.
–		5609 #1, 0	–	Specifies whether to perform automatic position gain setting for axes other than the Cs contour control axis.
6469 ∫ 6572		3069 ∫ 3072	4069 ∫ 4072	Position gain of the Cs contour control axis This data is selected by the CTH1A and CTH2A PMC DI signals.
6780 ∫ 6799		5609 #0 #1	3900 ∫ 3944	Position gain of axes other than the Cs axis in the Cs contour control mode This data is selected by the CTH1A and CTH2A PMC DI signals.
0102	0103	1820	1820	For command multiplication, set 2 (one time)
0065 #1		1005 #0	3700 #1	Specifies whether to enable the reference position return function for the first G00 command after the serial spindle is switched to the Cs contour control mode.
0502	0503	1827	1826	In-position width
0506	0507	1828	1828	Positioning deviation limit along each axis during movement
0595	0596	1829	1829	Positioning deviation limit for each axis in the stopped state
–	–	1830	–	Positioning deviation limit for each axis in the servo off state
0332	0333	1832	1832	Limited deviation of the feed-stop position for each axis
0520	0521	1420	1420	Rapid traverse feedrate
0561	0562	1423	1423	Jog feedrate
–	–	1422	1422	Maximum cutting feedrate
0635		1622	1628	Time constant of linear acceleration/deceleration after interpolation in cutting feed (optional)
0524	0525	1620	1620	Time constant of linear acceleration/deceleration in rapid traverse

Parameter No.			Description
0C	15	16	
6521	3021	4021	Maximum spindle speed in the Cs contour control mode
6500	3000	4000	Direction of reference position return in the first Cs contour control mode entered after the power is turned on (#3)
6500	3000	4000	Direction of spindle rotation by the + move command in the Cs contour control mode (#1)
6546 6547	3046 3047	4046 4047	Proportional gain of the velocity loop in the Cs contour control mode This data is selected by the CTH1A PMC DI signal.
6554 6555	3054 3055	4054 4055	Integral gain of the velocity loop in the Cs contour control mode This data is selected by the CTH1A PMC DI signal.
6556 ~ 6559	3056 ~ 3059	4056 ~ 4059	Spindle-motor gear ratio data This data is selected by the CTH1A and CTH2A PMC DI signals.
6589	3086	4086	Motor voltage in the Cs contour control mode (Normally, 100 is set.)
6592	3092	4092	Change rate of the position gain when returning to the reference position in the Cs contour control mode
6594	3094	4094	Disturbance torque compensation constant
6597	3097	4097	Feedback gain of the spindle speed
6599	3099	4099	Delay time for motor activation
6635	3135	4135	Grid shift in the Cs contour control mode

2.5 Diagnosis

Address				Description
0TC	0MC	15	16	
0802	0803	3000	0418	Axis positioning deviation in the Cs contour control mode

2.6 Adjustment Procedure in the Cs Contour Control Mode

2.6.1 Adjustment in reference position return operation

(1) Speed of reference position return operation (parameter No. 6521)
After the power is turned on, the first reference position return operation is similar to spindle orientation. The machine returns to the reference position after a one-rotation signal of the Cs contour control detector is detected.
When the reference position return command is input, the serial spindle rotates at a reference position return speed (which is set in parameter No. 6521 as the maximum spindle speed in the Cs contour control mode). When the one-rotation signal is detected, the spindle decelerates, then stops when the reference position is reached. The reference position return operation then terminates.
If the reference position return speed is too high, a smaller value must be set in parameter No. 67521. If the set value is smaller than the maximum speed for rapid traverse and cutting feed, the maximum speed is clamped at the parameter data, resulting in an excessive error alarm.

(2) Overshoot in return to the reference position (parameter No. 6592)
If the speed of reference position return operation is high or large spindle inertia exists, an overshoot may occur.
To suppress overshoot, set a smaller value (5 to 50) in parameter No. 6592 for the change rate of the position gain when returning to the reference position in the Cs contour control mode.

(3) Reference position to which return is made (parameter No. 6635)
To change the reference position to which return is made, set data in parameter No. 6635 for the grid shift in the Cs contour control mode.

2.6.2 Direction of spindle rotation in the Cs contour control mode (parameter No. 6500#1)

To change the direction of spindle rotation in the Cs contour control mode, modify the value of bit 1 in parameter No. 6500.

2.6.3 Setting the position gain in the Cs contour control mode

A position gain in the Cs contour control mode must be set for the spindle as well as for the feed axis.
Note that the parameter of the position gain for the feed axis in the Cs contour control mode is not located at an ordinary parameter address. (See Section 2.4.)
If the position gain is modified for each gear, set data at the corresponding address. The parameter is selected by the CTH1A and CTH2A DI signals.

2.6.4 Rapid traverse time constant for the Cs contour control axis (No. 0524)

If the rapid traverse feedrate is high or the spindle inertia is large, an overshoot or hunting may occur when the rapid traverse is accelerated or decelerated.
In this case, adjust the parameter of the time constant of linear acceleration/deceleration in rapid traverse (No. 0524) to suppress overshoot and hunting.

2.6.5 Gear ratio of the spindle and motor (No. 6556 to 6559)

Gear ratio data is necessary to hold errors to an allowable level.
Be sure to set data for each gear.
The parameter is selected by the CTH1A and CTH2A DI signals.

2.6.6 Improving the rigidity during cutting operation in the Cs contour control mode

(1) Integral and proportional gains of the velocity loop in the Cs contour control mode
Setting larger values in the parameters for the integral gain and proportional gain of the velocity loop in the Cs contour control mode improves the rigidity in cutting in the Cs contour control mode.
Note, however, that setting an excessively large value causes oscillation.
Allowable values may vary according to the machine systems. As a rule of thumb, the following ranges can be set. Generally, larger values can be set for larger-scale motor models.
In some belt- or gear-coupled machines, large values cannot be set because of the backlash in the spring element of the belt or gear.

Proportional gain of the velocity loop	:	10 to 50
Integral gain of the velocity loop	:	50 to 500

(2) Disturbance torque compensation constant (No. 6594)
Setting the parameter for the disturbance torque compensation constant (No. 6594) improves the cutting stability.
In addition, when this parameter is set, a larger proportional gain of the velocity loop mentioned in (1) is allowed, resulting in improved rigidity.
As a general guideline, a value from 500 to 2000 may be set in this parameter.
The value must be less than 4000.

(3) Feedback gain of the spindle speed (No. 6597)
If the spindle and motor are connected via belts, feedback of the spindle speed may improve control stability.
As a general guideline, a value less than or equivalent to the proportional gain of the velocity loop (10 to 50) is set.

2.6.7 Excessive error in Cs contour control mode switching

When the Cs contour control mode is switched, a stop-time excessive error alarm may occur intermittently. This is due to abrupt change in motor activation that generates status transition in the motor and causes the motor to move a little.
In this case, set a value in the parameter for the delay time for motor activation (No. 6599). (Generally, set 400 (0.4 sec) or so.)

2.7 Additional Description of Series 0C in the Cs Contour Control Mode

2.7.1 Axis arrangement in the Cs contour control mode

The axis for which Cs contour control is performed is placed as the first axis of the control axes. The following tables list arrangements of axes.

X, Y, Z : Servo axes
C : Cs contour control axis

T system

Control axis No.	Axis name	Servo axis No.
1	X	1
2	Z	2
3	C	3
4	4th	4

M system

Control axis No.	Axis name	Servo axis No.
1	X	1
2	Y	2
3	Z	3
4	C	4

2.7.2 Gear selection signals (CTH1A, CTH2A)

The gear selection signals are used to select parameters used in the Cs contour control mode, such as position gain, gear ratio, and velocity loop gain parameters.

In the T system, four gear stages can be used.
In addition to GR1 and GR2, signals corresponding to clutch/gear signals CTH1A and CTH2A must be applied simultaneously as gear selection signals.
Although GR1 and GR2 are invalid in the Cs contour control mode, they are valid as usual in the spindle rotation control mode.

With the M system, three gear stages can be used according to the NC specifications.
In addition to GR10, GR20, and GR30, signals corresponding to clutch/gear signals CTH1A and CTH2A must be applied simultaneously as gear selection signals.
Although GR10, GR20, and GR30 are invalid in the Cs contour control mode, they are valid as usual in the spindle rotation control mode.

2.7.3 Position gain in the Cs contour control mode

In the Cs contour control mode, the position gains of the Cs contour control axis and the servo axis for which interpolation with the Cs contour control axis is performed must be set to the same value. The parameters for their position gains in the Cs contour control mode are as follows:

Position gain of the Cs contour control axis : Nos. 6569 to 6572
Position gain of the Servo control axis
in the Cs contour control mode : Nos. 6780 to 6799

These parameters are selected by gear selection signals CTH1A and CTH2A as listed in the following table. After switching to the Cs contour control mode, the position gains are not changed even if the CTH1A and CTH2A signals are changed. So, before the Cs contour control mode is entered, the CTH1A and CTH2A signals must be set.

(1) To set the same position gain for the servo axes and Cs contour control axis in the Cs contour control mode, set the following parameters.
In this case, set parameter Nos. 6784 to 6799 to 0.
Set parameter Nos. 6780 to 6783 to the same value as parameter Nos. 6569 to 6772.

Gear selection signal		Common to all servo axes	Cs contour control axis (spindle)
CTH1	CTH2		
0	0	6780	6569
0	1	6781	6570
1	0	6782	6571
1	1	6783	6572

(2) If the position gains of the servo axes and Cs contour control axis need not be equal, a position gain is specified for each axis in the parameters listed in the following table.
Parameter Nos. 6780 to 6783 which are common to all servo axes must be set to 0.

Gear selection signal		For each axis T system : X axis M system: X axis	For each axis T system : Z axis M system: Y axis	For each axis T system : Cs axis M system: Z axis	For each axis T system : 4th axis M system: Cs axis	Cs contour control axis (spindle)
CTH1	CTH2					
0	0	6784	6788	6792	6796	6569
0	1	6785	6789	6793	6797	6570
1	0	6786	6790	6794	6798	6571
1	1	6787	6791	6795	6799	6572

(3) The position gains of the servo control axes in the spindle rotation control mode must be set in parameter Nos. 517, and 512 to 515.

2.7.4 Return to the reference position in the Cs contour control mode

When the machine returns to the reference position in the normal operation mode, the rapid traverse is decelerated to the FL speed by the deceleration dog. In the Cs contour control mode, however, when the reference position return command is input, the one-rotation signal is detected, then the machine returns to the reference position. So no deceleration dog is necessary in the Cs contour control mode.

(1) Manual return to the reference position (jog mode)
The speed of the reference position return is determined by the parameter for the maximum spindle speed in the Cs contour control mode (No. 6521).
The direction of reference position return is set in parameter PRM 6500#3.
After switching to the Cs contour control mode, the reference position return mode is entered by setting the ZRN signal to ON. One of the feed axis selection signals –3 and +3 (for the T system) or –4 and +4 (for the M system) is set to ON. The Cs contour control axis then moves in the reference position return direction. As the reference position is reached, reference position return completion signal ZP3 (for the T system) or ZP4 (for the M system) is output.

(2) Automatic return to the reference position (AUTO or MDI mode)
The speed of the first reference position return operation performed after switching from the spindle rotation control mode to the Cs contour control mode is determined by the parameter for the maximum spindle speed in the Cs contour control mode (No. 6521).
The direction of the reference position return operation is set in parameter PRM 6500#3.
In the Cs contour control mode, the second and subsequent reference position return operations are performed at the speed set by the parameter.
After switching to the Cs contour control mode, the machine is returned to the reference position by executing the G00 or G28 command.
Whether the G00 command causes a reference position return operation is determined according to the following parameter. This parameter is valid only for the serial spindle (Cs contour control axis).

PRM No.65							CZRN	

CZRN 1 : The first G00 command issued after switching to the Cs contour control mode does not cause the machine to return to the reference position.

0 : The first G00 command issued after switching to the Cs contour control mode causes the machine to return to the reference position.

G00 command

PRM No. 65 CZRN=0

If the G00 command is executed when reference position return operation has not been performed since switching to the Cs contour control mode, the machine returns to the reference position.

The reference position is indexed, and at the same time, the spindle is positioned at the specified position.

Only when the spindle is positioned at the reference position (G00 G0.), reference position return completion signal ZP3 (for the T system) or ZP4 (for the M system) is output at the completion of positioning.

When the machine has returned to the reference position, the G00 command performs normal positioning.

PRM No. 65 CZRN = 1

If the G00 command is executed when the machine has not returned to the reference position since switching to the Cs contour control mode, the serial spindle performs normal positioning from its stopped position.

In this case, the reference position is not recognized.

So the G28 command is required to return the machine to the reference position.

When the machine has been returned to the reference position, the G00 command recognizes the reference position. A coordinate system is established, then normal positioning is performed.

G28 command

If G28 is specified after switching to the Cs contour control mode, the Cs contour control axis moves to a middle point. Reference position return, then positioning at the reference position are performed. Then, reference position return completion signal ZP3 (for the T system) or ZP4 (for the M system) is output.

When the machine has been returned to the reference position, positioning at the reference position is performed, then reference position return completion signal ZP3 (for the T system) or ZP4 (for the M system) is output.

(3) Operation after switching to the Cs contour control mode

Immediately after switching from the spindle rotation control mode to the Cs contour control mode is made, the current position is lost, so it is always necessary to return the machine to the reference position.

If the coordinate system for the Cs contour control axis is not required, however, a corresponding parameter is set so that the reference position return function is not used. In this case, movement is allowed without returning to the reference position.

(4) Interruption of return to the reference position

Manual operation mode

Reference position return for the Cs contour control axis can be interrupted by reset, emergency stop, or by turning the axis selection signal to OFF.

In all cases, after the interruption, the reference position return operation must be performed again from the beginning.

Automatic operation mode

The reference position return operation for the Cs contour control axis can be interrupted by reset, emergency stop or feed hold.

In all cases, after the interruption, reference position return operation must be performed again from the beginning.

2.7.5 Others

(1) Switching between the spindle rotation control and Cs contour control modes during automatic operation
When switching between the spindle rotation control and Cs contour control modes is performed during an automatic operation block, if position gains are changed immediately after the mode switch, normal operation is impossible. In this case, confirm the completion of the block, then perform automatic setting.

(2) The functions for memory type pitch error compensation and backlash compensation cannot be used for the Cs contour control axis.

(3) Before switching to the Cs contour control mode, signals MRDYA, *ESPA, and SFRA must be set to 1.

(4) When the PMC switches between the spindle rotation control mode and Cs contour control mode using an M code, the code must not be placed in the same block that contains a move command for the Cs contour control axis in the NC program. If such an M code and the move command are included together in the same block, alarm PS197 is generated.

2.7.6 Alarm

When the Cs contour axis control function is used, the following three alarms are added to the conventional alarms:

No.	Description
409	An alarm is generated in the serial spindle. Take corrective action according to the alarm in the serial spindle.
194	The Cs contour axis control, Cs axis control, or rigid tapping mode is specified in the serial spindle synchronization control mode. (Cancel the synchronization control mode, then specify the command.)
195	A command for switching to the spindle, Cs contour axis control, or servo mode (such as Cs axis control, or rigid tapping) is specified, but the specified switching operation is not performed by the serial spindle.

(Note 1) Alarm 409 is generated as a servo alarm, and alarms 195 and 194 are generated as P/S alarms. Alarm 194 is not generated when the serial spindle synchronization control option is not provided.
(Note 2) During the Cs contour axis control mode, for the T system a conventional servo alarm related to the third axis, or for the M system an alarm related to the fourth axis may be generated.

2.8 Additional Description of Series 15

2.8.1 Axis arrangement in the Cs contour control mode

(1) The same number as the control axis number must be set for the servo axis number of the axis for which Cs contour control is performed. If a different number is set, a servo alarm (SV026) is generated for all axes.

Sample arrangement X, Y, Z : Servo axes
C : Cs contour control axis

Control axis No.	Axis name	Servo axis No.
1	X	1
2	Y	2
3	Z	3
4	C	4

← Set the servo axis number to the same number as the control axis number.

(2) Removal of the control axis in the Cs contour control mode
If removal of the control axis is specified for the Cs contour control axis, the spindle enters the spindle rotation control mode. Therefore do not specify removal of the control axis.

(3) Axis arrangement for 15TT
In 15TT, two-spindle control is enabled. If both spindles are used as the Cs contour control axes, place one Cs contour control axis on a tool post, and the other axis on another tool post. The two Cs contour control axes cannot be placed on one tool post.

2.8.2 Gear selection signals and position gain in the Cs contour control mode

Gear stages 1 to 4 can be used. Stages 5 to 8 cannot be used.
In addition to gear selections signals GS1, GS2, and GS4, clutch/gear signals CTH1A and CTH2A must be applied simultaneously.
The relationships the selected position gain has with the gear selection and clutch/gear signals are listed below.

GS4	GS2	GS1		CTH1A	CTH2A		Position gain parameter for each axis in the Cs contour control mode (*1)
0	0	0		0	0		3069
0	0	1		0	1		3070
0	1	0		1	0		3071
0	1	1		1	1		3072
1	0	0		Not used			
1	0	1					
1	1	0					
1	1	1					

(*1) When the same position gain as the Cs contour control axis is set for servo axes other than the Cs contour control axis in the Cs contour control mode, set the parameter as follows:

Parameter No.	#7	#6	#5	#4	#3	#2	#1	#0
5609							NGC2	NGC1

NGC1 Specifies whether to set the position gain of the servo axes other than the Cs contour control axis (first spindle) to the same value as the position gain of the Cs contour control axis automatically.

0: Set automatically

1: Not set automatically

If there is no interpolation between the Cs contour control axis and the other servo axes, or if the same servo loop gain is used, set 1.

NGC2 Specifies whether to set the servo loop gain of the servo axes other than the Cs contour control axis (second spindle for FS15TT) to the same value as the servo loop gain of the Cs contour control axis automatically.

0: Set automatically

1: Not set automatically

If there is no interpolation between the Cs contour control axis and the other servo axes, or if the same servo loop gain is used, set 1.

2.8.3 Automatic position gain setting when switching between the spindle rotation control mode and Cs contour control mode

(1) Switching from the spindle rotation control mode to Cs contour control mode
If the servo loop gain of the Cs contour control axis is different from that of the other servo axes when the modes are switched, linear and circular interpolations with the Cs contour control axis fail.
To prevent this, at the same time that the modes are switched, the position gain selected by the clutch/gear signals (CTH1A and CTH2A) (PRM 3069, 3070, 3071, 3072) must be set for servo axes other than the Cs contour control axis automatically. (PRM 5609#1, 0)

(2) Switching from the Cs contour control mode to spindle rotation control mode
At the same time that the Cs contour control mode is switched to the spindle rotation control mode, the original position gain (PRM 1825) is set automatically for the servo axes.

(3) Switching between the spindle rotation control and Cs contour control modes during automatic operation
If mode switching between the spindle rotation control mode and Cs contour control mode is performed midway through an automatic operation block, the position gain is automatically set after completion of the block is confirmed.

(4) When the gain is not changed
If there is no interpolation between the Cs contour control axis and other axes, or if the Cs contour control axis and servo axes have the same position gain, the gain need not be changed. In this case, set the parameter to indicate that gain switching is not performed (PRM 5609#0, #1 = 0).

(5) For FS15TT
Only the gain of the servo axis of the tool post to which the Cs contour control axis belongs is changed automatically.

2.8.4 Return to the reference position in the Cs contour control mode

In normal operation, to return to the reference position, rapid traverse is decelerated to the FL speed by the deceleration dog. In the Cs contour control mode, when the reference position return command is input, the one-rotation signal is detected, then the machine returns to the reference position. So the conventional deceleration dog is unnecessary.

(1) Manual return to the reference position (jog mode)
The speed at which the machine returns to the reference position is determined by the parameter for the maximum spindle speed in the Cs contour control mode (No. 3021).
The direction for reference position return is set in parameter PRM 3000#3.
After switching to the Cs contour control mode, the reference position return mode is entered by setting the ZRN signal to ON. One of the feed axis direction selection signals –Jn and +Jn is set to ON. The Cs contour control axis then moves in the reference position return direction.

When the reference position is reached, reference position return completion signal ZPn is output.

(2) Automatic return to the reference position (AUTO or MDI mode)
The speed of the first reference position return operation performed after switching from the spindle rotation control mode to the Cs contour control mode is determined by the parameter for the maximum spindle speed in the Cs contour control mode (No. 3021).
The direction of reference position return is set in parameter PRM 3000#3.
In the Cs contour control mode, the second and subsequent reference position return operations are performed at the speed set by the parameters.
After switching to the Cs contour control mode, the machine returns to the reference position by executing the G00 or G28 command.

G28 command

If G28 is specified after switching to the Cs contour control mode, the Cs contour control axis moves to a middle point. The machine is returned to the reference position, then is positioned at the reference position. Then, reference position return completion signal ZPn is output.
When the machine has returned to the reference position, it is positioned at the reference position then reference position return completion signal ZPn is output.

G00 command

PRM No. 1005 #0 = 1
(ZRNx: Reference position return function is not provided for each axis.)

If the G00 command is executed when the machine has not returned to the reference position since switching to the Cs contour control mode, the serial spindle performs normal positioning from its stopped position.
In this case, the reference position is not recognized.
So the machine must be returned to the reference position by using the G28 command.
If the G00 command is executed after the machine has returned to the reference position, the reference position is recognized. The coordinate system is established, then normal positioning is performed.

PRM No. 1005 #0 = 0
(ZRNx: Reference position return function is provided for each axis.)

If the G00 command is executed when the machine has not returned to the reference position since switching to the Cs contour control mode, the PS alarm is generated.

(3) Operation after switching to the Cs contour control mode
Immediately after switching from the spindle rotation control mode to the Cs contour control mode, the current position is lost. Therefore it is necessary to return the machine to the reference position.
If parameter setting indicates that the reference position function is not provided and the coordinate system is not required, however, a move command for the Cs axis can be executed without returning to the reference position.

(4) Interruption of return to the reference position

Manual operation mode

The reference position return operation for the Cs contour control axis can be interrupted by reset, emergency stop, or by turning the axis selection signal to OFF.

In all cases, after the interruption, the reference position return operation must be performed again from the beginning.

Automatic operation mode

The reference position return operation for the Cs contour control axis can be interrupted by reset, emergency stop or feed hold.

In all cases, after the interruption, the reference position return operation must be performed again from the beginning.

2.8.5 Others

(1) Switching from the Cs contour control mode to the spindle rotation control mode

Before changing the modes, be sure to confirm that the move command for the spindle in automatic or manual operation has terminated.

If the modes are changed while the spindle is moving, an interlock or an excessive positioning deviation alarm may be generated.

(2) Operating monitor

The motor load rating of the spindle and Cs contour control axis is not set in conventional parameters. It is set in PRM 3127. (In models having motor model code, this parameter is set automatically, so no modification is necessary.)

(3) Remote buffer operation

- Operation with binary statements
- Operation with NC statements. In DNC operation using a remote buffer, setting is made so as to perform high-speed distribution if conditions for high-speed distribution are satisfied (PRM0000#DNC = 0).

Before entering the remote buffer operation mode, cancel the Cs contour control mode.

In the remote buffer operation mode, Cs contour control cannot be performed. Only rotation control is possible.

In the remote buffer operation mode, switching to the Cs contour control mode or spindle rotation control mode must not be performed.

The spindle parameters cannot be rewritten by rewriting programmable parameters.

(4) The functions for memory type pitch error compensation, straightness compensation, gradient compensation, and backlash compensation are invalid for the Cs contour control axis.

(5) Position coder check for broken wires
The parameter specifying whether to check the position coder for broken wires (PRM 5603#PDC) cannot be used.
To suppress the broken wire check, set a parameter (PRM 5602#NAL) so as to suppress alarm check of the spindle speed control unit. If this parameter is set, alarms of the spindle amplifier are not checked either.

(6) For Cs contour control, the BMI interface is needed.

(7) FS15TT spindle
An analog spindle and serial interface spindle cannot be used together.

2.9 Method of Calculating a Cutting Load Variation in Cs Contour Control

2.9.1 Outline

This section describes how to calculate a cutting load variation in serial spindle Cs contour control.

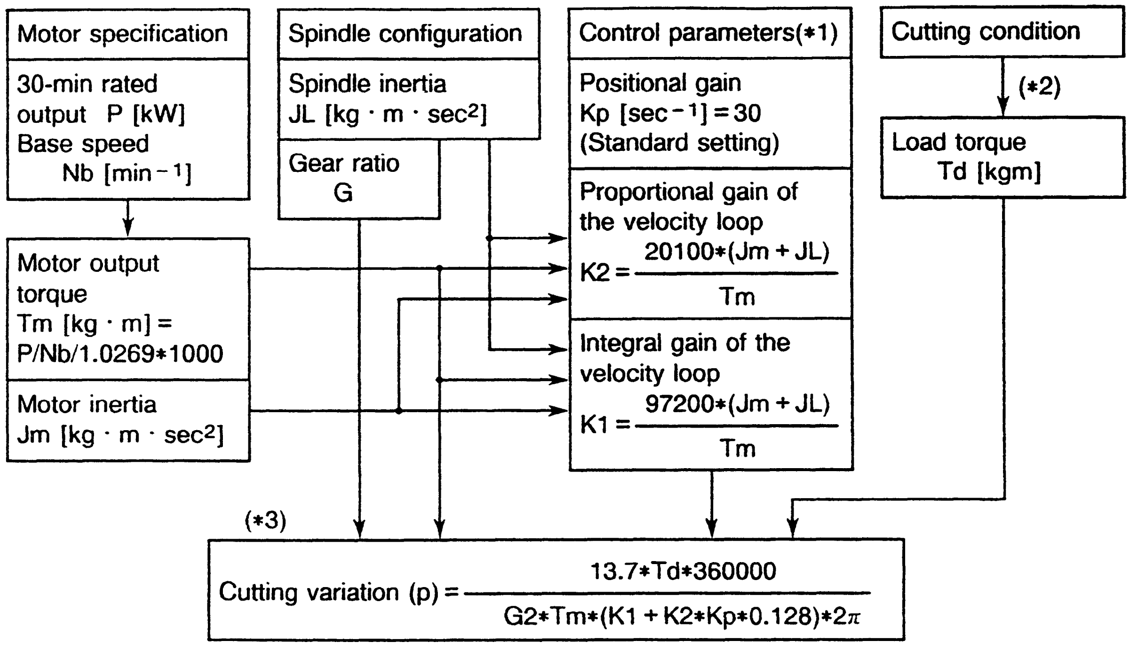
(1) A load variation in Cs contour control is usually caused by a cutting frequency variation of end mill flutes.
Example: When a two-flute end mill is used for cutting at 300 min^{-1}
The cutting variation is 10 Hz (= 300 min^{-1}/60*(2 flutes)).

(2) Standard control parameters are calculated from the motor specification and spindle configuration.

(3) A cutting torque is calculated from a cutting condition.

(4) From the above, a load variation (maximum calculated value) is found using the calculation method described in Section 2.9.2. Use the variation for reference to obtain motor selection, parameter setting, and cutting conditions.

2.9.2 Block diagram indicating the method of calculating a cutting variation



(*1) The table below lists the standard settings for the Cs contour control parameters.

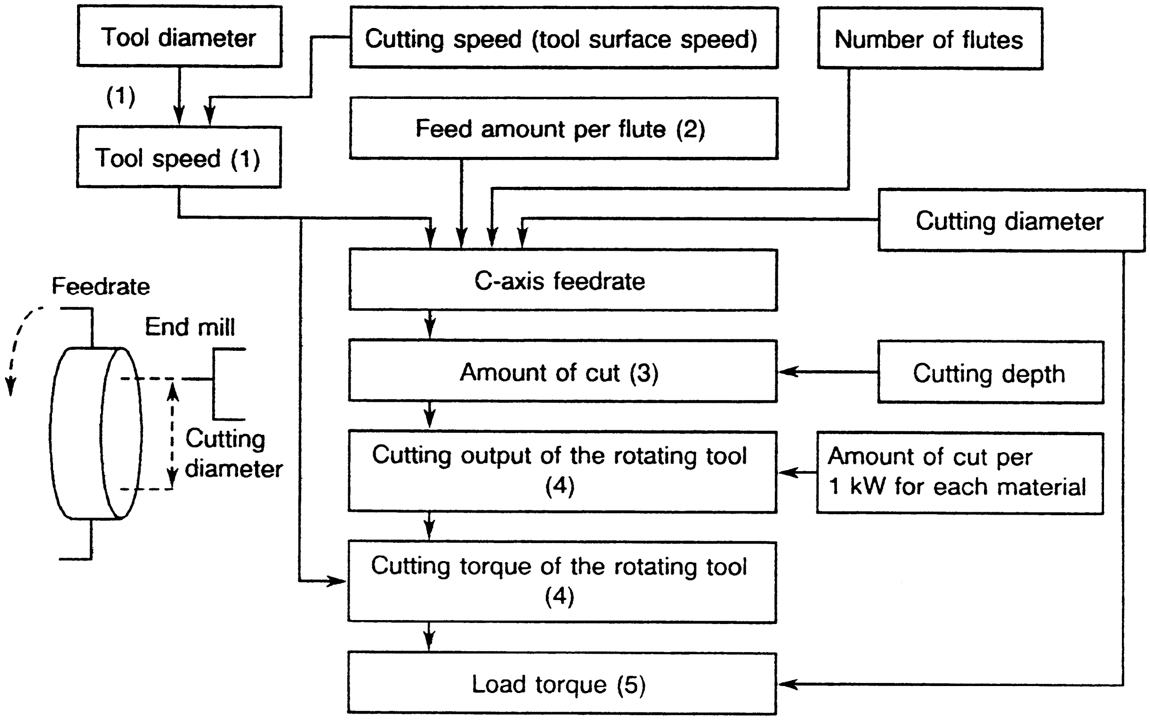
Parameter No.	Series 0	Series 16, 18	Series 15
K2: Parameter for the proportional gain of the velocity loop	6546 to 6547	4046 to 4047	3046 to 3047
K1: Parameter for the integral gain of the velocity loop	6554 to 6555	4054 to 4055	3054 to 3055
Kp: Positional gain parameter	6565 to 6568	4065 to 4068	3065 to 3068

(*2) See Section 2.9.3 for an example of calculating a load torque.

(*3) See Section 2.9.4 for an example of calculating a cutting variation. A cutting variation thus obtained is a maximum calculated value. Depending on the cutting frequency variation, the actual cutting variation may be smaller than a calculated value.

2.9.3 Example of calculating a load torque

This section describes an example of calculating a load torque applied to the spindle motor when the end face of a workpiece attached to the C-axis is cut with an end mill.



Known conditions: Tool diameter: Dm = 10 [mm], Number of flutes: Te = 2 [teeth]

(1) Cutting speed: It is assumed that Vc = 10 [m/min] = π*Dm*Ns/1000 (tool surface speed).

↓

Tool speed: Ns = 318 [min^{-1}] = Vc*1000/π/Dm = 10*1000/π/10

(2) When Dc (cutting diameter) = 50 [mm], find the feedrate, F, [deg/min] so that Ft (feed amount per flute) = 0.05 [mm/teeth].

↓

Feedrate: F = 73 [deg/min] = Ft/Dc/π*360*Ns*Te = 0.05/50/π*360*318*2
(32 [mm/min] = Dc*π/360*[deg/min] = 50*π/360*73)

(3) When d (cutting depth) = 1 [mm], find the amount of out Q [cc/min].

↓

Amount of cut: Q = 0.318 [cc/min] = Dc*π/360*F*Dm*d/1000 = 50*π/360*73*10*1/1000

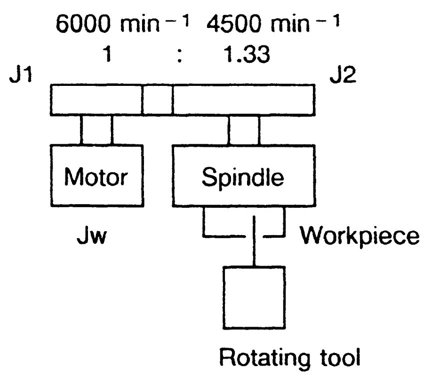
(4) Workpiece material: S45C → The amount of cut per 1 kW for each material is known.
→ Here, 20 [cc/min]) is assumed. (For aluminum, 60 [cc/min] is used.)
P [kW] = Q [cc/min]/20 [cc/min] = 0.318/20
When the tool speed, Ns [min^{-1}], and the cutting power, P [kW], are given, the output torque of the tool is found as follows:
Ts [kg · m] = P/Ns/1.0269*1000 = 0.318/20/318/1.0269*1000 = 0.048 [kg · m]

(5) For this cutting operation, the tool diameter Dm [mm] and the cutting diameter Dc [mm] are known, so the load torque (Td) applied to the C-axis is
Td = Ts*Dc/Dm [kg · m].
Td = 0.048*50/10 = 0.24 [kg · m]
Thus, the load torque Td in this example is
Td = 0.24 [kg · m]

2.9.4 Example of calculating a cutting variation

(1) Conditions

Nb	:	Base speed [min^{-1}] = 1500
P	:	30-min rated output [kW] = 7.5
Tm	:	Motor output torque [kg · m] = P/Nb/1.0269*1000 = 4.86
Jm	:	Motor inertia [kg · m · s^2] = 0.0022
J1	:	Motor pulley inertia [kg · m · s^2] = 0.0011
J2 + J3	:	Spindle inertia = 0.0058
JL	:	J1 + (J2 + J3)*$(1/1.33)^2$ = 0.0044 (Converted to motor shaft inertia)
Jm + JL	:	Spindle inertia = 0.0066
G	:	Gear ratio = 1:1.33
Ts	:	Spindle torque = Tm*G/2 = 4.86*1.33/2 = 3.23
Td	:	Load torque = 0.24 [kg · m] (taken from the example in Section 2.9.3).



(2) Control parameter calculation

Value of the parameter for the proportional gain of the velocity loop

$$K2 = \frac{20100*(Jm + JL)}{Tm} = \frac{20100*(0.0022 + 0.0044)}{4.86} = 27$$

Value of the parameter for the integral gain of the velocity loop

$$K1 = \frac{97200*(Jm + JL)}{Tm} = \frac{97200*(0.0022 + 0.0044)}{4.86} = 132$$

(3) Cutting variation calculation

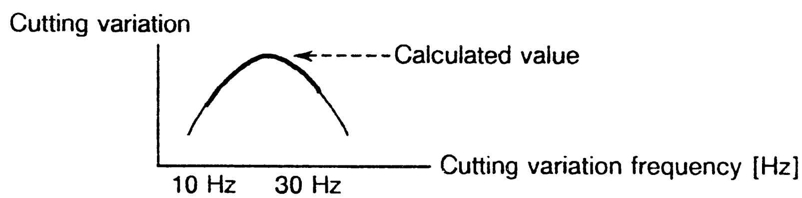
$$\text{Cutting variation (p)} = \frac{13.7*Td*360000}{G^2*Tm*(K1 + K2*Kp*0.128)*2\pi}$$

$$= \frac{13.7*0.24*360000}{1.33^2*4.86*(132 + 27*30*0.128)*2\pi}$$

$= 94p \rightarrow$ Cutting variation below 0.094 [deg]

(Note)

- For some spindle configurations, calculated values cannot be set in the parameters for the proportional gain and integral gain of the velocity loop (for example, when the rigidity is low because of a belt linkage, or gear linkage causes a large backlash).
- For some cutting variation frequencies, the actual cutting variation may be smaller than the calculated value. In general, the greatest cutting variation is observed from 10 Hz to 30 Hz.



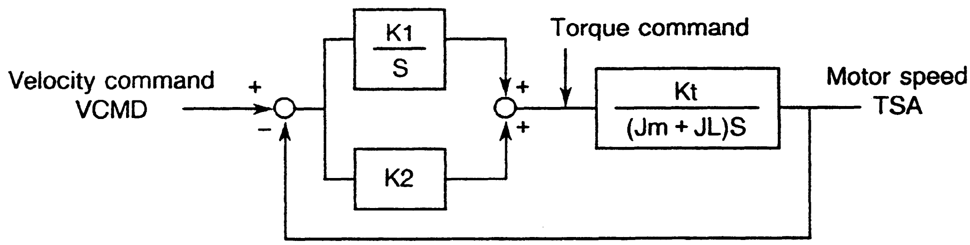
- Ultimately, a check must be made by actually using the machine.

2.10 Velocity Loop Control Gain

2.10.1 Outline

With the serial spindle amplifier, the relationship between the velocity loop control gain parameters and the spindle motor frequency response can be calculated from the motor output specification/ spindle inertia. When velocity loop response is required (such as for rigid tapping and Cs contour control), approximate values for the velocity loop gain parameters can be calculated.

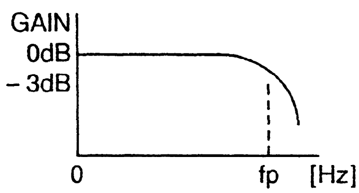
2.10.2 Control block diagram



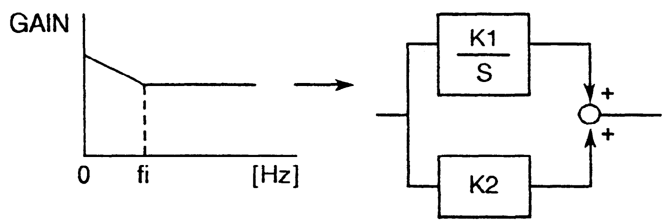
Kt : Torque constant
K1 : Integral gain of the velocity loop
K2 : Proportional gain of the velocity loop
Jm : Motor inertia
JL : Load inertia
S : Laplace operator

$$\text{Closed loop transfer function} = \frac{TSA}{VCMD} = \frac{Kt*K2/(Jm+JL)*S + Kt*K1/(Jm+JL)}{S^2 + Kt*K2/(Jm+JL)*S + Kt*K1/(Jm+JL)}$$

(Closed loop frequency characteristics)



(Frequency characteristics of the PI controller section)



fp : Cut-off frequency based on the proportional gain of the velocity loop [Hz]
fi : Cut-off frequency based on the integral gain of the velocity loop [Hz]

	Series 0	Series 16, 18	Series 15, PM
K2: Parameter for the proportional gain of the velocity loop	6540 to 6547	4040 to 4047	3040 to 3047
K1: Parameter for the integral gain of the velocity loop	6548 to 6555	4048 to 4055	3048 to 3055

Tm : Torque [kg m] = P/Nb/1.0269*1000
(Nb = Base speed [min^{-1}], P = 30-min rated output [kW])

Jm : Motor inertia [kg · m · s^2]

JL : Load inertia [kg · m · s^2]

(1) When K2, K1, Tm, Jm, and JL are known, and fp and fi are to be calculated

$$fp = \frac{K2*Tm}{670*(Jm+JL)} \quad , \quad fi = \frac{K1*Tm}{540*fp*(Jm+JL)}$$

(2) When fp, fi, Tm, Jm, and JL are known, and K2 and K1 are to be calculated

$$K2 = \frac{670*fp*(Jm+JL)}{Tm} \quad , \quad K1 = \frac{540*fp*fi*(Jm+JL)}{Tm}$$

Example: Single motor unit of model 6S

Nb : Base speed [min^{-1}] = 1500

P : 30-min rated output [kW] = 7.5

Tm : Torque [kg · m] = P/Nb/1.0269*1000 = 4.86

Jm : Motor inertia [kg · m · s^2] = 0.0022

JL : Load inertia [kg · m · s^2] = 0

Example 1: Find fp and fi (in Hz) when the parameters for the proportional gain and integral gain of the velocity loop are initially set to 10

K2 : Parameter for the proportional gain of the velocity loop (initial setting) = 10

K1 : Parameter for the integral gain of the velocity loop (initial setting) = 10

$$fp = \frac{K2*Tm}{670*(Jm+JL)} = \frac{10*4.86}{670*(0.0022+0)} = 33 \text{ Hz}$$

$$fi = \frac{K1*Tm}{540*fp*(Jm+JL)} = \frac{10*4.86}{540*33*(0.0022+0)} = 1.2 \text{ Hz}$$

Example 2: Find values to be specified in the parameters for the proportional gain and integral gain of the velocity loop to set the cut-off frequencies (fp and fi)

fp : Cut-off frequency based on the proportional gain of the velocity loop = 30 [Hz]

fi : Cut-off frequency based on the integral gain of the velocity loop = 6 [Hz]

$$K2 = \frac{670*fp*(Jm+JL)}{Tm} = \frac{670*20*(0.0022+0)}{4.86} = 9$$

$$K1 = \frac{540*fp*fi*(Jm+JL)}{Tm} = \frac{540*20*5*(0.0022+0)}{4.86} = 45$$

2.10.3 Notes

- The relationship between the velocity loop gains (proportional and integral) and the frequency characteristics described above is based on a simplified model; calculated values may not match the frequency characteristics of an actual machine.

- When velocity loop response is required (such as for rigid tapping and Cs contour control), approximate values for the velocity loop gain parameters can be calculated using Example 2 above. Set such approximate values, subject to later adjustment, in the velocity loop gain parameters K1 and K2, assuming:
  fp : Cut-off frequency based on the proportional gain of the velocity loop = Approx. 30 [Hz]
  fi : Cut-off frequency based on the integral gain of the velocity loop = Approx. 6 [Hz]

- However, for some spindle configurations, such calculated values may not be able to be set, (for example, when the rigidity is low because of a belt linkage, or gear linkage causes a large backlash).

3. START-UP PROCEDURE FOR SPINDLE SYNCHRONIZATION CONTROL

3.1 Start-up Procedure for Spindle Synchronization Control

A. Check that the system is ready for normal operation.

↓

B. Check and prepare the Ladder for spindle synchronization control. (See Section 3.2.)

↓

C. Set parameters for the spindle synchronization control. (See Section 3.3.)

↓

D. Connect the position coders and check the feedback signals.

↓

E. Check the spindle speed in synchronization.

↓

F. Check the direction of rotation of synchronized spindles.

↓

G. Check that an overshoot or hunting does not occur until the maximum speed is reached in spindle synchronization control.

OK ↓ / NG → H

H.
- Adjust the position gain in spindle synchronization control.
- Adjust the acceleration/deceleration time constant for spindle synchronization control. (Set identical values for the two spindles.)

↓

I. Check that the difference between the error pulses of the two spindles is within ±5 pulses.

↓ / NG → J

J.
- Check the position gain.
- Check the parameters for the gear ratio.
- Adjust the gain of the velocity loop for spindle synchronization control.

↓

K. Check the operation of spindle phase synchronization.

- See ** for synchronizing spindle phases.

↓

L. Check that the operation of spindle synchronization control is finished.

3.2 DI/DO Signals Used for Spindle Synchronization Control

3.2.1 Explanation of spindle synchronization control

(1) When the command for spindle synchronization control is issued while the two spindles are rotating at different speeds or stopped, each spindle increases or decreases its speed to the specified speed. The two spindles are then controlled in synchronization.

(2) If the synchronization speed is changed after the synchronous control of the two spindles is started, the spindles increase or decrease their speed to the new speed. The spindles are synchronized during the acceleration or deceleration as the speed is increased or decreased according to the time constant specified in the parameter. When the specified synchronization speed is 0 min^{-1}, the two spindles stop at the same time.

(3) When the command for spindle synchronization control is issued with the synchronization speed specified as 0 min^{-1} when both spindles are stopped, the spindles rotate two or three times. After detecting the signal indicating one rotation of the position coder (required for synchronous control of spindle phase), the spindles stop and enter the synchronous control state. If the synchronization speed is changed after the synchronous control state is established, the spindles increase or decrease their speed to the new speed. The spindles are synchronized during acceleration or deceleration as the speed is increased or decreased according to the time constant specified in the parameter.

(4) To handle a workpiece with a unique shape, the spindles need to rotate to keep the phases (angles) of rotation synchronous. When the command for spindle phase synchronization is issued when the spindles are already rotating in synchronization, each spindle is adjusted to the rotation phase specified in the parameter. At this time, the speed changes for a moment. Then the two spindles return to the synchronous control state. Rotation phase synchronization can be established by setting the parameters in advance so that the reference points of the two spindles match with each other.

(5) When the command for spindle phase synchronization is issued when the spindles are controlled in synchronization at 0 min^{-1}, each spindle is rotated and adjusted to the phase specified in the parameter then stops. It is similar to when the spindles are positioned in the stop state (spindle orientation). This causes the reference points of the spindles to match with each other (phase synchronization). If the synchronization speed is changed after a workpiece with a unique shape is held with the two spindles, the spindles increase or decrease their speed to the new speed. The spindles are synchronized during acceleration or deceleration as the speed is increased or decreased according to the time constant specified in the parameter.

(6) Constant surface speed control can be executed while a workpiece is being held with the two spindles in the synchronous control state. However, the time constant specified in the parameter is not exceeded even when a command for a larger increment or decrement in speed is specified.

(7) In the spindle synchronization control mode, keep the rotation command (SFR) on.

3.2.2 DI signals (PMC to CNC)

(1) Signal for controlling the spindles in synchronization (SPSYC)

[Function] Selects the spindle synchronization control mode.

[Operation] When the signal is set to 1, spindle synchronization control mode is selected. When the signal is set to 0, spindle synchronization control mode is released.

(2) Signal for controlling the spindle phases in synchronization (SPPHS)

[Function] Selects the spindle phase synchronization mode. It becomes effective when the signal for controlling the spindles in synchronization (SPSYC) is set to 1. Enter this signal after the signal that indicates that synchronous control of spindle speed is completed has been set to 1. Synchronous control of spindle phase is started at the rising edge of this signal. Even when this signal is set to 0, the synchronized phase does not change. When the signal is changed again from 0 to 1, phase synchronization is executed again.

[Operation] At the rising edge of the signal changing from 0 to 1, synchronous control of the spindle phase begins.

(3) Signal for executing integral speed control (INTGA)

[Function] Enables or disables integral speed control.

[Operation] When this signal is set to 1, integral speed control is disabled. (Same effect as when the integral gain of the velocity loop is set to 0.) When the signal is set to 0, integral speed control is enabled.
When the two spindles are mechanically connected with each other, this signal is set to 1 for both spindles so that integral speed control is disabled.
① When a cylindrical workpiece is held with the two spindles after they are synchronized in speed
② When a workpiece with a unique shape is held with the two spindles after they are synchronized in phase

	0TC	0TTC	15	16	7	6	5	4	3	2	1	0
	G146	G146		G038					SPPHS	SPSYC		
	G124	G124		G032	R08I	R07I	R06I	R05I	R04I	R03I	R02I	R01I
	G125			G033			SSGN		R12I	R11I	R10I	R09I
			G025		RI07	RI06	RI05	RI04	RI03	RI02	RI01	RI00
			G024		RISGN			RI12	RI11	RI10	RI09	RI08
			G111		SPPHS	SPSYC						
First Second	G229 G233	G229 G1429	G227 G235	G070 G074	MRDYA	ORCMA	SFRA	SRVA	CTH1A	CTH2A	TLMHA	TLMLA
First Second	G230 G234	G230 G1430	G226 G234	G071 G075	RCHA	RSLA	INTGA	SOCNA	MCFNA	SPSLA	*ESPA	ARSTA

3.2.3 DO signals (CNC to PMC)

(1) Signal indicating that synchronous control of spindle speed is completed (FSPSY)

[Function] Reports that synchronous control of spindle speed is completed.

[Output conditions] This signal is set to 1 when the following conditions are satisfied:

- In spindle synchronization control mode, the two spindles reach the speed specified by the signal for specifying the spindle speed in synchronization, and the difference between the speeds of the two spindles is not more than the value specified in parameter 6533.

This signal is set to 0 when any of the following conditions is satisfied:

- In spindle synchronization control mode, the two spindles have not yet reached the speed specified by the signal for specifying spindle speed in synchronization.
- In spindle synchronization control mode, the difference between the speeds of the two spindle is larger than the value specified in parameter 6533.
- The spindles are not in spindle synchronization control mode.

(Note) The signal changes from 1 to 0 when the difference in spindle speed exceeds the value specified in parameter 6533 due to changes in the cutting load, etc.

(2) Signal indicating that synchronous control of spindle phase is completed (FSPPH)

[Function] Reports that synchronous control of spindle phase (control of phase difference) is completed.

[Output conditions] The signal is set to 1 when the following conditions are satisfied:

- In spindle synchronization control mode, the two spindles reach the speed specified by the signal for specifying spindle speed in synchronization, and the spindles are synchronized in phase by the signal for controlling spindle phases in synchronization. (The difference between the error pulses of the two spindles cannot be greater than the value set in parameter 303.)

The signal is set to 0 when any of the following conditions are satisfied:

- In spindle synchronization control mode, the spindles have not yet been synchronized in phase.
- In spindle synchronization control mode, the difference between the error pulses of the two spindles is greater than the value specified in parameter 303.
- The two spindles are not in the mode for synchronous control of spindle phase.

(Note) The signal is changed from 1 to 0 when the difference in the error pulse exceeds the value specified in parameter 303 due to changes in the cutting load, etc.

(3) Signal for issuing an alarm detected in spindle synchronization control (SYCAL)

[Function] Reports that the difference between the error pulses of the two spindles exceeds the value specified in the parameter for spindle synchronization control mode. This signal is used for error handling in spindle synchronization control.

[Output conditions] The signal is set to 1 when the following conditions are satisfied:

- In spindle synchronization control mode, the difference between the error pulses of the two spindles exceeds the value specified in parameter 576, after spindle synchronization control has been put in effect.

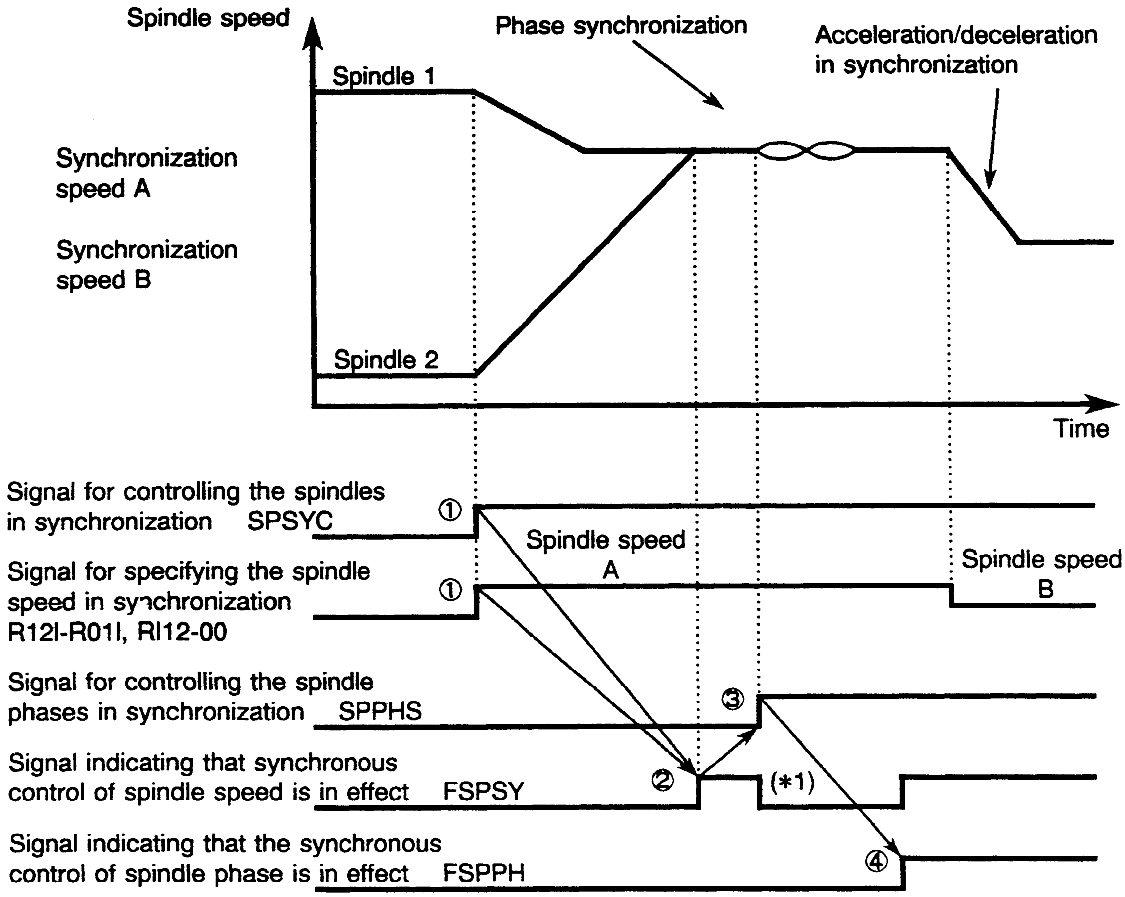
The signal is set to 0 when any of the following conditions is satisfied:

- The spindles are not in spindle synchronization control mode.
- In spindle synchronization control mode, the difference between the error pulses of the two spindles is not greater than the value specified in parameter 576.

	0TC	0TTC	15	16	7	6	5	4	3	2	1	0
	F178	F178		F044				SYCAL	FSPPH	FSPSY		
			F111		MSPPHS	MSPSYC	SPSYAL					
First Second	F281 F285	F281	F229 F245	F045 F049	ORARA	TLMA	LDT2A	LDT1A	SARA	SDTA	SSTA	ALMA
First Second	F282 F286	F282	F228 F244	F046 F050					RCFNA	RCHPA	CFINA	CHPA

3.2.4 Sample sequence in spindle synchronization control

(1) While spindle 1 is rotating, spindle 2 is accelerated to reach the speed of spindle 1. The phase of spindle 2 is synchronized with that of spindle 1. Then the synchronization speed is changed, and the two spindles increase or decrease their speed in synchronization.



① Enter the signal for specifying spindle speed in synchronization and set the signal for controlling the spindles in synchronization to high.

② Wait until the signal indicating that synchronous control of spindle speed is completed is set to 1.

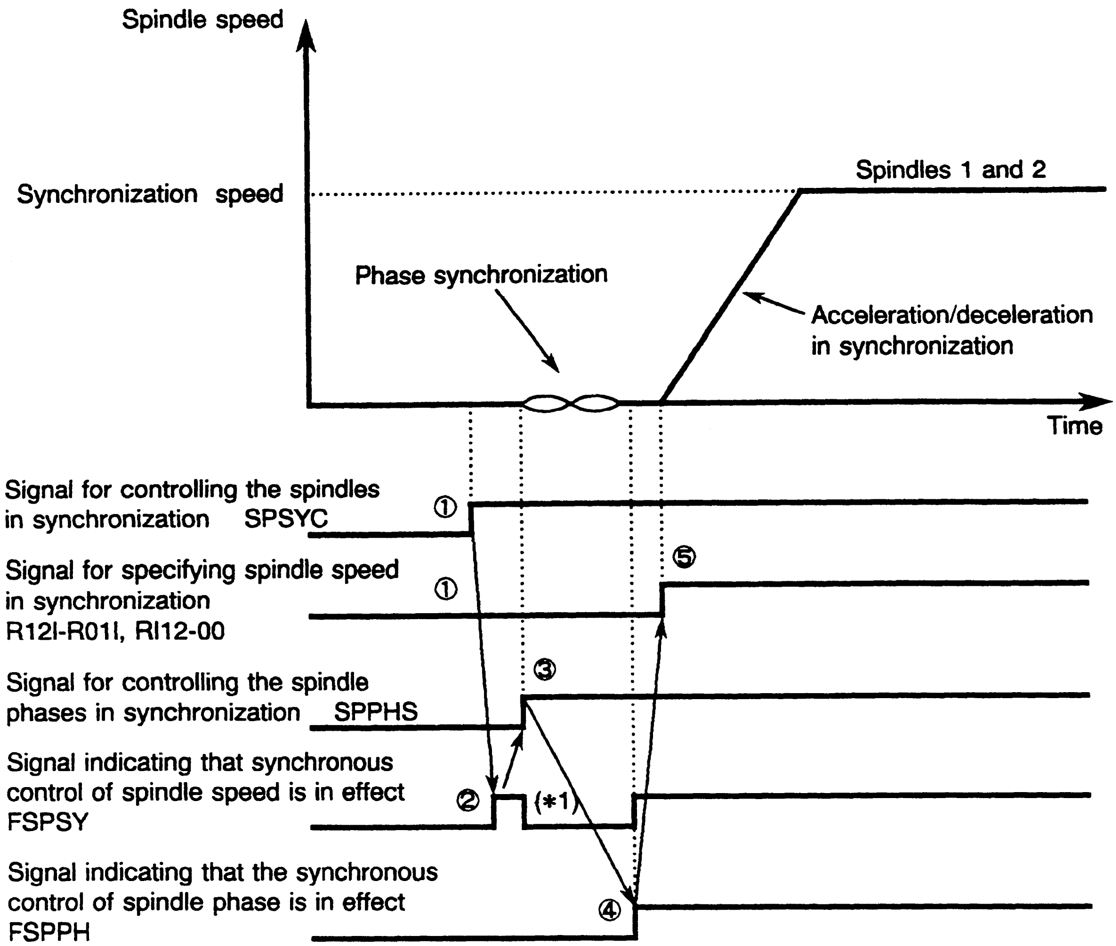
③ Set the signal for controlling the spindle phases in synchronization to 1.

④ Wait until the signal indicating that the synchronous control of spindle phase is completed is set to 1.

(Note 1) The signal indicating that the synchronous control of spindle speed is completed is set to 0 when the signal for controlling the spindle phases in synchronization is entered. It is changed to 1 when phase synchronization is put into effect.

(Note 2) Entering the spindle synchronization control command when the position coder one-rotation signal is not detected causes the spindle to stop after automatic rotation and one-rotation signal is detected, and sets the spindle synchronization speed control complete signal to 1.

(2) While spindles 1 and 2 are stopped, their phases are synchronized and their speeds are increased in synchronization.



① Set the signal for specifying the spindle speed in synchronization to 0 and the signal for controlling the spindles in synchronization to 1.

② Wait until the signal indicating that synchronous control of spindle speed is completed is set to 1.

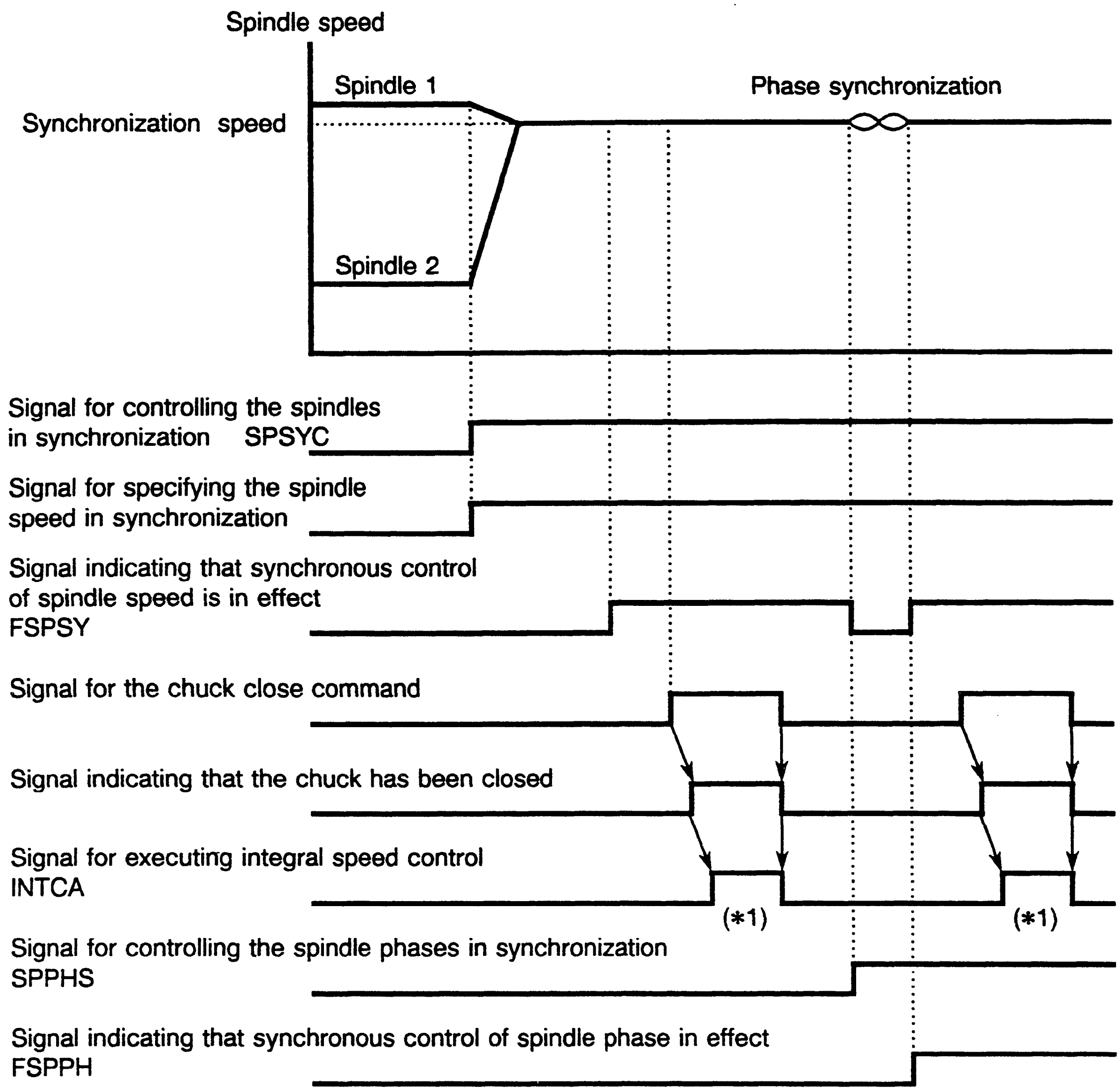
③ Set the signal for controlling the spindle phases in synchronization to 1.

④ Wait until the signal indicating that synchronous control of spindle phase is completed is set to 1.

⑤ Enter the signal for specifying the spindle speed in synchronization.

(*1) The signal indicating that synchronous control of spindle speed is completed is set to 0 when the signal for controlling the spindle phases in synchronization is entered. It is changed to 1 when phase synchronization is put in effect.

(3) Using the signal for executing integral speed control



(*1) Set the signal for executing integral speed control to 1 while a workpiece is being held with the two spindles.

3.3 Parameters Used for Spindle Synchronization Control (Upper Row: First Spindle, Lower Row: Second Spindle)

Parameter No.				Description
0TC	0TTC	15TT	16	
0080 #6	0080 #6	5820 #0	4800 #0	Direction of rotation of the spindle motor in spindle synchronization control (First spindle)
0080 #7	0080 #7	5820 #1	4800 #1	Direction of rotation of the spindle motor in spindle synchronization control (Second spindle)
0303		5810	4810	Difference in the error pulses between the two spindles. When not exceeded, the signal indicating that synchronous control of spindle phase is completed is issued.
0576		5811	4811	Difference in the error pulses between the two spindles. When exceeded, the signal for issuing an alarm detected in spindle synchronization control is issued.
6532 6672	6532	3032 3172	4032	Acceleration/deceleration time constant for synchronous control of the spindle Identical time constants need to be set for the first and second spindles.
6533 6673	6533	3033 3173	4033	Spindle speed to be detected in synchronization
6534 6674	6534	3034 3164	4034	Shift in the synchronous control of spindle phase
6535 6675	6635	3035 3175	4035	Compensation data for spindle phase synchronization
6544 6684 6545 6685	6544 6545	3044 3184 3045 3185	4044 4045	Proportional gain of the velocity loop in spindle synchronization control Data is selected by CTH1A, a DI signal of PMC.
6552 6692 6553 6693	6552 6553	3052 3192 3053 3193	4052 4053	Integral gain of the velocity loop in spindle synchronization control Data is selected by CTH1A, a DI signal of PMC.
6506 6646	6506	3006 3146	4006	Gear ratio unit (#1) (*1)

(*1) One of the causes of a continually large difference between the position errors of the two spindles is that the gear ratio is set with rounded-down data. This large difference between errors can be reduced by setting the gear ratio unit to 1/1000.

Parameter No.				Description
0TC	0TTC	15TT	16	
6556 ~ 6559 6696 ~ 6699	6556 ~ 6559	3056 ~ 3059 3196 ~ 3199	4056 ~ 4059	Gear ratio of the spindle to the motor (*1) Data is selected by CTH1A and CTH2A, DI signals of PMC.
6565 ~ 6568 6705 ~ 6708	6565 ~ 6568	3065 ~ 3068 3205 ~ 3208	4065 ~ 4068	Position gain in spindle synchronization control Data is selected by CTH1A and CTH2A, DI signals of PMC. Identical position gains need to be set for the first and second spindles.
6506 6646	6506	3006 3146	4006	Bit 4 of this parameter is set to prevent automatic detection of the signal indicating one rotation when spindle synchronization control mode is changed. See Section 3.5.2.
6507 6647	6507	3007 3147	4007	Bit 6 of this parameter sets the function for detecting an abnormal position coder signal and for issuing alarm AL-47. See Section 3.5.4.
6585 6725	6585	3085 3225	4085	Motor voltage in spindle synchronization control

(*1) One of the causes of a coutinually large difference between the position errors of the two spindles is that the gear ratio is set with rounded-down data. This large difference between errors can be reduced by setting the gear ratio unit to 1/1000.

3.4 Diagnosis

Address				Description
0TC	0TTC	15TT	16	
–		1508	–	Sequence state in spindle synchronization control
0754		1509	0414	Error pulse of the first spindle in spindle synchronization control
0755		1510	0415	Error pulse of the second spindle in spindle synchronization control
0756		1511	0416	Difference in the error pulses between the two spindles in spindle synchronization control

3.5 Additional Explanations of the Parameters Used for Spindle Synchronization Control

3.5.1 Error pulse in spindle synchronization control

The error pulse in spindle synchronization control is calculated as shown below:

$$\text{Error pulse} = \frac{\text{Spindle speed in synchronization } (\text{min}^{-1})}{60 \text{ sec}} \times 4096 \text{ p/rev.} \times \frac{1}{\text{Position gain (sec-1)}}$$

[Example] When the spindle speed in synchronization is 1000 rpm and the position gain is 20 (sec-1)

$$\text{Error pulse} = \frac{1000 \ (\text{min}^{-1})}{60 \text{ sec}} \times 4096 \text{ p/rev.} \times \frac{1}{20 \text{ (sec-1)}} = \text{About 3413 pulses}$$

If the actual error pulse in spindle synchronization control differs too greatly from the value obtained by the expression above, check the following points:

- Spindle speed: Check the spindle speed on the SACT display of the CNC machine.
- Parameters 6556 to 6559 of the gear ratio of the spindle to the motor: Check the actual gear ratio by comparing the spindle speed obtained above and the speed (motor speed) indicated on the printed circuit board for the serial spindle amplifier.
- Position gain parameters 6565 to 6568
- Selection statuses of gear selection signals CTH1A and CTH2A: Check the selection statuses using diagnosis parameters, bits 2 and 3 of G229.

The error pulses of the two spindles in the steady rotation mode may differ from each other by several pulses when the unit used for the gear ratio of the spindle to the motor is set to 1/100 and data is rounded down. The difference can be reduced by setting bit 1 of parameter 6506 to 1. This will change the gear ratio unit to 1/1000 and data will be set in units of 1/1000.

3.5.2 Automatic detection of the signal indicating a rotation when spindle synchronization control mode is changed

When the system enters spindle synchronization control mode after the power is turned on, each spindle automatically rotates two or three times to detect the signal used to indicate a rotation. This signal needs to be detected so that synchronous control of spindle phase can be executed later.

Automatic detection of the signal used to indicate a rotation can be suppressed by setting parameter 6506, #4 to 1 in the following case: when automatic detection should not be executed for two spindles mechanically connected or when the synchronous control of spindle phase is not to be executed.

3.5.3 Determining the shift (parameter) in synchronous control of spindle phase

This section describes an example of determining the shift for phase synchronization in synchronous control of spindle phase.

(1) Execute synchronous control of spindle phase under the following conditions:
  (a) Set SFR = ON (SRV = OFF) for both the first and second spindles : M03
  (b) Set the spindle speed in synchronization to 0 min^{-1} : S0
  (c) For both the first and second spindles, set the parameter specifying the shift in synchronous control of spindle phase to 0.
  First spindle: Parameter 6534 = 0 Second spindle: Parameter 6674 = 0

(2) After synchronous control of spindle phase is in effect, turn off SFR for the second spindle (turn off motor activation). Since the motor is turned off, the second spindle needs to be rotated manually.

(3) Manually rotate the second spindle until the desired spindle phase synchronization is established. The number of pulses between the previous and new positions of spindle phase synchronization is indicated on the diagnosis screen (displays the difference between the error pulses of the spindles). This value is the shift to be set in the parameter.
  Diagnosis No. 755 (Difference in the error pulses between the spindles)

(4) Set parameter 6674 of the second spindle to the shift value in synchronous control of spindle phase obtained above. Usually, the shift parameter of the first spindle needs to be set to 0.

(5) Cancel the command for spindle synchronization control, then execute synchronous control of spindle phase under the following conditions. Check that the desired phase synchronization state is established.
  (a) Set SFR = ON (SRV = OFF) for both the first and second spindles : M03
  (b) Set the spindle speed in synchronization to 0 min^{-1} : S0

3.5.4 Function for detecting an abnormal position coder signal and for issuing alarm AL-47

The function for detecting an abnormal position coder signal and for issuing alarm AL-47 will not work properly and the alarm will be incorrectly detected in the following conditions: When the spindle and position coder are not connected at a ratio of one to one and two or more signals indicating one rotation of the position coder are generated during one rotation of the spindle. In either of these cases, set bit 4 of parameter 6507 to 1 to suppress the function.

3.6 Additional Explanations of the Function of Spindle Synchronization Control, Series 0TC

(1) Synchronous control of spindle phase is executed when the signal for controlling spindle phase in synchronization is entered in spindle synchronization control mode (after output of the signal indicating that synchronous control of spindle speed is completed). The signal indicating that synchronous control of spindle phase is completed is output when the difference between the error pulses of the two spindles does not exceed the number of pulses specified in parameter 303 of the NC function. The two spindles are not synchronized when synchronous control of spindle phase is in progress (until the signal indicating that the synchronous control of spindle phase is completed is set high). The command for spindle phase synchronization must not be issued while a workpiece is being held with the two spindles. If it is issued, synchronous control of spindle phase is started automatically.

(2) PMC signal, SYCAL is provided to monitor synchronization errors between spindles for which spindle synchronization control or synchronous control of spindle phase is in effect. The synchronization error between the two spindles is always monitored. The SYCAL signal is set to 1 when the error (the absolute value of the error pulse) specified in parameter 576 of the first spindle is exceeded, and set to 0 when not exceeded.

(3) Like the conventional spindle speed (S) command for which 4 or 5 digits are issued for the first spindle, the signal for specifying spindle speed can be generated when spindle synchronization control or synchronous control of spindle phase are in the process of being put into effect. The SIND, SSIN, SSGN, R01I to R12I, *SSTP, and SOR signals are effective as usual. The maximum speed in synchronization control is determined by the maximum speed set for the motor of the first spindle (parameter 6520).

[Example] Maximum speed of the motor of the first spindle : 6000 min^{-1}
Maximum speed of the motor of the second spindle : 4500 min^{-1}

However, the maximum speed during synchronization control is limited by the maximum speed of the second axis. In the example above, the maximum speed that can be specified by the 12-bit speed command is 6000 rpm for the first spindle. However, if 6000 rpm is specified in synchronization control, an overspeed alarm is issued from the second spindle. The spindle speed specified by the command must not exceed 4500 min^{-1}.

(4) The S command for the first spindle and the PMC control signal for spindle control become effective when issued before spindle synchronization control or synchronous control of spindle phase are put into effect. The S command issued in synchronization control becomes effective for the first spindle immediately after synchronization control is canceled.

(5) In the usual mode of spindle rotation control, spindle speed can be controlled by the PMC function when the following conditions are satisfied: The SIND signal is set to 1 and the SSIN, SSGN, and R01I to R12I signals are provided. When spindle synchronization control is in the process of being put into effect, something other than the R01I to R12I signals is required to control the spindle speed in synchronization. The maximum spindle gear speed must be properly set in parameters 540, 541, 542, and 543. When the value set in the parameter corresponding to the selected gear is 0, the rotations of the spindles are not synchronized even if a command is entered in the 12-bit signal of the SIND signal.

(6) The load may change due to cutting (or threading). When the load changes in spindle synchronization control, the spindle speed may change and the signal indicating that the synchronous control of spindle speed is completed may go off temporarily.

(7) Parameters PRM 0080, #6 and #7 are used to set the direction of rotation of the first spindle and second spindle, respectively.

Parameter PRM 0080 #6 or #7 = "0"	Counterclockwise (CCW)
Parameter PRM 0080 #6 or #7 = "1"	Clockwise (CW)

(8) The gear ratio of the spindle to the position coder must be set to one-to-one.

(9) In spindle synchronization control, the compensation value for spindle speed offset (parameter 516) is disabled.

3.6.1 Alarm

The following alarm may be issued in spindle synchronization control.

P/S alarm

Alarm number	Description
194	A command for Cs contour control, spindle indexing, or rigid tapping was issued in spindle synchronization control.

3.7 Additional Explanations of the Function of Spindle Synchronization Control, Series 0TTC

(1) Synchronous control of spindle phase is executed when the signal for controlling the spindle phases in synchronization is entered in spindle synchronization control mode (after output of the signal indicating that the synchronous control of spindle speed has been completed).
The signal indicating that the synchronous control of spindle phase is completed is output when the difference between the error pulses of the two spindles does not exceed the number of pulses specified in parameter 303 of the NC function.
The positions of spindle phase synchronization for both spindles one and two can be specified in spindle parameter 6534.
The two spindles are not synchronized when synchronous control of spindle phase is in progress (until the signal indicating that the synchronous control of spindle phase is completed is set high).
The command for spindle phase synchronization must not be issued while a workpiece is being held with the two spindles.
If it is issued, synchronous control of spindle phase is started automatically.

(2) PMC signal, SYCAL is provided to monitor a synchronization errors between spindles for which spindle synchronization control or synchronous control of spindle phase is in effect. The synchronization error between the two spindles is always monitored. The SYCAL signal is set to 1 when the error (the absolute value of the error pulse) specified in parameter 576 of tool post one is exceeded, and set to 0 when not exceeded.

(3) When generated while spindle synchronization control or synchronous control of spindle phase is in the process of being put into effect, the signal specifying the speed is used as the signal for specifying the synchronization speed.
The signal depends on information specified at addresses G124 and G125 by PMC. 0TTC cannot use the four or five digit spindle speed (S) command.
However, it can use the function of the four or five digit S command via PMC by using the S 12-bit information output at addresses F172 and F173.
With this function, constant surface speed control can be executed in synchronization control even while a workpiece is being held with the two spindles.
However, the time constant specified in the parameter is not exceeded even if a larger speed increment is specified.

(4) The maximum speed in synchronization control is determined by the maximum speed of the spindle motor of tool post 1 (parameter 6520).

[Example] Maximum speed of the spindle motor of tool post 1 : 6000 min^{-1}
Maximum speed of the spindle motor of tool post 2 : 4500 min^{-1}

However the maximum speed during synchronization control is limited by the maximum speed of tool post 2. In the example above, the maximum speed that can be specified by the 12-bit speed command is 6000 min^{-1} for tool post one. However, if 6000 min^{-1} is specified in

synchronization control, an overspeed alarm is issued from tool post 2.
The spindle speed specified by the command must not exceed 4500 min^{-1}.

(5) When the spindles are controlled by PMC in the usual spindle control mode, the SIND signal needs to be set to 1. In synchronization control mode, the spindles are controlled according to the synchronization speed specified by the SSGN and R01I to R12I signals. Control does not depend on the states of the usual spindle control signals, *SSTP, SOR, SIND, and SSIN.
However, settings other than signals R01I to R12I are required to specify synchronization of spindle speed.
The maximum spindle gear speed must be properly set in parameters 540, 541, 542, and 543 of tool post 1.
When the value set in the parameter corresponding to the selected gear is 0, the rotations of the spindles are not synchronized even if a command is entered in the 12-bit signal of the SIND signal.

(6) The load may change due to cutting (or threading). When the load changes in spindle synchronization control, the spindle speed may change and the signal indicating that the synchronous control of spindle speed is completed may go off temporarily.

(7) Parameter PRM 0080, #6 is used to set the direction of rotation of the first and second spindles.

Parameter PRM 0080 #6 = "0"	Counterclockwise (CCW)
Parameter PRM 0080 #6 = "1"	Clockwise (CW)

(8) The gear ratio of the spindle to the position coder must be set to one-to-one.

(9) In spindle synchronization control, the compensation value for the spindle speed offset (parameter 516) is disabled.

(10) The command for spindle phase synchronization is effective only in spindle synchronization control mode.

3.7.1 Alarm

The following alarm may be issued in spindle synchronization control.

P/S alarm

Alarm number	Description
194	A command for Cs contour control, spindle indexing, or rigid tapping was issued in spindle synchronization control.

3.8 Additional Explanations of the Function of Spindle Synchronization Control, Series 15TT

(1) The BMI interface needs to be used when this function is used. (This function cannot be used with the FS3/6 interface.)

(2) Synchronous control of spindle phase is executed when the signal for controlling the spindle phases in synchronization is entered in spindle synchronization control mode (after output of the signal indicating that synchronous control of spindle speed is in effect).
The signal indicating that synchronous control of spindle phase is completed is output when the difference between the error pulses of the two spindles does not exceed the number of pulses specified in parameter 5810 of the NC function.
The positions of spindle phase synchronization for spindles one and two can be specified in spindle parameters 3034 and 3174, respectively.
The two spindles are not synchronized when synchronous control of spindle phase is in progress (until the signal indicating that synchronous control of spindle phase is completed is set high). The command for spindle phase synchronization must not be issued while a workpiece is being held with the two spindles.
If issued, synchronous control of spindle phase is started automatically.

(3) PMC signal, SPSYAL is provided to monitor the synchronization error between spindles for which spindle synchronization control or synchronous control of spindle phase is in effect. The synchronization error between the two spindles is always monitored. The SPSYAL signal is set to 1 when the error (the absolute value of the error pulse) specified in parameter 5811 of the first spindle is exceeded, and set to 0 when not exceeded.

(4) When generated while spindle synchronization control or synchronous control of spindle phase is in the process of being put into effect, the signal specifying speed is used as the signal for specifying the synchronization speed.
The signal for specifying the spindle speed can be generated like the conventional spindle motor command which sends a voltage signal.
Signals RISGN and RI00 to RI12 are effective as usual.
The maximum spindle speed in synchronization control is determined by the maximum speed of the motor of the first spindle (parameter 3020).

[Example] Maximum speed of the motor of the first spindle : 6000 min^{-1}
Maximum speed of the motor of the second spindle : 4500 min^{-1}

However, maximum speed in synchronization control is limited by the maximum speed of the second spindle. In the example above, the maximum speed that can be specified by the 13-bit speed command is 6000 min^{-1} for the first spindle.
However, if 6000 min^{-1} is specified in synchronization control, an overspeed alarm is issued from the second spindle. The spindle speed specified by the command must not exceed 4500 min^{-1}.

(5) The command for spindle phase synchronization is effective only in spindle synchronization control mode.

(6) The load may change due to cutting (or threading). When the load changes in spindle synchronization control, the spindle speed may change and the signal indicating that synchronous control of spindle speed is completed may go off temporarily.

(7) Bit 0 and 1 of parameter PRM 5820 are used to set the direction of rotation of the first spindle and second spindle respectively.

Parameter PRM 5820 #0 or #1 = "0"	Counterclockwise (CCW)
Parameter PRM 5820 #0 or #1 = "1"	Clockwise (CW)

(8) The gear ratio of the spindle to the position coder can be set only to one to one.
Identical gear ratios must be set for the first and second spindles. (Parameters 5610 and 5660)

3.8.1 Sequence state in spindle synchronization control

Diagnosis No.	Data							
	#7	#6	#5	#4	#3	#2	#1	#0
1508					SPSYC3	SPSYC2	SPSYC1	SPSYC0

SP SYC3	SP SYC2	SP SYC1	SP SYC0	Internal processing state
0	0	0	0	The spindles are not in spindle synchronization control mode. (SPSYC = 1 is waited.)
0	0	0	1	Waits for the signal that indicates that synchronization speed has been reached to be generated. (Synchronous control of spindle speed is in progress.)
0	0	1	0	Waits for the signal that indicates that synchronization speed has been reached to be set.
0	0	1	1	Waits for the signal that indicates that synchronous control of spindle speed is completed and the command for spindle phase synchronization to be generated. (Waits for SPPHS = 1.)
0	1	0	0	Phase synchronization, on/off
0	1	0	1	Waits for the signal that indicates that synchronization speed has been reached to be cleared. (Synchronous control of spindle phase is in progress.)
0	1	1	0	Waits for the signal that indicates that synchronization speed has been reached to be set.
0	1	1	1	Synchronous control of spindle phase is in effect.

4. SPINDLE ORIENTATION FUNCTION IN SPINDLE SYNCHRONIZATION CONTROL

4.1 Outline

In the spindle synchronization control mode, this function rotates the spindles in a direction specified externally and stops them at the externally specified orientation (synchronous orientation) (0-4095: one spindle rotation) while maintaining the synchronization of the two spindles. The bell-shaped acceleration/deceleration function can also be used in spindle orientation.
With this function, the following operations can be performed:

- A workpiece with a non-standard shape can be loaded and unloaded.
- A long workpiece can be held at both ends so machining such as drilling the side face of the workpiece by indexing can be performed.

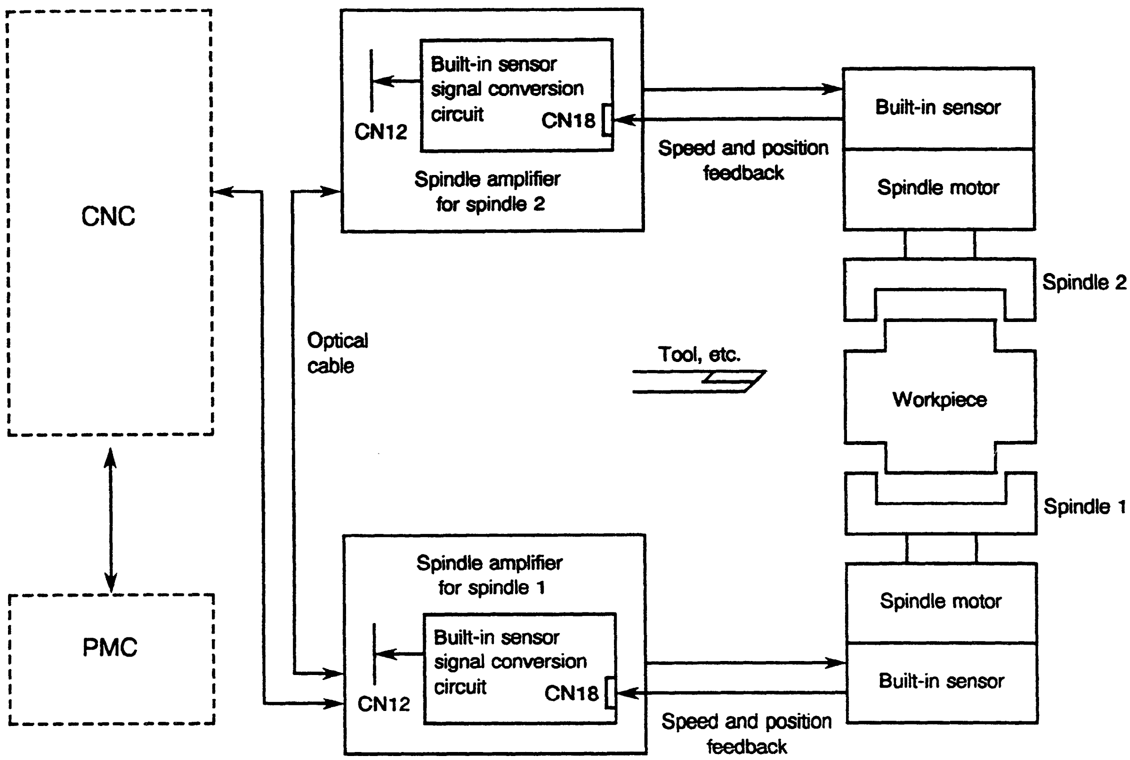
This function has been added to the conventional spindle synchronization control function. This section describes this new function only. For a better understanding of this function, see the description of the conventional spindle synchronization control function in this Appendix.

Appendix 3. 3. Start-up Procedure for Spindle Synchronization Control

(Note) Applicable serial interface spindle amplifier (IGBT type)
A06B-6064-H3xx#H550
Applicable control software series: 9A50 Edition P and later

(Note) This function is currently applicable to the following CNCs:
Series 0-C
Series 16, 18

4.2 Example of System Configuration



4.3 Example of Control Sequence

This section describes an example of the control sequence (in which a workpiece is loaded, machined, then unloaded) applicable when the spindle orientation function is used in the spindle synchronization control mode. Also see the notes, timing chart, and the examples of speed waveforms described later in this section.

(1) Set the spindle synchronization control mode.
 ① Set the orientation operation request command (SORISL) for both spindles to 0.
 ② Set the spindle synchronization control command (SPSYC) to 1 to set the spindle synchronization control mode.

(2) Determine the reference position of each spindle (usually by establishing spindle phase synchronization)
 ① Wait for the spindle synchronization speed control complete signal (FSPSY) to be set to 1, with both spindles disengaged.
 ② Upon completion of synchronization establishment, check that the orientation enable signal (SORIEN) is set to 0 for both spindles.

③ Set the spindle phase synchronization command (SPPHS) to 1.
Each spindle establishes spindle phase synchronization on a rising edge of SPPHS. If the synchronization speed command is set to 0, when spindle phase synchronization is established, the spindle stops at the position indicated below. This stop position serves as the reference position (stop position when SHA11-00 = 0) for spindle orientation.
[One-rotation signal position]
+ [Shift amount in spindle synchronization control (PRM4034: FS16/18)] . . . ①

④ When the establishment of phase synchronization is confirmed (with a 0-to-1 transition of the spindle phase synchronization complete signal (FSPPH)), reference position determination is completed. Load a workpiece.

(3) After the workpiece is loaded, rotate both spindles at a synchronization speed to machine the workpiece.
① When the synchronization speed command is set to 0, set SORISL to 0 for both spindles.
② Check that SORIEN is set to 0 for both spindles.
③ Enter the synchronization speed command. Both spindles are accelerated according to a set time constant until thespecified synchronization speed is reached.

(4) After the workpiece is machined, perform spindle operation to stop both spindles at the specified positions for workpiece unloading, while maintaining the synchronization.
① Apply the following signals for spindle 1 and spindle 2:
· SHA11-00 = 0 (for spindle 1), 0 (for spindle 2)
· ROTAA = 0 (CCW) (for spindle 1), 1 (CW) (for spindle 2)
· SORISL = 1 (for spindle 1), 1 (for spindle 2)
② Check that SORIEN is set to 1 for both spindles.
③ Set the synchronous orientation command (SPPHS) to 1.
Both spindles decelerate to the orientation start speed after detecting a rising edge of SPPHS, then read SHA11-00 and ROTAA to calculate the travel distances to the specified stop positions. Each spindle then rotates until the specified stop position is reached.
④ After confirming the completion of spindle orientation (with a 0 to 1 transition of FSPPH), unload the workpiece.

[Notes]

When using this function, observe the following notes:

(Note 1) After changing a parameter or sequence, be sure to disengage the spindles and operate the machine with no load before actual operation in order to check as the rotation directions and stop positions of the spindles, the synchronization error, and so forth for safety.

(Note 2) Before determining the reference position of each spindle by using spindle phase synchronization, disengage the spindles, then confirm that the spindles are synchronized. If an attempt is made to establish spindle phase synchronization before the same specified speed is reached, one spindle becomes out of phase with the other.

If such a case occurs, or the phase relationship between the two spindles is lost (as in the case where the spindle synchronization control mode is released, or excitation is turned off for some reason such as an alarm), determine the reference position of each spindle again by establishing spindle phase synchronization, and determine the phase relationship between the two spindles before starting orientation operation.

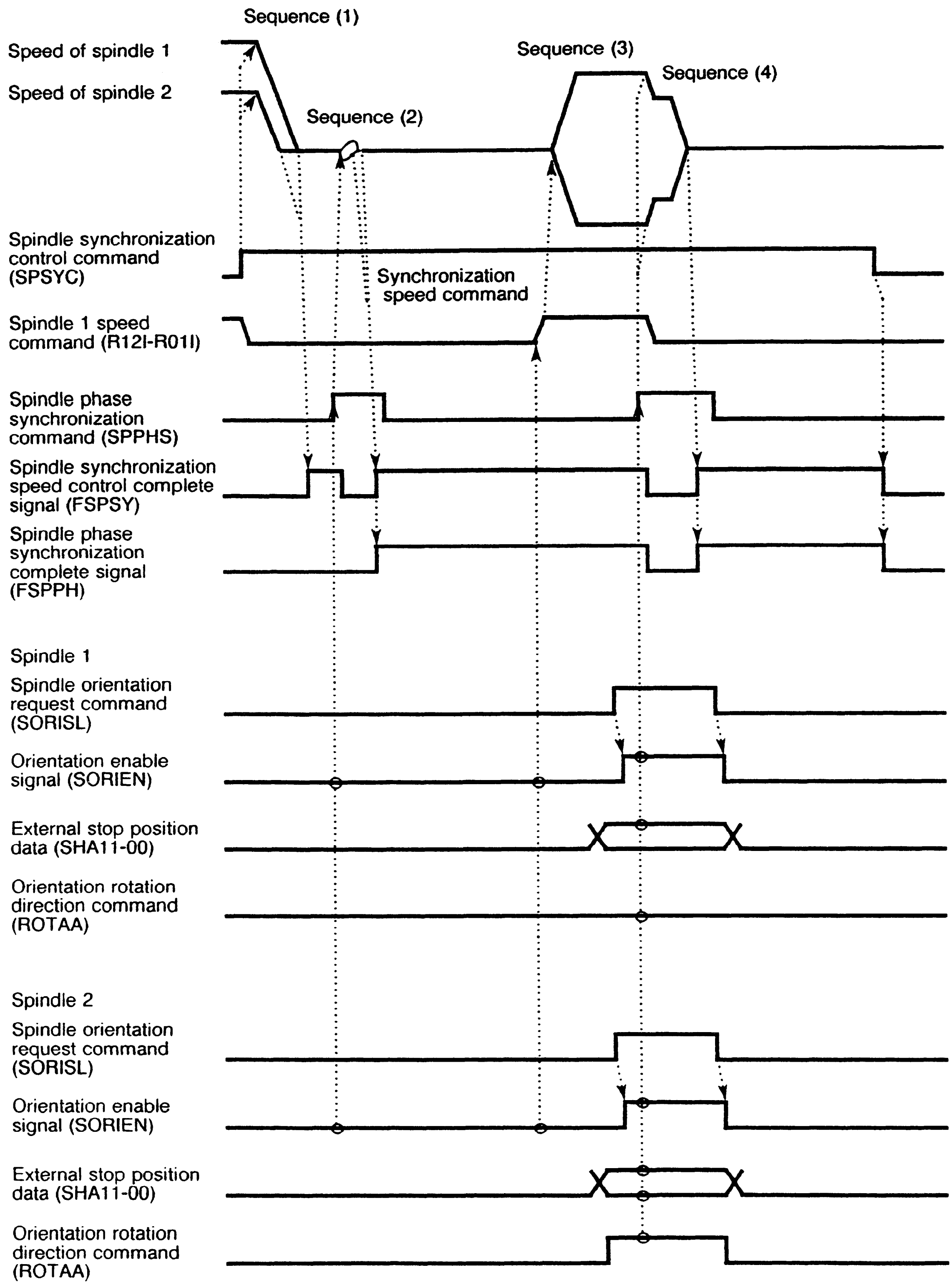
(Note 3) In synchronous spindle orientation, ensure that the same stop position is specified with SHA11-00 for spindle 1 and spindle 2. Otherwise, the workpiece, if held at both ends, is twisted.

(Note 4) In spindle orientation, be sure to set the synchronization speed command to 0. Otherwise, when the spindle orientation is released (SORISL = 0), the spindles are accelerated to the currently specified synchronization speed. This acceleration causes spindle 1 to be out of phase with spindle 2 if the two spindles do not detect SORISL at the same time; SORISL is not necessarily received at the two spindles with the same timing. If only one of the SORISL lines is disconnected, only the spindle to which the SORISL line is not connected starts rotating, causing a dangerous situation.

(Note 5) In spindle orientation, carefully check the rotation direction commands and stop position commands for spindle 1 and spindle 2. If the two spindles face each other, the same command may have the opposite effect.

(Note 6) To establish spindle speed synchronization, first check that SORIEN is set to 0 for both spindles, then enter synchronization speed commands.

[Timing chart]



[Examples of speed waveforms when the spindle orientation function is used]

When the spindle orientation function is used in the spindle synchronization control mode, the speed waveform depends on the rotational speed of the spindle when the spindle orientation command is input as shown below. (The figures below show waveforms obtained when bell-shaped acceleration/deceleration is disabled. When bell-shaped acceleration/deceleration is enabled, waveforms reflecting such acceleration/deceleration are obtained.)

(1) When spindle orientation is specified with a speed higher than the orientation speed (Fig. ①)
First the spindles are decelerated to the orientation speed (with a deceleration time constant specified in parameter 4032 (FS16/18)). Next, the travel distance to the stop position is calculated. Then, the spindles are gradually decelerated and stopped at the specified stop position.

(2) When spindle orientation is specified with a speed lower than the orientation speed (Fig. ②)
The spindles are accelerated with the same time constant as the deceleration time constant as far as possible in movement to the stop position. If the orientation speed is exceeded as a result of the acceleration, the speed is clamped to the orientation speed. After acceleration becomes impossible, the spindles are gradually decelerated and stopped at the specified stop position.

(3) When spindle orientation is specified while the spindles are stopped (Fig. ③)
As with (2) above, the spindles are accelerated in the allowable range. When acceleration becomes impossible, the spindle are gradually decelerated and stopped at the specified stop position.

(4) When the current direction of rotation is opposite to the specified orientation direction (Fig. ④)
When the direction of spindle orientation is opposite to the current direction of rotation, first the spindles are gradually decelerated and stopped calculated. Next, the travel distance to the stop position is calculated. Then, the spindles are accelerated in the specified orientation direction. When acceleration becomes impossible, the spindles are gradually decelerated and stopped at the specified stop position.

Fig. ① When Spindle Orientation is Specified with a Speed Higher than the Orientation Speed

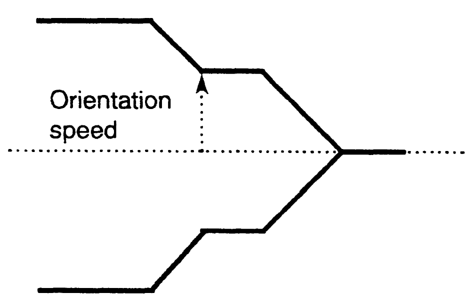


Fig. ② When Spindle Orientation is Specified with a Speed Lower than the Orientation Speed

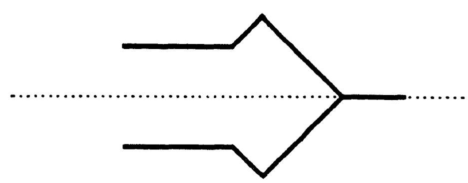


Fig. ③ When Spindle Orientation is Specified while the Spindles are Stopped

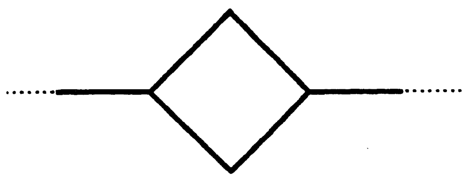
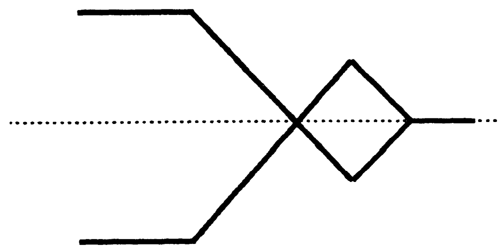


Fig. ④ When the Current Direction of Rotation is Opposite to the Specified Orientation Direction



4.4 PMC Signals (DI/DO Signals)

This section describes the PMC signals (DI/DO signals) used with the spindle orientation function in the spindle synchronization control mode.

(1) PMC to CNC (DO signals)

	0C	15	16/18	b7	b6	b5	b4	b3	b2	b1	b0
No.1 No.2	G110 G112	G231 G239	G078 G080	SHA07	SHA06	SHA05	SHA04	SHA03	SHA02	SHA01	SHA00
No.1 No.2	G111 G113	G230 G238	G079 G081					SHA11	SHA10	SHA09	SHA08
No.1 No.2	G231 G235	G229 G237	G072 G076							ROTA	
No.1 No.2	G232 G236	G228 G236	G073 G077					SORISL			
	G146	G111	G038					SPPHS	SPSYC		

- SHA11-00 (External stop position data)
  This 12-bit signal specifies the position where the spindle is to be stopped. One spindle rotation corresponds to 0-4095. Reference position 0 is the position where the spindle stops when spindle phase synchronization is established while the spindles are stopped and the synchronization speed command is set to 0; that is
  [One-rotation signal position]
  + [Amount of shift in spindle synchronization control (PRM4034: FS18)]

- ROTAA (Orientation rotation direction command)
  This command signal specifies the direction in which rotation is to be stopped in spindle orientation.
  0 : Stops rotation in the CCW direction.
  1 : Stops rotation in the CW direction.

- SORISL (Spindle orientation request command)

  This signal requests spindle orientation. In response to this signal, the spindle outputs the orientation enable signal, SORIEN. If the spindle orientation command, SPPHS (or INDX) is entered when SORIEN is set to 1, the synchronization speed command is disabled, and spindle orientation is started. When SORIEN is set to 0 with SORISL set to 0, the spindle orientation is released, and the synchronization speed command is read.

  0 : Requests that spindle speed synchronization be established, and that SPPHS is to be used as the spindle phase synchronization command.

  1 : Requests that SPPHS (or INDX) is to be used as the spindle orientation command.

- SPSYC (Spindle synchronization control command)

  This command sets and releases the spindle synchronization control mode.

  0 : Releases the spindle synchronization control mode.

  1 : Sets the spindle synchronization control mode.

- SPPHS (Spindle phase synchronization command, synchronous orientation command)

  This signal is used as the spindle phase synchronization command or synchronous orientation command. The function of this signal changes as described below, depending on the state of the SORIEN signal.

  Before SPPHS is applied, ensure that SORISL and SORIEN have the same setting for spindle 1 and spindle 2.

  0 → 1 : Spindle phase synchronization command (when SORIEN = 0)
  Synchronous orientation command (when SORIEN = 1)

(2) CNC to PMC (DI signals)

	0C	15	16/18	b7	b6	b5	b4	b3	b2	b1	b0
No.1 No.2	F283 F287	F231 F247	F047 F051					SORIEN			
	F178		F044				SYCAL	FSPPH	FSPSY		

- SORIEN (Orientation enable signal)

  This signal is output from the spindle in response to SORISL. If a rising edge of SPPHS (or a falling edge of INDX) is detected when SORIEN is set to 1, spindle orientation is started. When SORIEN is set to 0 with SORISL set to 0, the spindle orientation is released.

  Before releasing orientation, check that the synchronization speed command is set to 0 for both spindle 1 and spindle 2.

  0 : Establishes spindle speed synchronization, and uses SPPHS as the spindle phase synchronization command.

  1 : Uses SPPHS (or INDX) as the orientation start command.

- FSPSY (Spindle synchronization speed control complete signal)
  Before starting reference position determination, check that the synchronization speed command is set to 0, and FSPSY is set to 1.
  0 : Spindle synchronization speed control not complete
  1 : Spindle synchronization speed control complete

- FSPPH (Spindle phase synchronization (reference position determination) complete signal, orientation complete signal)
  This signal is used as the spindle phase synchronization (reference position determination) complete signal, or the orientation complete signal. The completion of either operation is detected when this signal changes from 0 to 1.
  0 : Operation not complete
  1 : Operation complete

- SYCAL (Spindle synchronization control alarm signal)
  This signal reports that the error pulse difference between the spindles in the spindle synchronization control mode exceeded a parameter setting. If this signal is detected, the PMC usually performs alarm processing. However, this signal is to be ignored when spindle orientation is performed with only one spindle.
  0 : Indicates that the error pulse difference between the spindles is not larger than a parameter setting.
  1 : Indicates that the error pulse difference between the spindles is larger than a parameter setting.

4.5 Setting Parameters

This section describes the parameters used with the spindle orientation function in the spindle synchronization control mode and their meanings.

0C	15	16/18	b7	b6	b5	b4	b3	b2	b1	b0
0080	5609	3702					OR2	OR1		

- OR1, OR2: Enables or disables the external setting of a stop position in spindle 1 and spindle 2 orientation. Specify 1 (enable) for both spindle 1 and spindle 2.
  0 : Disable
  1 : Enable

	0C	15	16/18	b7	b6	b5	b4	b3	b2	b1	b0
No.1	6514	3014	4014		SYCORI						
No.2	6654	3154									

- SYCORI : Enables or disables the orientation command function in the spindle synchronization control mode. Set this bit to the same value for both spindle 1 and spindle 2.
  0 : Disable
  1 : Enable

	0C	15	16/18	
No.1	6575	3075	4075	Spindle orientation completion pulse width (standard setting: 10)
No.2	6715	3215		

Valid data range : 0 to 100

This parameter sets a completion pulse width in spindle orientation. Set the same value in this parameter for both spindle 1 and spindle 2. Usually, this parameter also serves as an orientation completion detection level parameter.

	0C	15	16/18	
No.1	6284	3464	4320	Spindle orientation deceleration constant (high)
No.2	6464	3684		
No.1	6285	3465	4321	Spindle orientation deceleration constant (medium high)
No.2	6465	3685		
No.1	6286	3466	4322	Spindle orientation deceleration constant (medium low)
No.2	6466	3686		
No.1	6287	3467	4323	Spindle orientation deceleration constant (low)
No.2	6467	3687		

Valid data range : 0 to 32767 (standard setting : 0)

This parameter determines the orientation speed and acceleration/deceleration time constant used for spindle orientation. Set the same value for both spindle 1 and spindle 2. This parameter also serves as a parameter to set a deceleration constant for shortest-time orientation. So, if a value set in this parameter differs from a setting for the shortest-time orientation function, change the value to the setting for shortest-time orientation by using the gear signal.

Use the formula below to calculate the value to be set. Note that the value assigned to "acceleration [min^{-1}/s]" in the formula below must not exceed the value set in the parameter (No. 4032) for setting an acceleration/deceleration time constant for spindle synchronization control. The value set in this parameter serves as an orientation speed [min^{-1}], and the value assigned to "acceleration [min^{-1}/s]" in the formula below is an orientation operation acceleration/deceleration time constant.

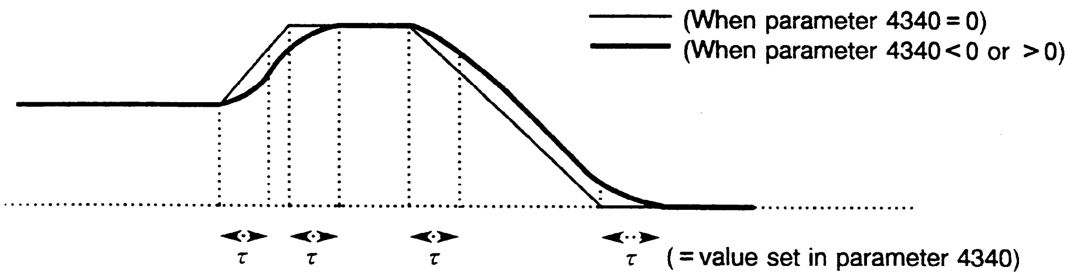
$$\text{Parameter setting} = \sqrt{120 \times \text{acceleration } [\text{min}^{-1}/\text{s}]}$$

	0C	15	16/18	
No.1	6304	3484	4340	Bell-shaped acceleration/deceleration time constant for spindle synchronization control (standard setting : 0)
No.2	6484	3704		

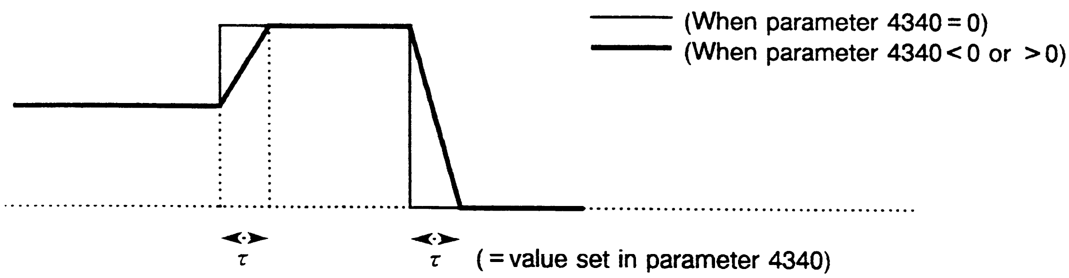
Valid data range : 0 to 512 msec

This parameter specifies the bell-shaped acceleration/deceleration used when the synchronization speed command for spindle synchronization control is changed. This bell-shaped acceleration/deceleration is applied to the move command to which the linear acceleration/deceleration time constant set in parameter 4032 (FS15/18) (or acceleration/deceleration time constant determined by parameters 4320 to 4323 in spindle orientation) has already been applied. This means that when parameter 4032 is set to 0, the linear acceleration/deceleration with a time constant specified here results. (See the figures below.)
If this parameter is set, the spindle synchronization speed control complete signal output when the synchronization speed is first reached after the spindle synchronization control mode is set is delayed by the amount set in this parameter.
Set the same value in this parameter for both spindle 1 and spindle 2.

(1) When parameter 4032 < 0 or > 0



(2) When parameter 4032 = 0



5. SERIAL SPINDLE RIGID TAPPING TECHNICAL MANUAL

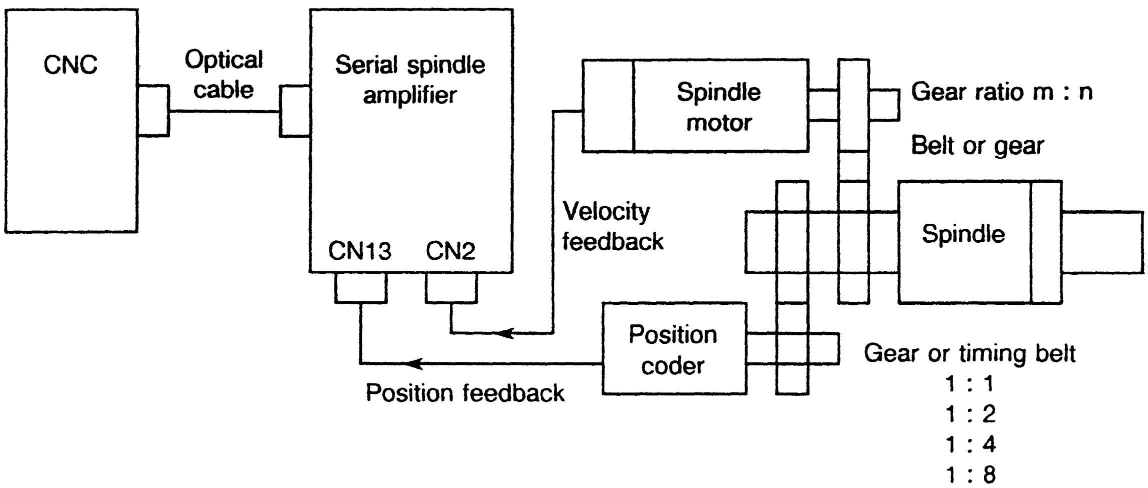
5.1 Outlines

This manual describes the rigid tapping set-up procedure.

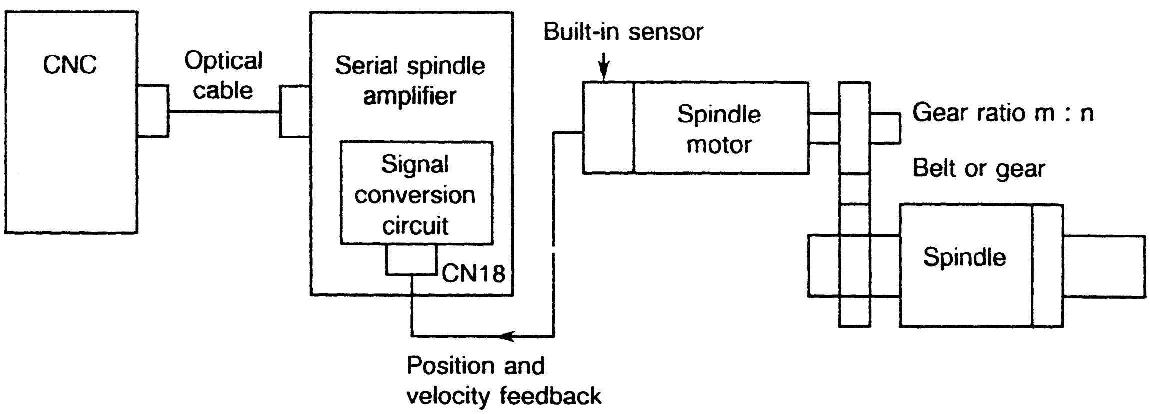
5.2 System Configuration

5.2.1 Classification by the detector

(1) System that the position coder is attached to the spindle



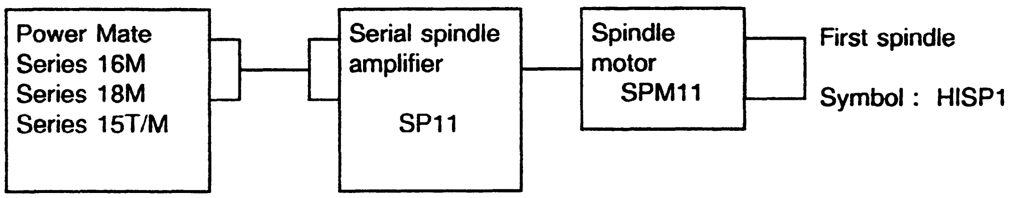
(2) System to use the motor with the built-in sensor
(The built-in motor is included)



5.2.2 Classification by the CNC Series

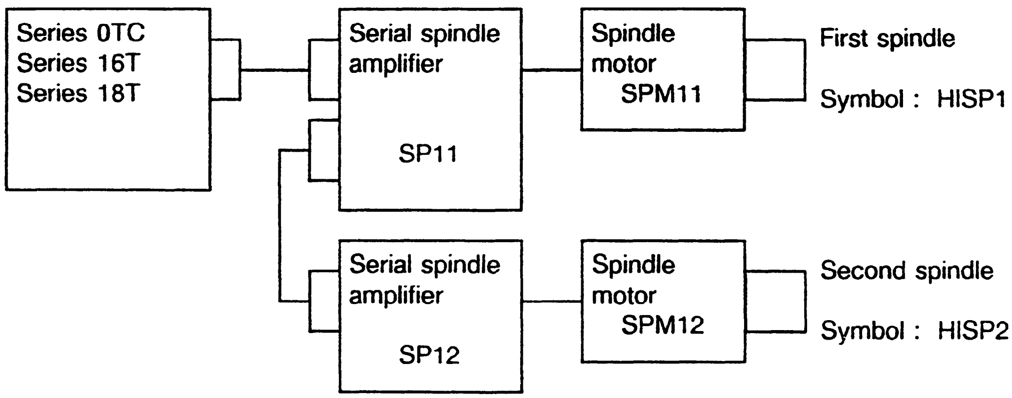
According to CNC type, there are following systems.

(1) Power Mate, Series 0MC Series 16M/18M, Series 15T/M



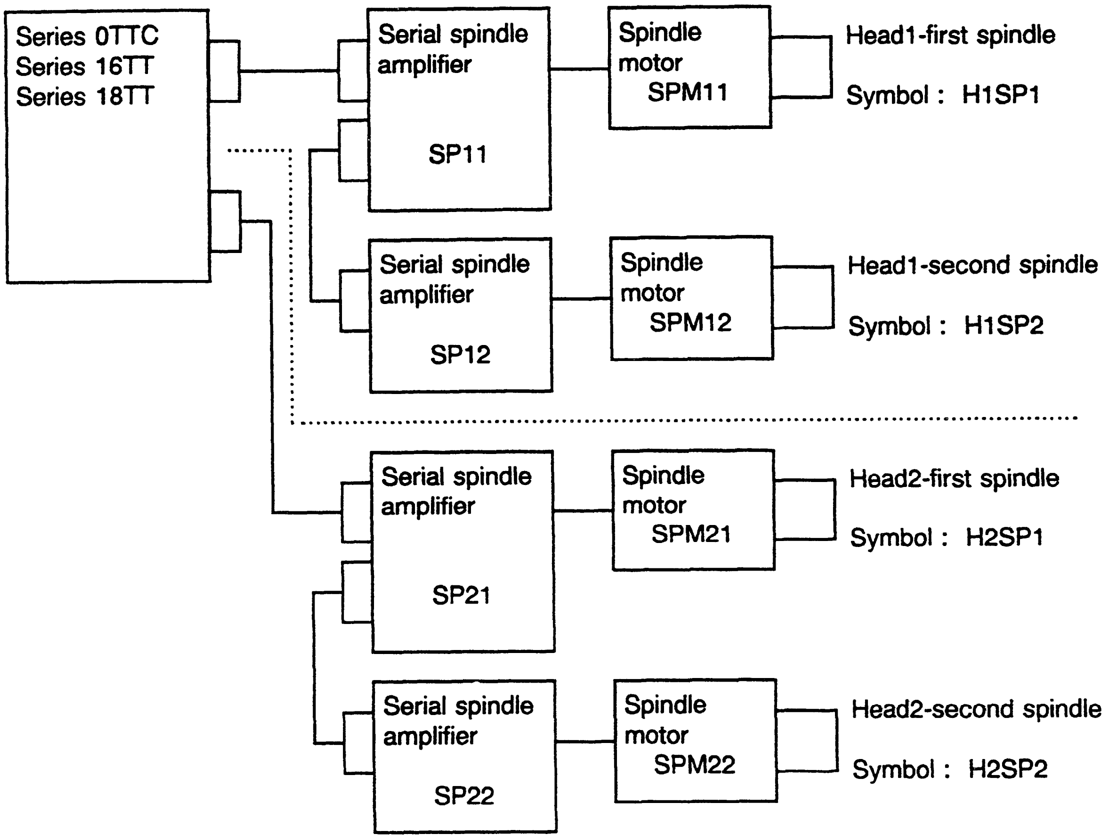
(2) Series 0TC, Series 16T/18T

In case of doing rigid tapping by the second spindle, the software option of the multi-spindle control function is needed.



(3) Series 0TTC/16TT/18TT

In case of doing rigid tapping by the second spindle, the software option of the multi-spindle control function is needed.



5.3 Rigid Tapping Sequence (PMC Ladder Program)

5.3.1 Outline

The DI/DO signals relating to the rigid tapping are as follows.

(1) Rigid tapping mode signals
(RGTAP, RGTPN)

(2) Gear select signals which show gear status for selecting parameters
(GR1, GR2, GR21, GR10, GR20, GR30)

(3) Signal for excitating the spindle motor
(Spindle forward rotation signal : SFR)

(4) Formerly TLML signal was inputted when rigid tapping, but there is no need to input TLML signal in case of serial spindle.

Refer to CNC Connecting Manual shown in 5.3.2 about the DI/DO signals of the rigid tapping.
The list of the DI/DO signals relating to the rigid tapping is shown in 5.3.3.

5.3.2 Sequence

(1) Power mate : Please refer to the following manual.
「FANUC Power Mate - MODEL A
Connecting/Programming/Maintenance Manual」: B-61613E/03
10.2.72 Rigid Tapping
(2) Interface with PMC

(2) Series 0C : Please refer to the following manual.
「FANUC Series 0 Connecting Manual」: B-61393E/02
Appendix 4 Rigid Tapping
1.2 Interface with PMC

(3) Series 15 : Please refer to the following manual.
「FANUC Series 15 Connecting Manual (BMI interface)」: B-61213E-2/02
2.3.51 Rigid Tapping

(4) Series 16/18 : Please refer to the following manual.
「FANUC Series 16/18 Connecting Manual」: B-61803E/03
8.41 Rigid Tapping
8.41.2 Interface with PMC

5.3.3 DI/DO signals relating to rigid tapping

(1) DI signals (PMC → CNC)

[Power Mate]

	7	6	5	4	3	2	1	0
G099								RGTAP
G112			SFR		CTH1	CTH2		

[Series 0C]

	0TTC HEAD2	7	6	5	4	3	2	1	0
G118	G1318					GR2 (*1)	GR1 (*1)		
G123	G1323					GR2 (*2)	GR1 (*2)	RGTPN (*3)	
G135	G1335								RGTAP (*4)
G145	G1345		GR21 (*6)					SWS2 (*5)	SWS1 (*5)
G229	G1429			SFRA		CTH1A	CTH2A		

(*1) This signal is effective when parameter 0031#5 = 0 and Turning system.

(*2) This signal is effective when parameter 0031#5 = 1 and Turning system. This signal is also effective when Machining system with the surface speed constant control option.

(*3) This signal is effective when parameter 0019#4 = 0 and this signal is always effective when Turning system.

(*4) This signal is effective when parameter 0019#4 = 1 and this signal is always ineffective when Turning system.

(*5) The rigid tapping of the second spindle is available by the multi-spindle control function.

(*6) This signal is used when the rigid tapping of the second spindle.

[Series 15]

	7	6	5	4	3	2	1	0
G026								SPSTP
G227			SFRA		CTH1A	CTH2A		

[Series 16/18]

	TT-HEAD2	7	6	5	4	3	2	1	0
G028	G1028						GR2	GR1	
G061	G1061								RGTAP
G027	G1027							SWS2 (*1)	SWS1 (*1)
G029	G1029								GR21 (*2)
G070	G1070			SFRA		CTH1A	CTH2A		

(*1) The rigid tapping of the second spindle is available by the multi-spindle control function.
(*2) This signal is used when the rigid tapping of the second spindle.

(2) DO signals (CNC → PMC)

[Power Mate]

	7	6	5	4	3	2	1	0
F196						GR3	GR2	GR1

[Series 0C]

	7	6	5	4	3	2	1	0
F152 (*1)						GR30	GR20	GR10

[Series 15]

	7	6	5	4	3	2	1	0
F040				RTAP				

[Series 16/18]

	7	6	5	4	3	2	1	0
F034 (*1)						GR30	GR20	GR10

(*1) These signals are effective when Machining system.

5.3.4 Gear signal of Series 0C/16/18

The gear signal of Series 0C/16/18 has following two kinds of types.

(1) Turning and Machining with surface speed constant option.
In this type, the gear signal GR1, GR2 (GR21 for Snd. sp) is inputted from PMC to CNC. The parameters in CNC is selected according to the gear signal.

(2) Standard Machining
In this type, the gear signal GR10, GR20, GR30 is outputted from CNC to PMC according to the following (1) parameters setting and S command.
The parameters in CNC is selected according to the gear signal.
About the details, refer to "S" function of each CNC connecting manual and the parameter explanation of each CNC operation manual.

(i) Parameter table relating to the gear signal

Items	0MC	16M/18M
Spindle maximum speed for each gear (10V at maximum speed)	0541 0539 0555	3741 3742 3743
Maximum clump speed of motor	0542	3736
Minimum clump speed of motor	0543	3735
Selection of gear change type Gear 1-2 change motor speed Gear 2-3 change motor speed	0035#6 0585 0586	3706#2 3751 3752
Gear change speed at tapping Gear 1-2 change motor speed Gear 2-3 change motor speed	0012#6 3761 3762	3706#3 3761 3762

5.3.5 Rigid tapping by the second spindle of Turning system of Series 0C/16/18. (The multi-spindle control option is needed.)

(1) SWS1, SWS2 signals of the multi-spindle control select the spindle axis.
In case of SWS1 = 1 → Rigid tapping by the first spindle.
In case of SWS1 = 0 and SWS2 = 1 → Rigid tapping by the second spindle.

(2) In case of the second spindle rigid tapping, the gear signal GR21 is used.

5.4 Parameter Setting

5.4.1 Parameter setting procedure

Set the rigid tapping parameter as follows.

(1) Set the parameter 「Position coder signal is used」
Refer to item 4.2 in details.

(2) Set the parameter 「Rotation direction of the motor and the spindle」
Refer to item 4.3 in details.

(3) Set the parameter 「Attached direction of the position coder」
Refer to item 4.4 in details.

(4) Set the parameter relating to the system in which the position coder is used.
Refer to item 4.5 in details.

(5) Set the parameters relating to the system in which the motor with the built-in sensor (including the built-in motor) is used.
Refer to item 4.6 in details.

(6) Set the parameter 「Gear Ratio between the spindle and the motor」
Refer to item 4.7 in details.

(7) Set the parameter 「Position gain」
Refer to item 4.8 in details.

(8) Set the parameter 「Acceleration/Deceleration time constant」 and 「Spindle maximum speed at rigid tapping」
Refer to item 4.9 in details.

(9) Set the parameter 「Motor voltage」
Refer to item 4.10 in details.

(10) About the other parameters, refer to the parameter explanation of each CNC Operation Manual and Serial Spindle Maintenance Manual.

5.4.2 Set the parameter 「Position coder signal is used」 (=1)

The parameter setting address is as follows.

Power Mate	FS0C T/M/TT Fst. sp	FS0C T/TT Snd. sp	FS15 T/M	FS16/18 T/M/TT
3001#2	6501#2	6641#2	3001#2	4001#2

0 : Position coder signal is not used
1 : Position coder signal is used

5.4.3 Set the parameter 「Rotation direction of the motor and the spindle」

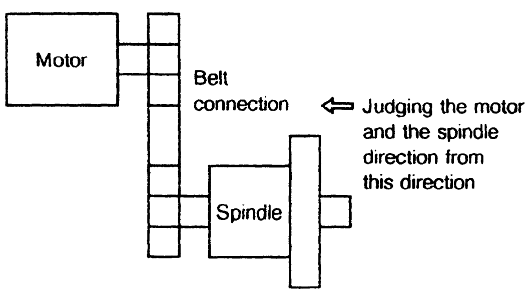
(1) The parameter setting address is as follows.

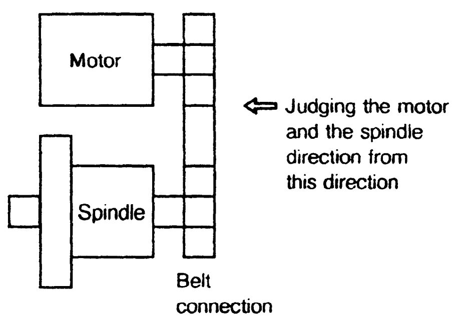
Power Mate	FS0C T/M/TT Fst. sp	FS0C T/TT Snd. sp	FS15 T/M	FS16/18 T/M/TT
3000#0	6500#0	6640#0	3000#0	4000#0

0 : Spindle and motor are the same direction
1 : Spindle and motor are the reverse direction

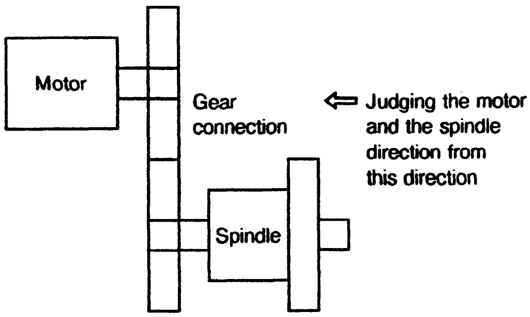
(2) Example of the rotation direction
The rotation direction is judged from the same direction facing to the motor and the spindle.
Set "The same direction" in case of the built-in motor.

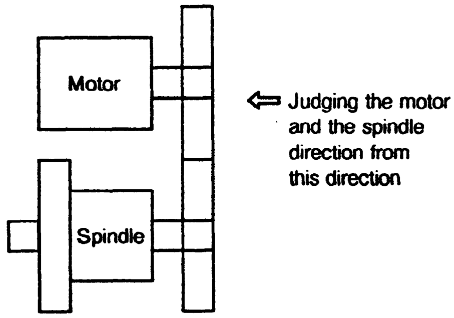
(i) In case of the belt connection between the motor and the spindle, the direction is "the same direction" independently of the spindle direction.



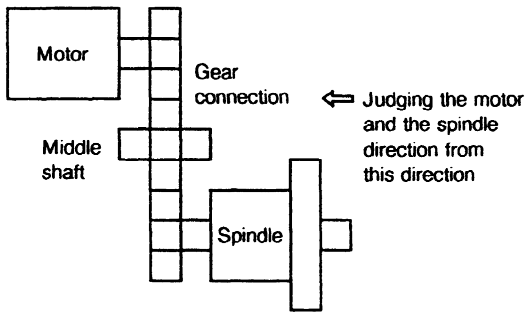


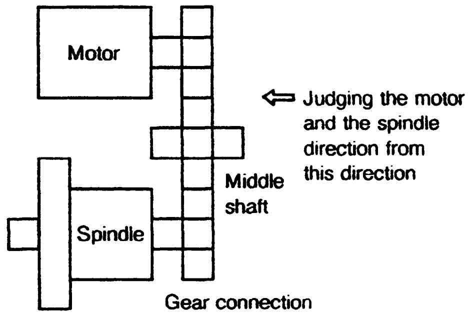
(ii) In case of the gear connection and there is no middle shaft between the spindle and the motor, the direction is "the reverse direction" independently of the spindle direction.





(iii) In case of the gear connection and there is a middle shaft between the spindle and the motor, the direction is "the same direction" independently of the spindle direction.





5.4.4 Set the parameter 「Attached direction of the position coder」

(1) The parameter setting address is as follows.

Power Mate	FS0C T/M/TT Fst. sp	FS0C T/TT Snd. sp	FS15 T/M	FS16/18 T/M/TT
3000#2	6500#2	6640#2	3000#2	4000#2

0 : The spindle and the position coder is the same direction

1 : The spindle and the position coder is the reverse direction

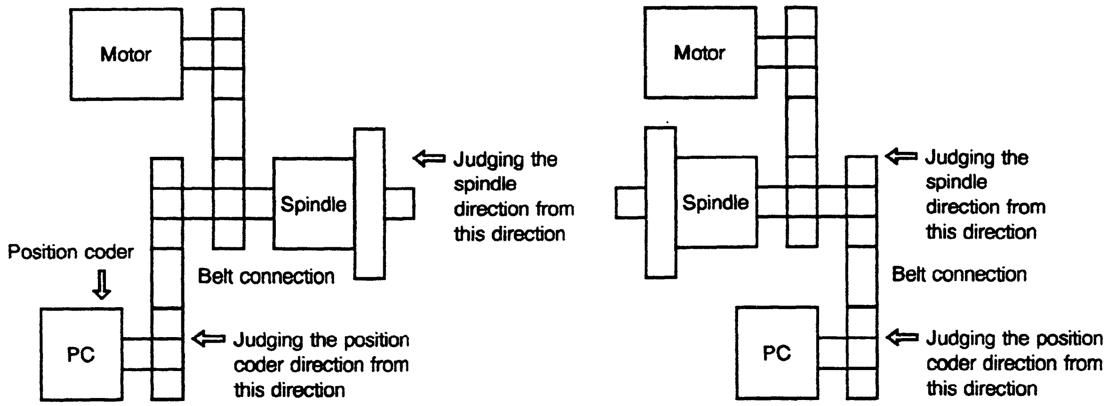
(2) Example of the attached direction of the position coder

The rotation direction of the position coder is judged facing to the position coder shaft.

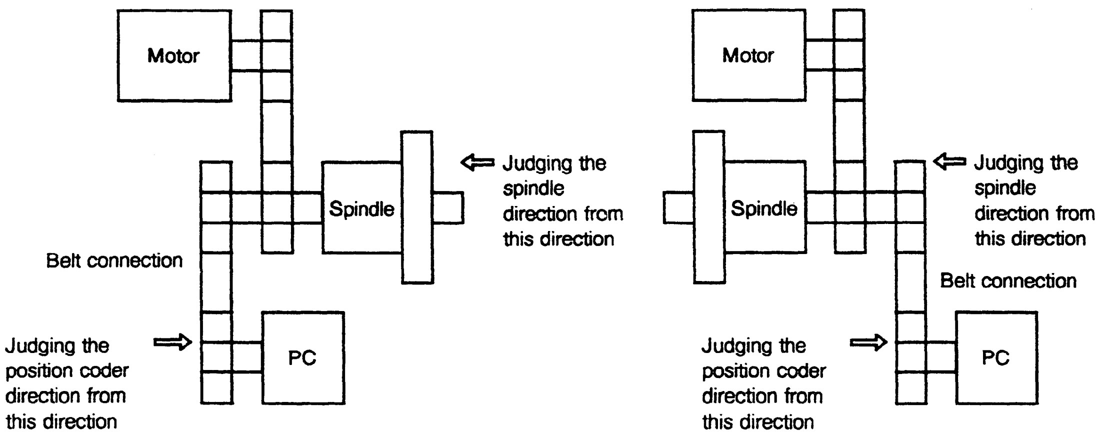
The rotation direction of the spindle is judged from the same direction facing to the motor shaft.

Set "The same direction" in case of the built-in motor.

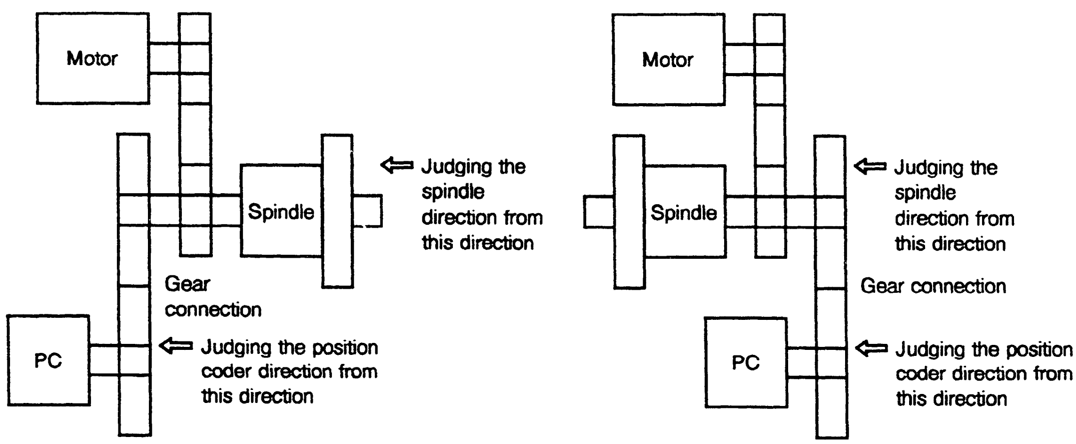
(i) In case of the following belt connection, the spindle and the position coder are the same direction.



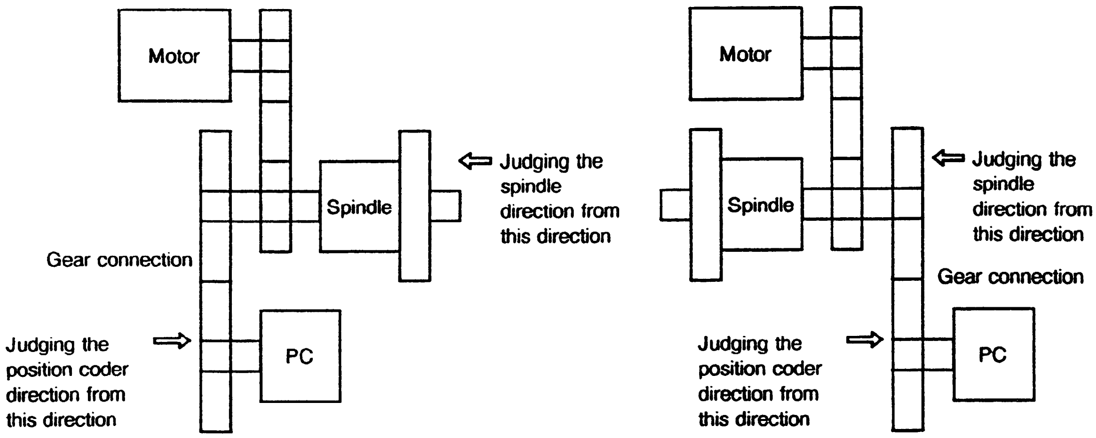
(ii) In case of the following belt connection, the spindle and the position coder are the reverse direction.



(iii) In case of the following gear connection, the spindle and the position coder are the reverse direction.



(iv) In case of the following gear connection, the spindle and the position coder are the same direction.



5.4.5 Parameter setting relating to the system in which the position coder is used.

(1) When the gear ratio between the spindle and the position coder is 1:2, 1:4, and 1:8.
Refer to each CNC operation manual about the relation between the gear ratio and the parameter setting data.

Power Mate	FS0C M Fst. sp	FS0C T/TT Fst. sp	FS0C T/TT Snd. sp	FS15 T/M	FS16/18 T/M/TT Fst. sp	FS16/18 T/TT Snd. sp
0026#7,6	0028#7,6	0003#7,6	0064#7,6	5610	3706#1,0	3707#1, 0

5.4.6 Parameter setting relating to the system in which the motor with the built-in sensor (including the built-in motor) is used.

(1) Set the following parameter according to the pulse number of the sensor.

Power Mate	FS0C T/M/TT Fst. sp	FS0C T/TT Snd. sp	FS15 T/M	FS16/18 T/M/TT
3003#4	6503#4	6643#4	3003#4	4003#4

0 : 1024 p/rev ×4
1 : 512 p/rev ×4

(2) Set the parameter 「Doing the rigid tapping by using the motor with the built-in sensor」 (=1)

Power Mate	FS0C T/M/TT Fst. sp	FS0C T/TT Snd. sp	FS15 T/M	FS16/18 T/M/TT
3006#7	6506#7	6646#7	3006#7	4006#7

0 : Except the below case
1 : Doing the rigid tapping by using the motor with the built-in sensor

(3) Set the following parameters when the gear ratio between the spindle and the motor (the sensor) is not 1:1.

(i) Set the parameter to validate 「the arbitrary gear ratio between the spindle and the position coder」.

Power Mate	FS0C M	FS0C T/TT	FS15 T/M	FS16/18 T/M/TT
0025#0	0063#3	0063#6	5604#2, 1	5200#1

(ii) Set the parameter 「the arbitrary gear ratio between the spindle and the position coder」 according to each CNC.

[Power Mate]

- Set the gear teeth number of the spindle side.
  Each parameter is selected according to the gear selection signal (GR1, GR2, GR3).

Gear selection signal			Parameter No.
GR1	GR2	GR3	
1	0	0	266
0	1	0	267
0	0	1	268

- Set the gear teeth number of the position coder side.
  Each parameter is selected according to the gear selection signal (GR1, GR2, GR3).

Gear selection signal			Parameter No.
GR1	GR2	GR3	
1	0	0	269
0	1	0	270
0	0	1	271

[Series 0C]

- Set the gear teeth number of the spindle side.
  Each parameter is selected according to the gear selection signal.
  Standard machining : GR30, GR20, GR10
  Turning and machine with surface speed constant option : GR2, GR1
  Second spindle of turning : GR21 (Multi-spindle control option is needed)

Standard machining

Gear signal			Parameter No.
GR10	GR20	GR30	
1	0	0	663
0	1	0	664
0	0	1	665

Turning and machining with surface speed constant

Gear selection signal			Parameter No.	
Fst. sp		Snd. sp		
GR1	GR2	GR21	T/TT	M
0	0	0	427	663
1	0	1	428	664
0	1	–	429	665
1	1	–	430	

- Set the gear teeth number of the position coder side.
  Each parameter is selected according to the gear selection signal.
  Standard machining : GR3O, GR2O, GR1O
  Turning and machining with surface speed constant option : GR2, GR1
  Second spindle of turning : GR21 (Multi-spindle control option is needed)

Standard machining

Gear signal			Parameter No.
GR10	GR20	GR30	
1	0	0	666
0	1	0	667
0	0	1	668

Turning and machining with surface speed constant

Gear selection signal			Parameter No.	
Fst. sp		Snd. sp		
GR1	GR2	GR21	T/TT	M
0	0	0	431	666
1	0	1	432	667
0	1	–	433	668
1	1	–	434	

[Series 15]

(i) Only one arbitrary gear ratio parameter is valid in case of 5604#1 = 1, 5604#2 = 0.

	Parameter No.
Gear teeth number of spindle side	5703
Gear teeth number of position coder side	5704

ii) Four kinds of arbitrary gear ratio parameters are valid in case of 5604#2 = 1.
Each parameter is selected according to the gear selection signal (CTH1A, CTH2A).

Gear signal		Parameter No.	
CTH1A	CTH2A	Gear teeth number of spindle side	Gear teeth number of position coder side
0	0	5771	5781
0	1	5772	5782
1	0	5773	5783
1	1	5774	5784

[Series 16/18]

- Set the gear teeth number of the spindle side.
  Each parameter is selected according to the gear selection signal.
  Standard machining : GR30, GR20, GR10
  Turning and machining with surface speed constant option : GR2, GR1
  Second spindle of turning : GR21 (Multi-spindle control option is needed)

Standard machining

Gear signal			Parameter No.
GR10	GR20	GR30	
1	0	0	5221
0	1	0	5222
0	0	1	5223

Turning and machining with surface speed constant

Gear selection signal			Parameter No.	
Fst. sp		Snd. sp		
GR1	GR2	GR21	T/TT	M
0	0	0	5221	
1	0	1	5222	
0	1	–	5223	
1	1	–	5224	5223

- Set the gear teeth number of the position coder side.
  Each parameter is selected according to the gear selection signal.
  Standard machining : GR3O, GR2O, GR1O
  Turning and machining with surface speed constant option : GR2, GR1
  Second spindle of turning : GR21 (Multi-spindle control option is needed)

Standard machining

Gear signal			Parameter No.
GR10	GR20	GR30	
1	0	0	5231
0	1	0	5232
0	0	1	5233

Turning and machining with surface speed constant

Gear selection signal			Parameter No.	
Fst. sp		Snd. sp		
GR1	GR2	GR21	T/TT	M
0	0	0	5231	
1	0	1	5232	
0	1	–	5233	
1	1	–	5234	5233

5.4.7 Parameter setting of 「Gear ratio between the spindle and the motor」

The loop gain constant parameter is not used in the serial spindle system. 「Gear ratio between the spindle and the motor」 parameter should be set instead of it. Each parameter is selected according to the gear selection signal (CTH1A/B, CTH2A/B). About the setting data, refer to the parameter explanation of the serial spindle maintenance manual B-65045E.

[Power Mate, 0M/T/TT Fst. sp, 15M/T, 16(18) T/M/TT Fst. sp]

Gear signal		Parameter number			
CTH1A	CTH2A	Power Mate	0M/T/TT Fst. sp	15M/T	16(18) T/M/TT Fst. sp
0	0	3056	6556	3056	4056 (S1)
0	1	3057	6557	3057	4057 (S1)
1	0	3058	6558	3058	4058 (S1)
1	1	3059	6559	3059	4059 (S1)

[0T/TT Snd. sp, 16(18) T/TT Snd. sp]

Gear signal		Parameter number	
CTH1B	CTH2B	0M/T/TT Snd. sp	16(18) T/M/TT Snd. sp
0	0	6696	4056 (S2)
0	1	6697	4057 (S2)
1	0	6698	4058 (S2)
1	1	6699	4059 (S2)

5.4.8 Parameter setting of 「Position gain」

In the rigid tapping, the tapping axis and the spindle is controlled to be synchronized.
So, the position gain of the tapping axis and the spindle must be set to the same value.

(1) Power Mate

The position gain parameter of the tapping axis in the rigid tapping is selected as follows according to the gear selection signal (GR1, GR2, GR3).

Gear selection signal			Parameter No.
GR1	GR2	GR3	
1	0	0	272
0	1	0	273
0	0	1	274

The position gain parameter of the spindle in the rigid tapping is selected as follows according to the gear selection signal (CTH1A, CTH2A).

Gear signal		Parameter No.
CTH1A	CTH2A	
0	0	3065
0	1	3066
1	0	3067
1	1	3068

Take care to input the gear selection signal GR1, GR2, GR3 and CTH1A, CTH2A according to the real gear state in order to get the same position gain of the tapping axis and that of the spindle, because GR1, GR2, GR3 and CTH1A, CTH2A are inputted independently.

(2) Series 0C

The position gain parameter of the tapping axis in the rigid tapping is selected as follows according to the gear selection signal.

Standard machining : GR30, GR20, GR10

Turning and machining with surface speed constant option : GR2, GR1

Second spindle of turning : GR21 (Multi-spindle control option is needed)

Standard machining

Gear signal			Parameter No.
GR10	GR20	GR30	
			615 (*1)
1	0	0	669
0	1	0	670
0	0	1	671

Turning and machining with surface speed constant

Gear selection signal			Parameter No.	
Fst. sp		Snd. sp		
GR1	GR2	GR21	T/TT	M
		(*1) →	406	615
0	0	0	407	669
1	0	1	408	670
0	1	–	409	671
1	1	–	410	

(*1) When this parameter is "0", each gear parameter becomes valid.
When this parameter is not "0", each gear parameter becomes invalid, and this parameter is always used.

The position gain parameter of the spindle in the rigid tapping is selected as follows according to the gear selection signal (CTH1A/B, CTH2A/B).

[Fst. sp]

Gear signal		Parameter No.
CTH1A	CTH2A	
0	0	6565
0	1	6566
1	0	6567
1	1	6568

[Snd. sp]

Gear signal		Parameter No.
CTH1B	CTH2B	
0	0	6705
0	1	6706
1	0	6707
1	1	6708

Take care to input the gear selection signal GR1, GR2, GR21 and CTH1A, CTH2A according to the real gear state in order to get the same position gain of the tapping axis and that of the spindle, because GR1, GR2, GR21 and CTH1A, CTH2A are inputted independently.

(3) Series 15

In the rigid tapping, the same parameter address data is used for the position gain of the tapping axis and the spindle.

Each position gain is selected as follows according to the gear selection signal (CTH1A, CTH2A).

Gear signal		Parameter No.
CTH1A	CTH2A	
0	0	3065
0	1	3066
1	0	3067
1	1	3068

(4) Series 16/18

The position gain parameter of the tapping axis in the rigid tapping is selected as follows according to the gear selection signal.

Standard machining : GR30, GR20, GR10

Turning and machining with surface speed constant option : GR2, GR1

Second spindle of turning : GR21 (Multi-spindle control option is needed)

Standard machining

Gear signal			Parameter No.
GR10	GR20	GR30	
			5280 (*1)
1	0	0	5281
0	1	0	5282
0	0	1	5283

Turning and machining with surface speed constant

Gear selection signal			Parameter No.	
Fst. sp		Snd. sp		
GR1	GR2	GR21	T/TT	M
			5280 (*1)	
0	0	0	5281	
1	0	1	5282	
0	1	–	5283	
1	1	–	5284	5283

(*1) When this parameter is "0", each gear parameter becomes valid.

When this parameter is not "0", each gear parameter becomes invalid, and this parameter is always used.

The position gain parameter of the spindle in the rigid tapping is selected as follows according to the gear selection signal (CTH1A/B, CTH2A/B).

[Fst. sp]

Gear signal		Parameter No.
CTH1A	CTH2A	
0	0	4065 (S1)
0	1	4066 (S1)
1	0	4067 (S1)
1	1	4068 (S1)

[Snd. sp]

Gear signal		Parameter No.
CTH1B	CTH2B	
0	0	4065 (S2)
0	1	4066 (S2)
1	0	4067 (S2)
1	1	4068 (S2)

Take care to input the gear selection signal GR1, GR2, GR21 and CTH1A, CTH2A according to the real gear state in order to get the same position gain of the tapping axis and that of the spindle, because GR1, GR2, GR21 and CTH1A, CTH2A are inputted independently.

5.4.9 Parameter setting of 「Acceleration/Deceleration time constant」 and 「Spindle maximum speed at rigid tapping」

(1) Calculation of Acceleration/Deceleration time constant.

The Acc/Dec time constant is determined by the motor torque (calculated from the motor 30 min. output power at the rigid tapping speed), the total inertia (including the motor inertia and the load inertia), and cutting torque (including the machine friction and so on).

The calculating method of the Acc/Dec time constant under no cutting load condition is shown below.

(i) Motor torque : Tm [kg · m]

Rigid tapping speed : Nr [min^{-1}]

30 min output power at rigid tapping speed Nr : Pr [kW]

$$Tm = \frac{1000 \times Pr}{1.0269 \times Nr} \text{ [kg · m]}$$

(ii) Acc/Dec time constant : tr [sec]

Motor inertia : Jm [kg · cm · sec^2]

Load inertia reflected to motor shaft : Jl [kg · cm · sec^2]

$$Tm = \frac{Jm + Jl}{Tm \times 100} \times \frac{Nr}{60} \times 2\pi \text{ [sec]}$$

(iii) Example of the time constant calculation.
Rigid tapping by Model 6S at 3000 min^{-1}.
30 min output power at 3000 min^{-1} = 7.5 kW, then motor torque Tm is

$$Tm = \frac{1000 \times 7.5\ kW}{1.0269 \times 3000\ min^{-1}} = 2.43\ kg \cdot m$$

Motor inertial = 0.22 kg · cm · sec^2
If Load inertia = 0.3 kg · cm · sec^2, then time constant is

$$tr = \frac{0.22 + 0.3}{2.43 \times 100} \times \frac{Nr}{60} \times 2\pi = 0.672\ sec\ (=672\ msec)$$

It is necessary to set the longer time constant than the calculated value, because the cutting power is necessary besides the Acc/Dec power.

(2) Power Mate

(i) The time constant of the tapping axis and the spindle is selected according to the gear selection signal (GR1, GR2, GR3).
the time to get to the spindle maximum speed at the rigid tapping is set.

Gear selection signal			Time constant parameter No.	Spindle max. speed parameter No.
GR1	GR2	GR3		
1	0	0	250	233
0	1	0	251	234
0	0	1	252	235

(ii) The override at extracting

0025#1

0 : The override at extracting is not valid.
1 : The override at extracting is valid. (The override value is set to No. 137)

(3) Series 0C

(i) Set the steplessly switched time constant.

Machining	Turning
0037#6	(*1)

0 : Time constant is not steplessly switched in rigid tapping.
1 : Time constant is steplessly switched in rigid tapping.

(*1) In Turning system, the time constant is always steplessly switched in rigid tapping.

(ii) Set 「Acc/Dec type」

Machining	Turning
254	(*1)

0 : Exponential Acc/Dec
1 : Linear Acc/Dec (Standard setting)

(*1) Only linear Acc/Dec is applied to Turning system.

(iii) 「Low end speed at rigid tapping exponential Acc/Dec」 is set to the following address and is applied to all gear state

Machining	Turning
614	(*1)

(*1) This function is not valid to Turning system.

(iv) The time constant of the tapping axis and the spindle is set as follows. The time to get to the spindle maximum speed at the rigid tapping is set.

[Machining system]

Each gear time constant becomes valid by setting the parameter below.

0077#1

0 : The same time constant for all gear
1 : Each time constant for each gear

By setting the following parameter, the different time constant between the cutting in and cutting out (extracting) becomes available.

0035#5

0 : The same time constant between cutting in and out.
1 : The different time constant between cutting in and out.

As an summary, refer to the tables below.

Gear selection signal					Time constant (cutting in) Parameter No.		Time constant (cutting out) Parameter No. (Valid at 35#5 = 1)		Rigid tapping spindle max. speed Parameter No.
Standard Machin.			(*1)						
GR10	GR20	GR30	GR1	GR2	77#1 = 0	77#1 = 1	77#1 = 0	77#1 = 1	
1	0	0	0	0	613	692	402	400	617
0	1	1	1	1		693		401	
0	0	1	0	1		613		402	

(*1) The machining system with surface speed constant option.

[Turning system]

Set the parameters as below according to the gear selection signal.

Fst. sp : GR2, GR1

Snd. sp: GR21 (Multi-spindle control option is needed)

By setting the following parameter, the different time constant between the cutting in and cutting out (extracting) becomes available.

0029#3

0 : The same time constant between cutting in and out. (No. 415 to 418)

1 : The different time constant between cutting in and out.
  Cutting in : No. 415 to 418
  Cutting out : No. 419 to 422

Gear selection signal			Time constant (cutting in) Parameter No.	Time constant (cutting out) Parameter No.	Rigid tapping spindle max. speed Parameter No.
Fst. sp		Snd. sp			
GR1	GR2	GR21			
0	0	0	415	419	423
1	0	1	416	420	424
0	1		417	421	425
1	1		418	422	426

(v) The override at extracting

0063#4

0 : The override at extracting is not valid.
1 : The override at extracting is valid. (The override value is set to No. 258)

(4) Series 15

(i) 「Acc/Dec type」 is set to "5605#1".
0 : Exponential type Acc/Dec
1 : Linear type Acc/Dec (Standard setting)

(ii) Setting of 「Low end speed of exponential type Acc/Dec」

(a) When 5605#2 = 0, the same parameter data is used for all gear and the address is

5752

(b) When 5605#2 = 1, each parameter can be set for each gear.
Each parameter is selected according to the gear signal (CTH1A, CTH2A).

Gear signal		Parameter No.
CTH1A	CTH2A	
0	0	5761
0	1	5763
1	0	5765

(iii) Set the time constant of the tapping axis and the spindle.

(a) When 5605#2 = 0, the same parameter data is used for all gear.
The time to get to the spindle maximum speed at the rigid tapping is set.

Acc/Dec time constant	5751
Spindle maximum speed	5757

(b) When 5605#2 = 1, each parameter can be set for each gear.
Each parameter is selected according to the gear signal (CTH1A, CTH2A).
The time to get to the spindle maximum speed at the rigid tapping is set.

Gear signal		Time constant Parameter No.	Spindle max. speed Parameter No.
CTH1A	CTH2A		
0	0	5760	5757
0	1	5762	5758
1	0	5764	5759

(5) Series 16/18

(i) Each parameter can be set for each gear and is selected according to the gear selection signal.
By setting the following parameter, the different time constant between the cutting in and cutting out (extracting) becomes available.

5201#2

0 : The same time constant between cutting in and out. (No. 5261 to 5264)
1 : The different time constant between cutting in and out.
Cutting in : No. 5261 to 5264
Cutting out : No. 5271 to 5274

Standard Machining : GR30, GR20, GR10
Turning and Machining with surface speed constant : GR2, GR1
Snd. sp of Turning : GR21 (Multi-spindle control option is needed)

[Standard Machining]

Gear signal			Time constant (cutting in) Parameter No.	Time constant (cutting out) Parameter No.	Spindle max. speed Parameter No.
GR10	GR20	GR30			
1	0	0	5261	5271	5241
0	1	0	5262	5272	5242
0	0	1	5263	5273	5243

[Turning and Machining with surface speed constant option]

Gear selection signal			Time constant (cutting in) Parameter No.	Time constant (cutting out) Parameter No.	Spindle max. speed Parameter No.	
Fst. sp		Snd. sp				
GR1	GR2	GR21			Turning	Machining
0	0	0	5261	5271	5241	5241
1	0	1	5262	5272	5242	5242
0	1	–	5263	5273	5243	5243
1	1	–	5264 (*1)	5274 (*1)	5244 (*1)	–

(*1) This is not available for Machining.

(ii) The override at extracting.

5200#4

0 : The override at extracting is not valid.
1 : The override at extracting is valid. (The override value is set to No. 5211)

5.4.10 Parameter setting relating to the motor voltage.

(1) Set 「Motor voltage at servo mode (rigid tapping)」
The setting address is as follows according to CNC type.
This initial setting data is "30", but when the rigid tapping function is used, usually set "100" as a data.

Power Mate	FS0C T/M/TT Fst. sp	FS0C T/TT Snd. sp	FS15 T/M	FS16/18 T/M/TT	Remarks
3085	6585	6725	3085	4085	Standard motor, High speed
3137	6901	6941	3281	4137	Low speed range

(2) Set 「The delay time until the motor excitation becomes stable」.
The setting address is as follows according to CNC type.
The standard setting values is "400 msec".

Power Mate	FS0C T/M/TT Fst. sp	FS0C T/TT Snd. sp	FS15 T/M	FS16/18 T/M/TT
3099	6599	6739	3099	4099

5.4.11 「Spindle backlash」

(1) Power Mate

0135

(2) Series 0C

In the Machining system, the same parameter is applied for all gear.

In the Turning system, each parameter for each gear is set according to the gear selection signal.

Fst. sp : GR2, GR1

Snd. sp: GR21 (Multi-spindle control option is needed)

[Machining]

Gear signal			Parameter No.
GR10	GR20	GR30	
1	0	0	255
0	1	0	
0	0	1	

[Turning]

Gear selection signal			Parameter No.
Fst. sp		Snd. sp	
GR1	GR2	GR21	
0	0	0	214
1	0	1	215
0	1	—	216
1	1	—	217

(3) Series 15

Set the backlash data according to the following bit parameter.

5604#2

0 : The same parameter is applied for all gear. The address is No. 5756.

1 : Each parameter for each gear is set according to the gear selection signal (CTH1A, CTH2A) as follows.

Gear signal		Parameter No.
CTH1A	CTH2A	
0	0	5791
0	1	5792
1	0	5793
1	1	5794

(4) Series 16/18

In the Machining system, the same parameter is applied for all gear.

In the Turning system, each parameter for each gear is set according to the gear selection signal.

Fst. sp : GR2, GR1

Snd. sp: GR21 (Multi-spindle control option is needed)

[Machining]

Gear signal			Parameter No.
GR10	GR20	GR30	
1	0	0	5321
0	1	0	
0	0	1	

[Turning]

Gear selection signal			Parameter No.
Fst. sp		Snd. sp	
GR1	GR2	GR21	
0	0	0	5321
1	0	1	5322
0	1	–	5323
1	1	–	5324

5.5 Rigid Tapping Parameter Table

Parameter number					Remarks
Power Mate	0M/T/TT		15M/T	16/18 M/T/TT	
	Fst. sp	Snd. sp			
0136	0256		–	5210	M code of rigid tapping command
–	0031#5 (T)		–	–	Address selection of gear signal (5.3.3)
–	0019#4 (M)		–	–	DI signal selection of rigid tapping (5.3.3)
3001#2	6501#2	6641#2	3001#2	4001#2	Position coder signal (refer to 5.4.2)
3000#0	6500#2	6640#2	3000#0	4000#0	Rotation direction of spindle (5.4.3)
3000#2	6500#2	6640#2	3000#2	4000#2	Attached direction of position coder 5.4.4
0026 #7, 6	0028 #7, 6 0003 #7,6	0064 #7, 6	5610	3706 #1, 0 3707 #1,0	Gear ratio between spindle and position coder, 1:1, 1:2, 1:4, 1:8 (refer to 5.4.5)
3003#4	6503#4	6643#4	3003#4	4003#4	Pulse number of built-in sensor (5.4.6)
3006#7	6506#7	6646#7	3006#7	4006#7	Rigid tapping using the motor with built-in sensor (refer to 5.4.6)
0025#0	0063#3 (M) 0063#6 (T)		5604 #2, 1	5200#1	Selection of arbitrary gear ratio between spindle and position coder 5.4.6

Parameter number					Remarks
Power Mate	0M/T/TT		15M/T	16/18 M/T/TT	
	Fst. sp	Snd. sp			
0266 0267 0268	(M) 0663 0664 0665	(T) 0427 to 0430	5703 5771 to 5774	5221 5222 5223 5224	Teeth number of spindle side at arbitrary gear ratio setting (refer to 5.4.6)
0269 0270 0271	(M) 0666 0667 0668	(T) 0431 to 0434	5704 5781 to 5784	5231 5232 5233 5234	Teeth number of position coder side at arbitrary gear ratio setting (refer to 5.4.6)
3056 to 3059	6556 to 6559	6696 to 6699	3056 to 3059	4056 to 4059	Gear ratio between spindle and motor (refer to 5.4.7)
0272 0273 0274	(M) 0615 0669 0670 0671	(T) 0406 to 0410	3065 to 3068	5280 5281 to 5284	Position gain of tapping axis at rigid tapping (refer to 5.4.8)
3065 to 3068	6565 to 6568	6705 to 6708	3065 to 3068	4065 to 4068	Position gain of spindle at rigid tapping (refer to 5.4.8)
–	0037#6 = 1		–	–	Stepless time constant selection 5.4.9
–	0254 = 1		5605#1	–	Acc/Dec type (refer to 5.4.9)
0250 0251 0252	(M) 0613	(T) 0415 to 0418	5605#2 5751 5760 5762 5764	5261 5262 5263 5264	Acc/Dec time constant (refer to 5.4.9)
0233 0234 0235	(M) 0617	(T) 0423 to 0426	5605#2 5757 5758 5759	5241 5242 5243 5244	Spindle maximum speed at rigid tapping (refer to 5.4.9)
–	(M only) 0614		5605#2 5752 5761 5763 5765	– – – – –	Low end speed at exponential type (refer to 5.4.9)
0025#1	(M) 0063#4	(T) 29#3	–	5200#4	Override selection at extracting 5.4.9
0137	(M) 0258	(T) 0254	–	5211	Override value at extracting 5.4.9
–		(T) 0419 to 0422	–	5201#2 5271 to 5274	Time constant at extracting (refer to 5.4.9)

Parameter number					Remarks
Power Mate	0M/T/TT		15M/T	16/18 M/T/TT	
	Fst. sp	Snd. sp			
0255	(M) 0618	(T) 400	1827	5300	In-position width of tapping axis
0256	(M) 0619	(T) 401	5755	5301	In-position width of spindle
0257	(M) 0620	(T) 402	1837	5310	Allowable level of position error of tapping axis at moving
0258	(M) 0621	(T) 403	5754	5311	Allowable level of position error of spindle at moving
0259	(M) 0622	(T) 404	–	5312	Allowable level of position error of tapping axis at stop
0260	(M) 0623	(T) 405	–	5313	Allowable level of position error of spindle at stop
0135	(M) 0255	(T) 0214 to 0217	5604#2 5756 5791 to 5794	5321 to 5324	Backlash of spindle (refer to 5.4.11)
3044 3045	6544 6545	6684 6685	3044 3045	4044 4045	Velocity loop proportional gain at rigid tapping
3052 3053	6552 6553	6692 6693	3052 3053	4052 4053	Velocity loop integral gain at rigid tapping
3085	6585	6725	3085	4085	Motor voltage at rigid tapping 5.4.10
3137	6901	6941	3281	4137	Motor voltage at rigid tapping (low speed)
3099	6599	6739	3099	4099	Delay time for stable motor excitation (5.4.10)

5.6 Operation Check

5.6.1 Check of the position error value of the spindle at rigid tapping.

(1) Check whether the spindle rotates at rigid tapping speed or not.
When the spindle does not rotate at rigid tapping speed, check the following parameters.

- The parameter relating to the arbitrary gear ratio
- The parameter relating to the position coder pulse number

(2) Check whether the error pulse of the spindle is the same as the calculated error pulse at the rigid tapping speed.
The error pulse of the spindle is checked by the diagnosis (refer to Item 5.7).

The calculation of the error pulse is as follows.

Nr : Spindle speed at rigid tapping [min^{-1}]
Pg : Position gain [sec^{-1}]
Prev : Detection unit (=4096 pulse/rev)

$$\text{Error pulse} = \frac{Nr}{60} \times Prev \times \frac{1}{Pg} \text{ [pulse]}$$

When the pulse number which you checked at diagnosis is different from that you calculated, check the following parameters.

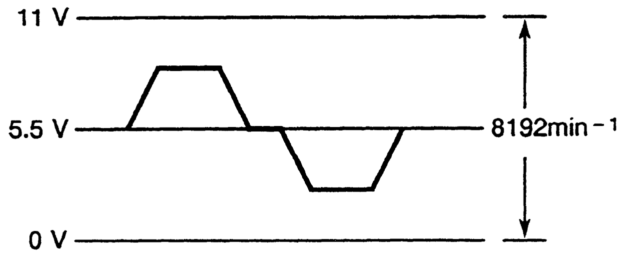
- Position gain
- Gear ratio parameter between the spindle and the motor
- The parameter relating to the position coder pulse number

5.6.2 Check the spindle motor velocity error during the rigid tapping.

There is no check terminal of the ordinary TSA, ER in the serial spindle. On the contrary, the velocity signal and velocity error signal can be measured at LM and SM terminal by setting data using 4 switches as the next page.

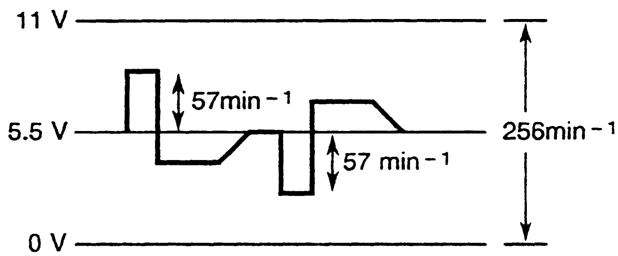
About details of the data setting method to check the internal data, refer to FANUC AC Spindle Servo Motor Descriptions B-65042/03 Appendix 5.

	Setting data
d-05 (Channel)	19 (Motor speed)
d-06 (Shift data)	17
d-07 (Shift direction)	0
d-08 (Offset)	1
	8192 min^{-1}/11 V



d-06 (Shift data) = 16 ⇒ 4096 min^{-1}/11 V
d-05 (channel) = 16 (Velocity command)

	Setting data
d-09 (Channel)	25 (Velocity error)
d-10 (Shift data)	12
d-11 (Shift direction)	0
d-12 (Offset)	1
	256 min^{-1} /11 V



d-10 (shift data) = 11 ⇒ 128 min^{-1}/11 V

In S series spindle, the rigid tapping possible error level is less than 0.3V to 0.4V. This value is equivalent to 43 to 57 min^{-1} velocity error in case of 6000 min^{-1} motor.

Error voltage × Maximum speed ÷ 4.17 ÷ 10 = Velocity error (min^{-1})
(0.3V to 0.4V) × 6000 ÷ 4.17 ÷ 10 = 43 to 57 min^{-1}

This velocity error level is equivalent to ±2 V for the serial spindle when the measuring data setting is 256 min^{-1}/11 V.

Adjust the position gain, velocity loop proportional and integral gain, and the motor voltage (usually 100%) parameters in order that there is no velocity over shoot and the velocity error becomes less than ±2 V.

Set the velocity integral gain as 5 times large as the velocity proportional gain, for the rigid tapping standard setting.

5.7 Diagnosis

(1) Power Mate

Diagnosis number	Contents	Unit
3040	Position error pulse of the tapping axis	Pulse

The contents below is shown in the parameter display.
The parameter address below is used for monitoring.

Parameter number	Contents	Unit
0264	Position error pulse of the spindle	Pulse
0265	Interpolation pulse of the spindle	Pulse
0318	Integrated interpolation pulse of the spindle	Pulse

(2) Series 0C

Diagnosis number		Contents		Unit
Machining	Turning	Machining	Turning	
0800	0800	Position error of X axis	Position error of X axis	Pulse
0801	0801	Position error of Y axis	Position error of Z axis	Pulse
0802		Position error of Z axis		Pulse

The contents below is shown in the parameter display.
The parameter address below is used for monitoring.

Parameter number		Contents	Unit
Machining	Turning		
0627	0435	Position error pulse of the spindle	Pulse
0628	0436	Interpolation pulse of the spindle	Pulse
0696	0437	Instant value of the position error difference between the tapping axis and the spindle	%
0697	0438	Maximum value of the position error difference between the tapping axis and the spindle	%
0799		Integrated interpolation pulse of the spindle	Pulse

(3) Series 15

Address	Contents	Unit
3000	Position error pulse of the tapping axis	Pulse
	Position error pulse of the spindle	Pulse

(4) Series 16/18

Address	Contents	Unit
0300	Position error pulse of the tapping axis	Pulse
0450	Position error pulse of the spindle	Pulse
0451	Interpolation pulse of the spindle	Pulse
0452	Instant value of the position error difference between the tapping axis and the spindle	%
0453	Maximum value of the position error difference between the tapping axis and the spindle	%
0454	Integrated interpolation pulse of the spindle	Pulse

5.8 Alarm

5.8.1 Program error (P/S alarm)

(1) Power Mate, Series 0C, Series 16/18

Alarm number	Contents
200	S command is over the range or not inputted.
201	F command is not inputted.
202	The interpolation pulse for the spindle is over the range.
203	The commanded place of M29 or S command is not proper.
204	The axis move command is inserted between M29 and G84 (G74).
205	The rigid mode DI signal is not ON during G84 (G74) although M29 is commanded. The rigid mode DI signal goes OFF during the rigid tapping.
206	The plane change is commanded during the rigid tapping.

5.8.2 Servo alarm

(1) Power Mate

Alarm number	Contents
408	The communication failure with the serial spindle occurs. · The power of the serial spindle is off. · The optical cable is disconnect.
409	The alarm occurs at the serial spindle side. · Check the alarm number on the display of the serial spindle control board.
410	The position error of the tapping axis at stop exceeds the alarm level.
411	The position error of the tapping axis at moving exceeds the alarm level.
490	The position error of the spindle at stop exceeds the alarm level (No. 260)
491	The position error of the spindle at moving exceeds the alarm level (No. 258)

(2) Series 0C

Alarm number	Contents
408	The communication failure with the serial spindle occurs. · The power of the serial spindle is off. · The optical cable is disconnect.
409	The alarm occurs at the serial spindle side. · Check the alarm number on the display of the serial spindle control board.
4□0 (*1)	The position error of the tapping axis or the spindle at stop exceeds the alarm level.
4□1 (*1)	The position error of the tapping axis or the spindle at moving exceeds the alarm level.

(*1) □ = 1, 2, 3 is corresponding to the tapping axis.
In Machining, 1 = X, 2 = Y, 3 = Z, In Turning, 1 = X, 2 = Z.
These alarms of the spindle are common with the tapping axis.

(3) Series 15

Alarm number	Contents
OT3□□	The alarm occurs at the serial spindle side. · Check the alarm number on the display of the serial spindle control board.
SV008	The position error of the tapping axis at stop exceeds the alarm level.
SV009	The position error of the tapping axis at moving exceeds the alarm level.
SV31	The position error of the spindle exceeds the alarm level (5757).

(4) Series 16/18

Alarm number	Contents
408	The communication failure with the serial spindle occurs. · The power of the serial spindle is off. · The optical cable is disconnect.
409	The alarm occurs at the serial spindle side. · Check the alarm number on the display of the serial spindle control board.
410 (*1)	The position error of the tapping axis or the spindle at stop exceeds the alarm level.
411 (*1)	The position error of the tapping axis or the spindle at moving exceeds the alarm level.

(*1) These alarms of the spindle are common with the tapping axis.

6. SERIAL SPINDLE RIGID TAPPING TECHNICAL MANUAL (NO. 2)

This manual describes the outline of the rigid tapping and the adjusting method of the spindle side.

6.1 The Outline of the Rigid Tapping

(1) About the Acc/Dec time constant and the Spindle maximum speed at right tapping.
The Acc/Dec time constant and the Spindle maximum speed at rigid tapping depend on the tap diameter, spindle speed, feed speed, and the spindle Acc/Dec capacity.
The spindle Acc/Dec capacity depends on the spindle motor output power and the spindle inertia. So, it is necessary to set the proper parameter for each machine according to the spindle Acc/Dec capacity.

(2) About the judgement of the serial spindle rigid tapping.
Generally, the capacity of the rigid tapping depends on the spindle Acc/Dec capacity. When the Acc/Dec time constant at rigid tapping is set according to the spindle side, the tapping axis side has enough Acc/Dec torque. And the tapping axis has enough response to the motion command. Please refer the following example.

(Example) Tapping axis side: Rapid feed = 20000 mm/min (20 m/min), time constant = About 100 to 200 msec.
Spindle side: 2000 min^{-1}, Acc/Dec time = About 500 to 1000 msec.
Rigid tapping condition: S2000, F2000 (2000 mm/min)
In this case, the tapping axis needs about 1/10 of the Acc/Dec torque compared with the rapid feed.

(Example) Tapping axis side system: 1μ/1p (10000 p/rev)
Rigid tapping condition: When the spindle rotates 1 rev, the tapping axis feeds 1 mm.
In this case, when the spindle rotates 1 rev, the tapping axis feedback pulses are 1000 p. In other words, when the spindle rotates 1 rev, the motor of tapping axis rotates 1/10 rev.

* The synchronous error between the spindle and tapping axis at the rigid tapping make smaller, the velocity loop control method of the tapping axis side is PI control better than IP control.

In spindle side, it is necessary to improve the velocity loop response because the spindle side is used in maximum Acc/Dec capacity area.
The velocity error is used for the judgement of velocity loop response
So, the velocity error becomes smaller by adjusting velocity loop gain, and we have enough accuracy of the synchronous error between the spindle and the tapping axis.

The accuracy of the synchronous error between the spindle and the tapping axis is about 20 to 30 μ at the spindle 1 rev. (Condition: When the spindle rotates 1 rev, the tapping axis feed 1 mm). (The gear ratio between spindle and spindle motor is 1:1)
When the total accuracy of the synchronous error between the spindle and the tapping axis is

less than 50 μ at the spindle 1 rev (Include the mechanical loss), we will be able to get JIS:2 class tap.

(3) Improve the rigid tapping capacity

For the reduction of the rigid tapping cycle time, it is necessary to shorten the time constant at rigid tapping, or, it is necessary to raise the spindle speed/feed speed.

To realize, it is necessary to improve the spindle Acc/Dec capacity. (Up spindle output power or down the spindle inertia.) Please refer to the next page examples.

[Example of the rough calculation at the rigid tapping]

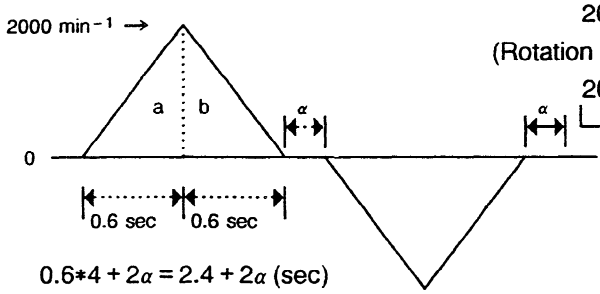
Tap is M6×1 mm

The roughly estimated cycle time in case of S2000, F2000, Z-20.

(In-position time: α, the delay of the velocity loop etc is ignored.)

(To shorten the in-position time: α, it is better that the position gain is high and the in-position level is wide.)

i) The time constant of the rigid tapping is 600 msec from 0 to 2000 min^{-1}.



20 mm/1 mm = 20 rev = (a + b)

(Rotation number of the spindle from R point to Z point)

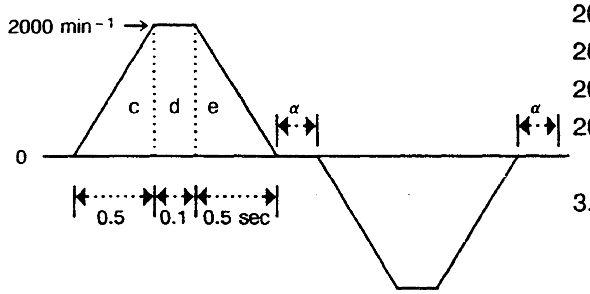
$2000\ min^{-1}/60\ sec * 0.6\ sec = 20\ rev = (a + b)$

(rev/sec)

$0.6*4 + 2\alpha = 2.4 + 2\alpha$ (sec)

ii) The time constant of the rigid tapping is 500 msec from 0 to 2000 min^{-1}.

(The spindle Acc/Dec capacity is improved at 1.2 times.)



20 mm/1 mm = 20 rev = (c + d + e)

$2000\ min^{-1}/60 sec * 0.5\ sec = 16.7\ rev = (c + e)$

20 rev − 16.7 rev = 3.3 rev = (d)

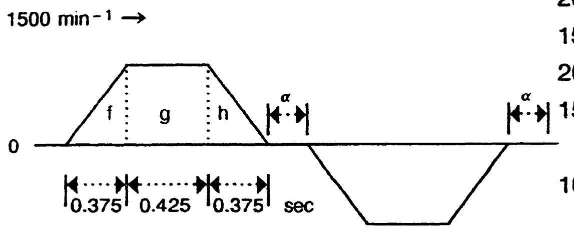
$2000\ min^{-1}/60\ sec = 33.3$ rev/sec

↓

3.3 rev/0.1 sec

$0.5*4 + 0.1*2 + 2\alpha = 2.2 + 2\alpha$ (sec) → It is possible to shorten 0.2 sec compared with the i) condition.

iii) The time constant of the rigid tapping is 375 msec at 0 to 1500 min^{-1}.
(The spindle Acc/Dec capacity is the same as ii) condition)
Tap is M6×1 mm
The roughly estimated cycle time in case of S1500, F1500, Z-20.



20 mm/1 mm = 20 rev = (f + g + h)
1500 min^{-1}/60sec*0.375 sec = 9.375 rev = (f + h)
20 rev − 9.375 rev = 10.625 rev = (g)
1500 min^{-1}/60 sec = 25 rev/sec
↓
10.625 rev/0.425 sec

$0.375*4 + 0.425*2 + 2\alpha = 2.35 + 2\alpha$ (sec) → When the spindle speed/feed speed is reduced, the cycle time becomes longer 0.15 sec than ii) condition.

6.2 Rigid Tapping Adjusting Method of the Spindle Side.

Generally, the capacity of the rigid tapping depend on the spindle Acc/Dec capacity. Because, the time constant of the spindle is bigger than the time constant of tapping axis. (The time constant at rigid tapping must be longer than the spindle Acc/Dec time) This manual described the rigid tapping adjusting method of the spindle side in order to improve the capacity of the rigid tapping.

(1) The calculation of the Acc time.
To set the time constant at rigid tapping, we calculate the Acc time from 0 min^{-1} to the spindle maximum speed at the rigid tapping.

Spindle maximum speed at the rigid tapping	= Nr (min^{-1})
30 min rated output at the spindle maximum speed at the rigid tapping	= Pr (kW)
Total inertia of the spindle (J = JL + Jm)	= J(kg ·cm · sec^2)
30 min rated torque at the spindle maximum speed at the rigid tapping	= T (kg·m)
	= Pr*1000/Nr/1.0269

$$tr\ (sec) = \frac{J}{T*1000} * \frac{2\pi}{60} * Nr$$

(2) The measurement of the Acc time.
We have different the Acc time data between the calculation data and measurement data because of the difference of load inertia, the effect of load friction loss and so on.
To set the time constant at rigid tapping, we measure the Acc time from 0 min^{-1} to the spindle maximum speed at the rigid tapping.

Series 16 PRM5241 to 5244
↑
(Example: In case of the spindle maximum speed at the rigid tapping is 3000 min^{-1})
(Unit: min^{-1})

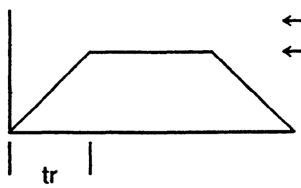
About details of the data setting method to check the internal data, please refer the AC SPINDLE MOTOR DESCRIPTION: B-65042E/03 or later Appendix 5.

Please measure the motor speed at the SM terminal.

d-09 = 19
d-10 = 16
d-11 = 0
d-12 = 0

4096 min^{-1}/11 V

TSA



← 11 V (4096 min^{-1})
← 8 V (3000 min^{-1}) = 3000/4096*11 V
← 0 V (0 min^{-1})

Motor rotates CCW.
(SFR = 1)

Series 16 PRM5261 to 5264
↑
The time constant at the rigid tapping is set to 1.2 to 1.5 times of the Acc time.
(Unit: msec)

(3) Position gain parameter setting

Series 16 PRM4065 to 4068 ←

- In case of the built-in spindle, Position gain is set to 30 sec^{-1}. (Parameter setting value = 3000)
- In case of the spindle system linked by the gear or belt, Position gain is set to 20 to 25 sec^{-1} (Parameter setting value = 2000 to 2500)

(4) Parameter setting related to the spindle system

PRM4056 to 4059 ←

- The spindle system linked by the gear or belt, it is necessary to set the gear ratio parameter.
- The spindle system linked by the gear or belt and the spindle motor with the built-in sensor, it is necessary to set the PRM4006#7 = 1 (Series 16) and the arbitrary gear ratio parameter.

(5) Motor voltage parameter setting

PRM4085 ←

- Motor voltage parameter at the rigid tapping, Initial setting = 30 → Please try the setting about 70 to 100. (If the motor exciting noise is big, the setting is about 30 to 70.)

(6) Delay time for stable motor excitation,

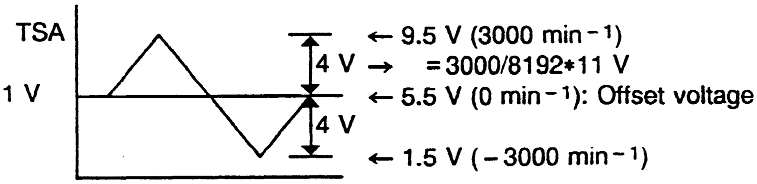
PRM4099 ←

- Please set to 250 to 400. (Unit: msec)

(7) Velocity loop gain parameter setting.
We measure the motor speed and velocity error of the spindle motor during the rigid tapping at the non load.

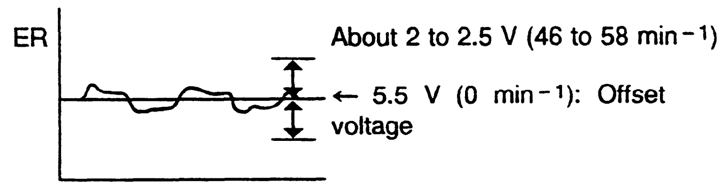
[Examples]
Please measure the motor speed at the SM terminal.

d-09 = 19 d-10 = 17 d-11 = 0 d-12 = 1	8192 min^{-1}/11 V



Please measure the velocity error at the LM terminal.

d-05 = 25 d-06 = 12 d-07 = 0 d-08 = 1	256 min^{-1}/11 V



The velocity error becomes smaller by adjusting velocity loop gain, we have enough accuracy of the synchronous error between the spindle and the tapping axis.
The velocity error level should be less than about 2 to 2.5 V (46 to 58 min^{-1}).
The spindle response is higher when the velocity error is smaller and smaller.

Series 16
PRM4044 ←
PRM4045

- <u>Velocity loop proportional gain at the rigid tapping</u> is set without the spindle oscillation.
(The setting parameter) = (The setting of the spindle oscillation level)*(0.7 to 0.8)
Initial setting = 10 → Please try the setting about 15 to 25.

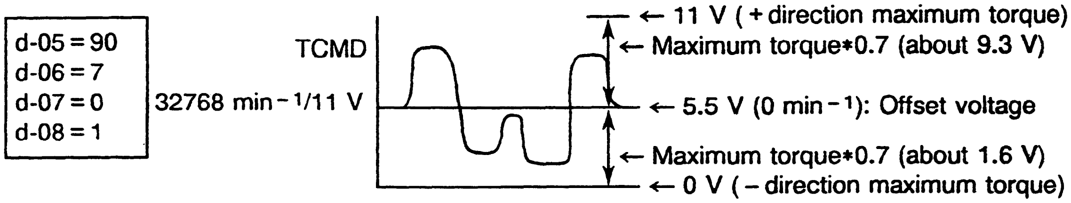
PRM4052 ←
PRM4053

- <u>Velocity loop integral gain at the rigid tapping</u> is set as 3 to 5 times large as the velocity loop proportional gain at the rigid tapping.

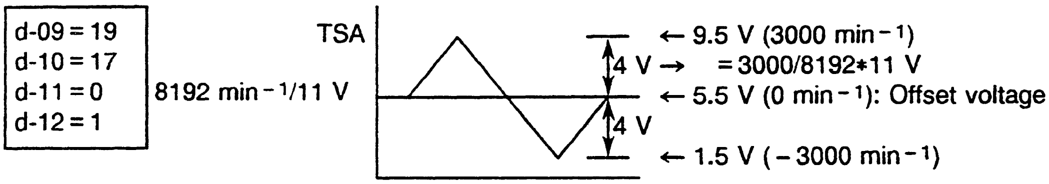
(8) Check the torque command
(Total torque at the rigid tapping) = (Acc/Dec torque) + (Cutting torque)
So we have to check the margin of the torque against the maximum torque.
If we have not enough margin of the torque, we have to change the time constant parameter more longer. And the cutting torque became big because of the tap diameter or the work material, we have to change the time constant parameter more longer.

[Examples]

Please measure the torque command at the LM terminal.



Please measure the motor speed at the SM terminal.



(9) Check of the position error value of the spindle at the rigid tapping

The calculation of the error pulse is as follows.

Nr : Spindle speed at rigid tapping [min^{-1}]
(In the case of the spindle motor with the built-in sensor: Nr = spindle motor speed)

PG : Position gain [sec^{-1}]

Prev : Detection unit (= 4096 pulse/sec)

Series 16

DGN450 ← Error pulse = Nr/60*Prev/PG [pulse] (The error pulse is checked by the diagnosis)

(10) Check the rigid tapping actual cutting.

If you can not get an acceptable result, it is necessary to check again the time constant parameter, the position gain parameter etc.

[Citation]

About details of the parameter setting and diagnosis, please refer to the Technical report No. TMS 92/031E "SERIAL SPINDLE RIGID TAPPING TECHNICAL MANUAL" (Issued Aug, 1992)

7. ITEMS CONCERNING SPINDLE ORIENTATION WITH A POSITION CODER

7.1 DI and DO Signals

7.1.1 DI signals (PMC → CNC)

	PM	OC	15	16	7	6	5	4	3	2	1	0
1st : 2nd :		G110 G112	G231 G239	G078 G080	SHA07	SHA06	SHA05	SHA04	SHA03	SHA02	SHA01	SHA00
1st : 2nd :		G111 G113	G230 G238	G079 G081					SHA11	SHA10	SHA09	SHA08
1st : 2nd :	G112	G229 G234	G227 G235	G070 G074	MRDYA	ORCMA	SFRA	SRVA	CTH1A	CTH2A	TLMHA	TLMLA
1st : 2nd :	G113	G230 G234	G226 G234	G071 G075	RCHA	RSLA	INTGA	SOCNA	MCFNA	SPSLA	*ESPA	ARSTA
1st : 2nd :		G231 G235	G229 G237	G072 G076				OVRA	DEFMDA	NRROA	ROTAA	INDXA

7.1.2 DO signals (CNC → PMC)

	PM	OC	15	16	7	6	5	4	3	2	1	0
1st : 2nd :	F228	F281 F285	F229 F245	F045 F049	ORARA	TLMA	LDT2A	LDT1A	SARA	SDTA	SSTA	ALMA
1st : 2nd :	F229	F282 F286	F228 F244	F046 F050					RCFNA	RCHPA	CFINA	CHPA

7.2 Spindle Orientation Parameters (Number following #: Bit number)

Parameter No.				Description
PC	0C	15	16	
3015	6515	3015	4015	Specifies whether to use the spindle orientation function. (Set #0 to 1.) The CNC software option is required.
–	0080	5609	3702	Specifies whether to use the spindle orientation function with the stop position set externally. (#2 for the 1st spindle and #3 for the 2nd spindle)
3001	6501	3001	40001	Specifies whether to use the position coder signal. (Set #2 to 1 when using the signal.)
3000	6500	3000	4000	Orientation of the position coder (#2)
3003	6503	3003	4003	Selects use of a position coder or magnetic sensor for the orientation function. Set #0 to 0 when using a position coder.
3003	6503	3003	4003	Direction of rotation in spindle orientation (#2 and #3)
3003	6503	3003	4003	Specifies the number of pulses of a position coder. (#4, #6, and #7)
3031	6531	3031	4031	Stop position in orientation with a position coder This data item is disabled when using the function with the stop position externally set.
3042 3043	6542 6543	3042 3043	4042 4043	Proportional gain of the velocity loop in spindle orientation This data item is selected by CTH1A in the DI signal from PMC.
3050 3051	6550 6551	3050 3051	4050 4051	Integral gain of the velocity loop in spindle orientation This data item is selected by CTH1A in the DI signal from PMC.
3056 ~ 3059	6556 ~ 6559	3056 ~ 3059	4056 ~ 4059	Gear ratio of the spindle to the motor
3060 ~ 3063	6560 ~ 6563	3060 ~ 3063	4060 ~ 4063	Position gain in spindle orientation
3064	6564	3064	4064	Change rate of the position gain when spindle orientation is completed
3075	6575	3075	4075	Level for detecting the spindle orientation completion signal (ORARA)
3076	6576	3076	4076	Motor velocity limit in spindle orientation
3077	6577	3077	4077	Shift of the stop position in spindle orientation
3084	6584	3084	4084	Motor voltage in spindle orientation

7.3 Adjusting the Serial Spindle Orientation

(1) Adjustment procedure for spindle orientation with a position coder (not covering shortest-time orientation) and spindle orientation with a magnetic sensor

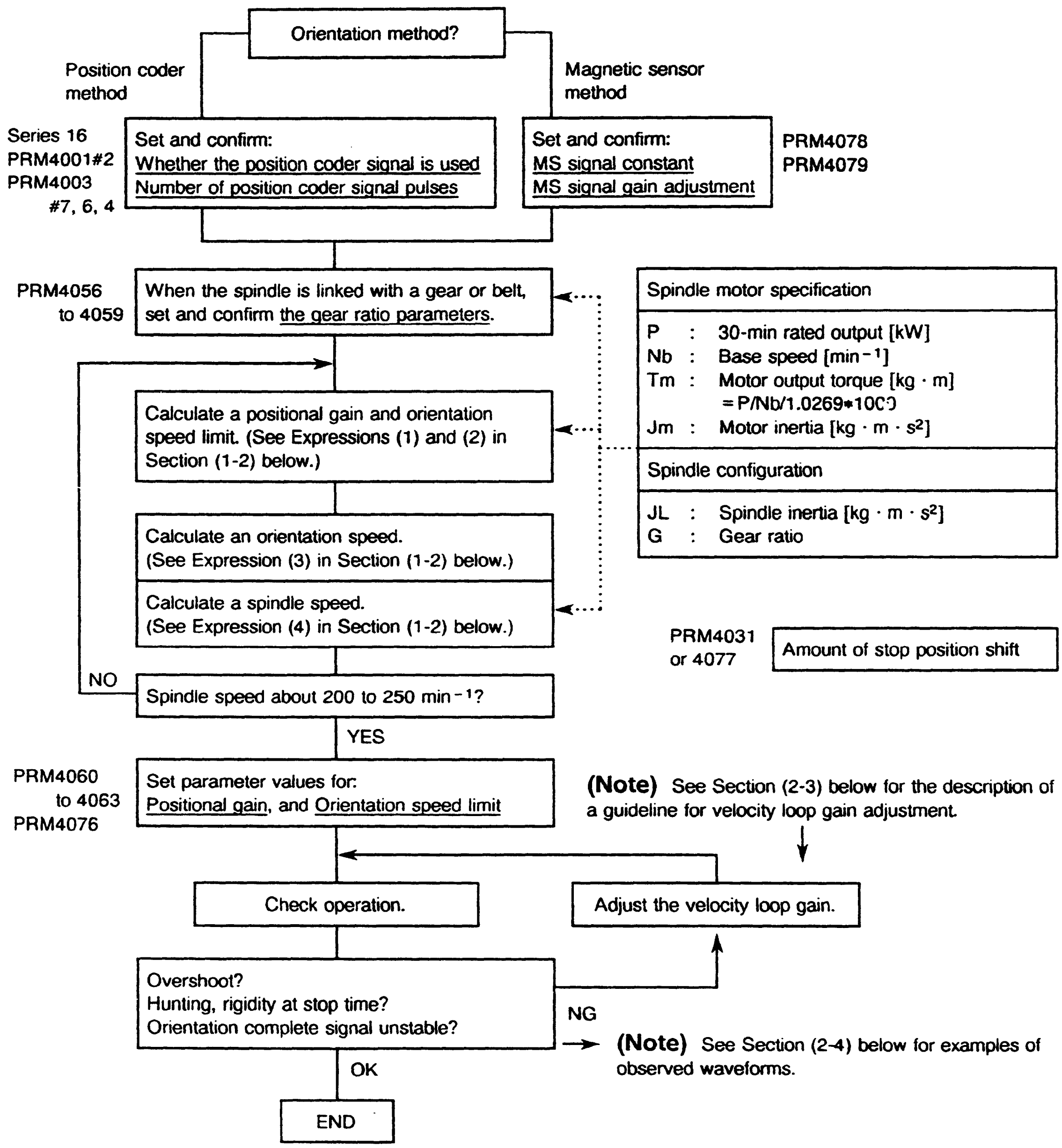
The parameter numbers described below are for Series 16.

Series 0: PRM65xx, Series 15: PRM30xx

↑

(The last two digits (indicated by xx) hold the same values as for Series 16.)

(1-1) Adjustment procedure



(1-2) Calculating the positional gain and orientation speed limit

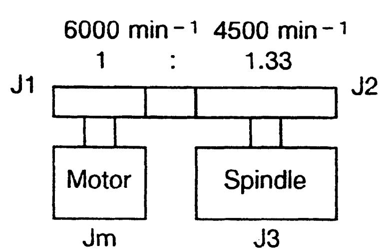
From the output specifications of the spindle motor and the inertia of the spindle system, an approximate positional gain and orientation speed limit can be calculated using Expressions (1) through (4) below. Of those positional gain and orientation speed limit combinations that produce spindle speeds from 200 to 250 min^{-1}, set the values of the combination that allows the maximum positional gain to be set. (See the example below.)

Positional gain (sec^{-1}) = $\sqrt{\dfrac{Tm*100}{2\pi*(Jm+JL)*(\text{gear ratio})*(\text{orientation speed limit})}}$		····· (1)
Orientation speed limit = $\dfrac{Tm*100}{2\pi*(Jm+JL)*(\text{gear ratio})*(\text{positional gain})^2}$		····· (2)
Orientation speed (min^{-1}) = 60*(positional gain(sec^{-1})*(gear ratio)*(orientation speed limit)/100		····· (3)
Spindle speed = orientation speed/gear ratio	(The orientation speed is the speed of the spindle motor.)	····· (4)

Gear ratio = GEAR/GEARUNIT: GEAR = gear ratio parameter → Series 16: PRM4056 - 4059
GEARUNIT = 100 → Series 16: PRM4006#1 = 0, GEARUNIT = 1000 → PRM4006#1 = 1
Tm: Torque [kg · m] = P/Nb/1.0269*1000
(Nb = Base speed [min^{-1}], P = 30-min rated output [kW])
Jm: Motor inertia [kg · m · s^2], JL = Load inertia [kg · m · s^2]

Example: Example of calculation when model 6S is used, and the spindle configuration is such that the gear ratio is 1:1.33.

Nb : Base speed [min^{-1}] = 1500
P : 30-min rated output [kW] = 7.5
Tm : Torque [kg · m] = P/Nb/1.0269*1000 = 4.86
Jm : Motor inertia [kg · m · s^2] = 0.0022
J1 : Pulley inertia on the motor = 0.0011
J2 + J3 : Inertia on the spindle = 0.0058
→ Load inertia converted to motor shaft inertia = $(J2+J3)*(1/1.33)^2$ = 0.0033
JL : $J1+(J2+J3)*(1/1.33)^2$ = 0.0044
Jm + JL: Spindle inertia [kg · m · s^2] = 0.0066



Positional gain (sec^{-1})	Orientation speed limit (%)	Orientation speed (min^{-1})	Spindle speed (min^{-1})
10	33	263	198
16	33	421	316
20	22	351	264
<u>25</u>	<u>14</u>	279	210 (*)
30	9	215	162

When the parameters are set to the initial values, an orientation speed and spindle speed are calculated from Expressions (3) and (4).

When the limit is 33%, the maximum allowable positional gain is calculated from Expression (1).

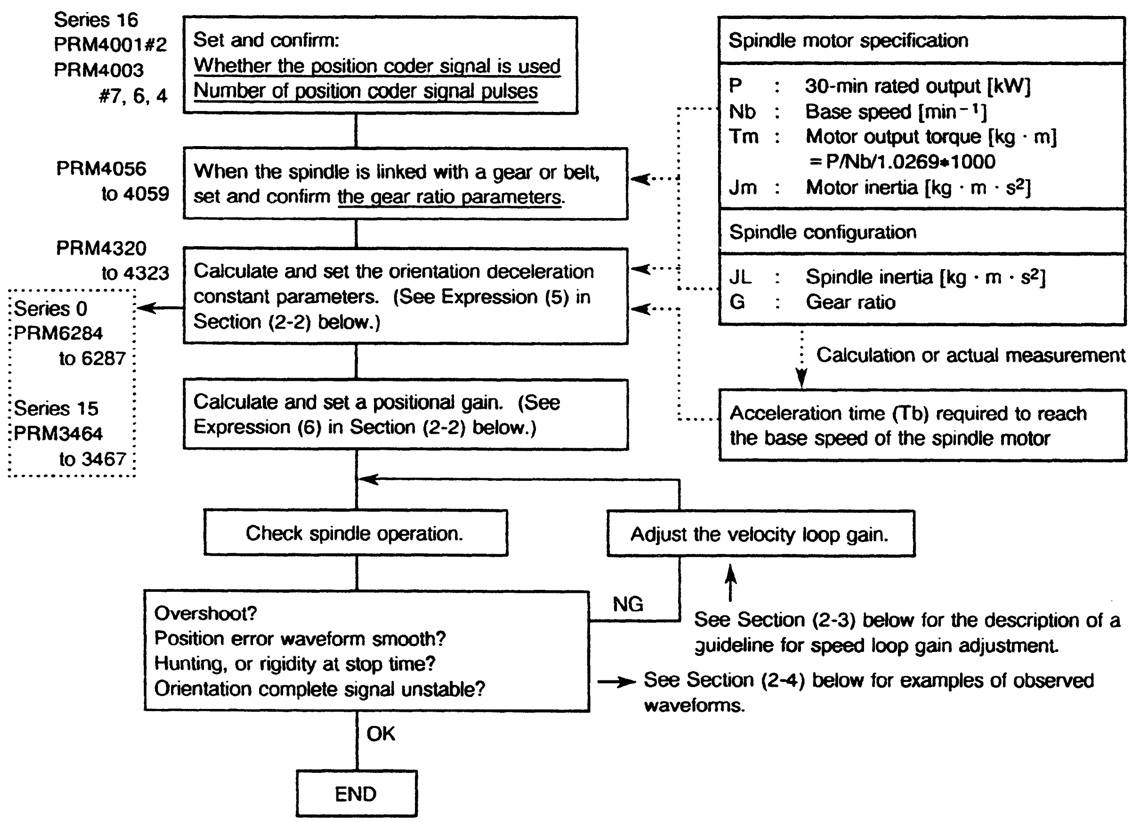
When the positional gain is 20 sec^{-1} to 30 sec^{-1}, a limit is calculated from Expression (2).

(*) Combination that produces a spindle speed from 200 min^{-1} to 250 min^{-1}, and allows a maximum positional gain to be set

Thus, in this example, set the positional gain to 25 (parameter setting = 2500) and the orientation speed limit to 14, then check the spindle operation. (In some cases these values cannot be set because of the rigidity of the belt, etc..)

(2) Adjustment procedure for shortest-time spindle orientation control with a position coder

(2-1) Adjustment procedure



(2-2) Calculating and setting the orientation deceleration constant parameter/positional gain parameter

- The acceleration time, Tb [sec], required to reach the base speed of the spindle motor can be calculated from the output specifications of the spindle motor and spindle inertia.

$$Tb = (Jm + JL)/Tm * 2\pi/60 * Nb \text{ [sec]}$$

- When the inertia of the spindle system is unknown, measure the acceleration time (Tb) required to reach the base speed.

	Value of orientation deceleration constant parameter $= \sqrt{\frac{Nb}{Tb} \times \frac{120}{1} \times \frac{GEAR}{GEARUNIT}} \times (0.8 \text{ to } 0.9)$	··· (5)
PRM4060 to 4063	Positional gain parameter = (value of orientation deceleration constant parameter) $\times 106\sqrt{205}$	··· (6)

- An overshoot can be reduced by increasing the values of the proportional gain and integral gain of the velocity loop in spindle orientation parameters.

- If an overshoot is observed, decrease the value of the orientation deceleration constant parameter and calculate the positional gain again, then check the spindle operation.

- For details about the parameters related to shortest-time orientation, see Part IX.

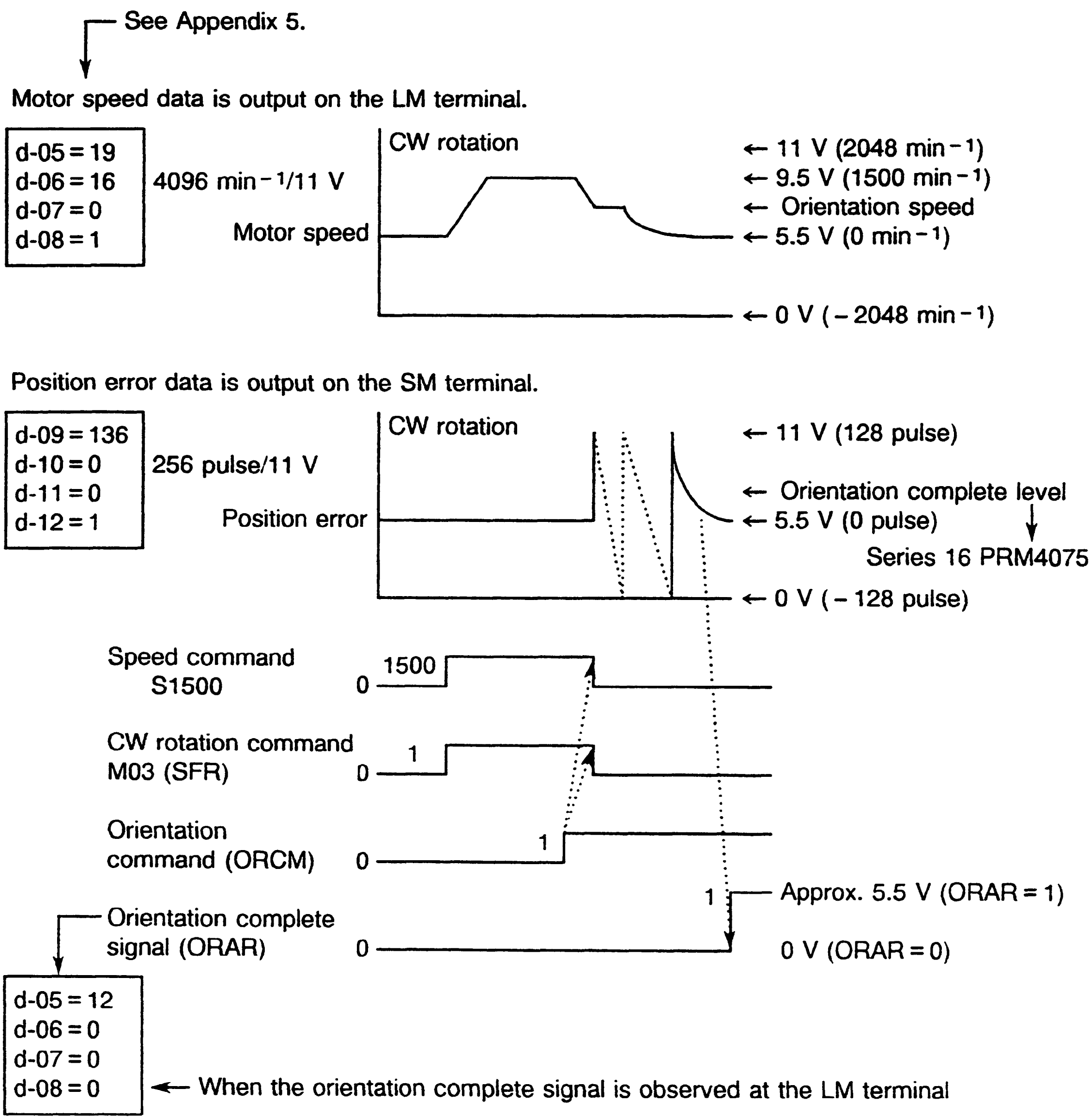
(2-3) Guideline for velocity loop gain adjustment

Series 16 PRM4042 PRM4043 ←
- Increase the proportional gain of the velocity loop in spindle orientation until the spindle starts oscillating (about 70% of the value that causes the motor to oscillate in the orientation stop state.)
(Increase the initial setting (10) to a value from 15 to 25. A higher value can be set when the spindle system has a large inertia.)

PRM4050 PRM4051 ←
- Set an integral gain of the velocity loop in spindle orientation greater than the proportional gain of the velocity loop by a factor or 3 to 5.

- An overshoot can be reduced by increasing the proportional gain (Series 16: 4041, 4042) and integral gain (Series 16: 4048, 4049) of the velocity loop in normal rotation. Increase the initial setting (10) to a value from 15 to 25.

(2-4) Example of observed waveforms (when spindle orientation is performed starting at 1500 min^{-1})



7.4 Adjusting the Parameter Which Indicates the Amount of Shift of Orientation Stop Position

① Display the contents of the position coder counter for position control, which are internal data, by using the following setting:

d-01 = 114
d-02 = 0
d-03 = 0
d-04 = 0

② Enter the orientation command.

③ After an orientation stop, 04096 or, a multiple of 4096 (such as 0, 4096, 8192, and so forth) is displayed.

④ Release the orientation command to stop excitation, and turn off the MCC for safety. (Perform an emergency stop operation.)

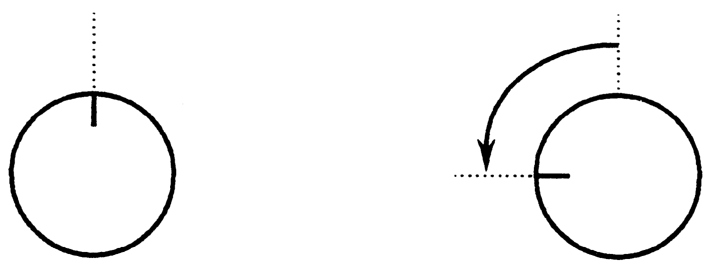
⑤ Turn the spindle manually until it reaches a desired stop position, then read the displayed value.

⑥ Find the difference between the displayed values of ③ and ⑤, and set the difference as the value of the parameter indicating the amount of shift of orientation stop position.

Example:

At the time of orientation stop (③)

When the spindle is manually turned after excitation is stopped (⑤)



Displayed value = 04096

Displayed value = 05120

Amount of orientation stop position shift	=	(displayed value of ⑤)	−	(displayed value of ③)
	=	5120	−	4096
	=	1024		

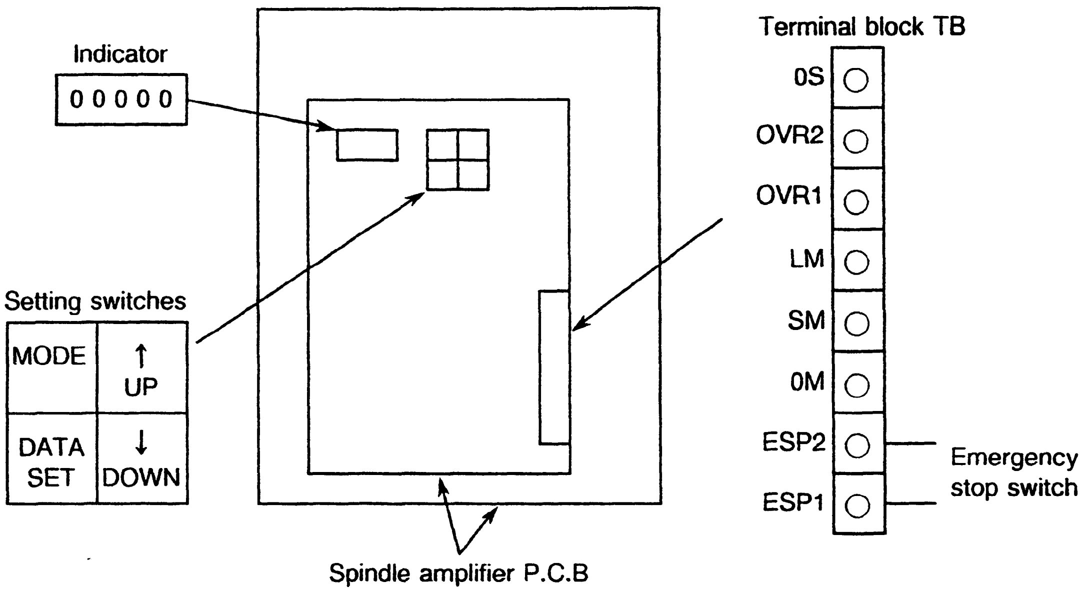
APPENDIX 4 METHOD FOR OPERATING THE SPINDLE MOTOR USING A SERIAL SPINDLE AMPLIFIER INSTEAD OF THE CNC

4.1 Outline

This appendix describes the method for operating the spindle motor using a serial spindle amplifier instead of the CNC.

4.2 Configuration

The indicator and setting switches on the PC board of the spindle amplifier are used to perform this function.
The following figure shows the configuration.



4.3 Use

4.3.1 Preparation

(1) Properly connect the power supply, motor power, and signal lines with the PC board of the serial spindle amplifier.

(2) Connect the emergency stop signal (ESP) switch with ESP1 and ESP2 of terminal block TB.

(3) Turn on power to the PC board.

(4) "SU-01" is then displayed on the indicator.

4.3.2 Operation

(1) Simultaneously pressing four setting switches for at least one second causes "FFFFF" to be displayed on the indicator.

(2) Pressing the "MODE" switch displays "d-00" and causes the system to enter the internal data monitor mode.

(3) When the "MODE" switch is released, "d-00" disappears about 0.5 second later, and data is displayed about one second.
The initial value of the data is 0.

(4) Press the "↑ UP" or "↓ DOWN" switch and change the data during the second it is displayed.

(5) If more than one second elapses, the system automatically enters the speed display mode, disabling change in the data. However, turning the "MODE" switch on or off allows the data to be changed.

(6) The following table describes mode d-00.

Mode	Data	Mode name	Indication
d-00	0	Parameter check mode	F-□□□
	1	Internal data monitor mode	0 0 0 0 0
	2	Mode of operation with a serial spindle amplifier	SI-□□
	3	Automatic operation mode	Ad-□□
	4	Parameter change mode	P-□□□
	5	————	————

4.3.3 Operation in the SI mode (mode of operation with a serial spindle amplifier)

Initial setting parameters for the serial spindle motor are automatically loaded using the following procedure in SI mode (mode of operation with a serial spindle amplifier).

(1) Immediately (within about a second) after changing data "d-00" to "00002", press the MODE and DATA SET switches at the same time. "CCCCC" appears about a second later.
Releasing the "MODE" and "DATA SET" switches causes "PLoAd" to appear flashing on the display.

(2) Pressing the MODE switch displays "SI-□□" .

(3) When the MODE switch is released, "SI-□□" disappears about 0.5 second later, and the data appears for about a second.

(4) To change the data, press the "↑ UP" or "↓ DOWN" switches while holding down the "MODE" switch during this second. Next, change the value □□, (the SI number).
The table in (7) shows a description of each number in the SI mode.

(5) If more than one second elapses, the SI number cannot be changed. However, turning on or off the "MODE" switch enables change in the SI number.

(6) Specify initial setting parameter data according to the motor model code using the following procedure.
First, select "SI-18" and enter the desired model code.
Next, select "SI-17" and immediately press and hold down the "↑ UP" and "↓ DOWN" switches at the same time; the indicator will count from "F-000" to "F-355".
When count-up is completed, all parameters have finished being loaded.

(7) The following table shows the description of each number in the SI mode.

SI mode No.	Description	Abbrev.
SI-00		
☆ SI-01	Velocity command	VCMD
SI-02		
SI-03		
SI-04		
☆ SI-05	Command for selecting reverse motor rotation	SRV
☆ SI-06	Command for selecting normal motor rotation	SFR
SI-07		
☆ SI-08	Machine tool ready signal	MRDY
☆ SI-09	Emergency stop signal	ESP
SI-10		
SI-11		
SI-12		
SI-13		
SI-14		
SI-15		
SI-16		
☆ SI-17	Parameter setting (loading)	
☆ SI-18	Model code	
SI-19		
SI-20		
SI-21		
SI-22		
SI-23		
SI-24		
SI-28	Analog override command	OVR

(Note) The numbers marked with an asterisk are used for controlling the motor.

4.3.4 Changing motor model parameters for which no motor code is prepared

When no motor model code is prepared, select "SI-18" and set the model code to 0. Then, select "SI-17" and perform automatic parameter loading using the procedure described in 4.3.3.
After parameter loading is completed, it is necessary to change parameters dedicated to the motor by using the following steps:

(1) Enter P-□□□ (parameter change mode).
Simultaneously pressing the four setting switches for at least a second displays "FFFFF" on the indicator and returns the system to the d-00 mode.
Immediately (within about a second) after changing data "d-00" to "00004", press both the "MODE" and "DATA SET" switches at the same time. "CCCCC" will appear and the system enters the P-□□□ mode.

(2) Pressing the "MODE" switch displays "P-□□□".

(3) When the "MODE" switch is released, "P-□□□" disappears about 0.5 second later. The parameter data appears for about a second.

(4) To change the parameter number in P-□□□, do the following. Press the "↑ UP" or "↓ DOWN" switch while holding down the "MODE" switch to change P-□□□.

(5) To change parameter data, press the "↑ UP" or "↓ DOWN" switches within a second, that is, while the data is displayed.

(6) If more than one second elapses, data cannot be changed. However, turning on, then off the "MODE" switch will allow data to be changed again.

(7) If parameter data is large in magnitude, the place of the digits of the data to be changed can be shifted. See 4.4 for the table of correspondence between CNC parameter numbers and P-□□□ numbers.
To shift the digit place, press the "↑ UP" or "↓ DOWN" switch while holding down the "DATA SET" switch within a second (the second that the data is displayed).

(Note) The parameters specified in the mode of operation with a serial spindle amplifier are erased if power is turned off. They must therefore be specified again after power is turned on.

(8) When specifying bit parameters, use two bit parameters to specify one value for P-□□□.
Specify even address data for the higher bytes of P-□□□ and odd address data for the lower bytes of P-□□□ in hexadecimal in four bit units.

(Example) To specify parameter 6512 (=00000000) and parameter 6513 (=00011010) in Series 0C, set P-006 to 0001A.

(9) To control a motor for which the output can be switched in the low-speed range: specify the low-speed range data in the corresponding parameter for the high-speed range.

4.3.5 Operation

When finished setting parameters, enter the SI mode using the following procedure:

(1) Press the four setting switches simultaneously. "FFFFF" will be display and the system returns to the "d-00" mode.
Immediately (within about a second) after changing "d-00" to "00002", press the "MODE" and "DATA SET" switches at the same time. "CCCCC" will be displayed and the system enters the SI-□□ mode.

(2) Turn on the magnetic contactor in the spindle amplifier using the following procedure.
Turn on the emergency stop (ESP) switch. (Connect ESP1 and ESP2 of terminal block TB.)
Turn on the machine ready signal by doing the following:
Select SI-08 and specify 00001.
Turn on the emergency stop signal by doing the following:
Select SI-08 and specify 00001.
After the above procedure is completed, the magnetic contactor in the spindle amplifier is turned on.

(3) Activate the spindle motor as follows:
Turn on the forward motor rotation command (SFR) by doing the following:
Select SI-06 and specify 00001. (Set SI-05 to 00001 when setting the reverse motor rotation command.)

(4) Input the velocity command.
Specify velocity command data for SI-01.
Setting is specified in min^{-1}.
The digit place for the data to be changed can be shifted according to the procedure in item (7) in 4.3.4.

(5) To stop rotation of the motor, do the following:

A. Turn off the forward motor rotation command (SFR).
(Turn off SRV in the case of the reverse motor rotation command.)
→ Set SI-06 to 00000. (Set SI-05 to 00000 when the reverse motor rotation command is entered.)

B. Specify 0 for the velocity command.
→ Set SI-01 to 00000. In this case, the motor is already activated.

C. Turn off the emergency (ESP) switch.
→ The motor is accelerated and stopped and the MCC in the spindle amplifier is turned off.

D. Turn off the emergency stop signal (SI-09) or machine ready signal (SI-08).

→ Set SI-09 or SI-08 to 00000.

→ The motor is accelerated and stopped and the MCC in the spindle amplifier is turned off.

4.3.6 Parameter table

(a) Parameter for standard motor (Refer to high speed area parameter for motor with speed range switching function)

P-□□□
F-□□□

Power Mate	0 No. 1 Spindle	0 No. 2 Spindle	15 No. 1 Spindle	15TT No. 2 Spindle	16	Standard setting data	Contents	Internal data number
3000	6500	6640	3000	3140	4000	00000000	Bit parameter	000
3001	6501	6641	3001	3141	4001	00000001	Bit parameter	
3002	6502	6642	3002	3142	4002	00000000	Bit parameter	001
3003	6503	6643	3003	3143	4003	00000000	Bit parameter	
3004	6504	6644	3004	3144	4004	00000000	Bit parameter	002
3005	6505	6645	3005	3145	4005	00000000	Bit parameter	
3006	6506	6646	3006	3146	4006	00000000	Bit parameter	003
3007	6507	6647	3007	3147	4007	00000000	Bit parameter	
3008	6508	6648	3008	3148	4008	00000000	Bit parameter	004
3009	6509	6649	3009	3149	4009	00000000	Bit parameter	
3010	6510	6650	3010	3150	4010	00000000	Bit parameter	005
3011	6511	6651	3011	3151	4011	According to motor model	Bit parameter	
3012	6512	6652	3012	3152	4012	According to motor model	Bit parameter	006
3013	6513	6653	3013	3153	4013	According to amplifier model	Bit parameter	
3014	6514	6654	3014	3154	4014	00000000	Bit parameter	007
3015	6515	6655	3015	3155	4015	00000000	Bit parameter	
3016	6516	6656	3016	3156	4016	00000000	Bit parameter	008
3017	6517	6657	3017	3157	4017	00000000	Bit parameter	
3018	6518	6658	3018	3158	4018	00000000	Bit parameter	009
3019	6519	6659	3019	3159	4019	00000000	Bit parameter	
3020	6520	6660	3020	3160	4020	According to motor model	Maximum speed	010
3021	6521	6661	3021	3161	4021	100	Maximum speed in Cs contouring control	011
3022	6522	6662	3022	3162	4022	150	Speed arrival level	012
3023	6523	6663	3023	3163	4023	30	Speed detecting level	013
3024	6524	6664	3024	3164	4024	75	Speed zero detecting level	014

P-□□□
F-□□□

Power Mate	0 No. 1 Spindle	0 No. 2 Spindle	15 No. 1 Spindle	15TT No. 2 Spindle	16	Standard setting data	Contents	Internal data number
3025	6525	6665	3025	3165	4025	50	Setting of torque limit value	015
3026	6526	6666	3026	3166	4026	83	Load detecting level 1	016
3027	6527	6667	3027	3167	4027	95	Load detecting level 2	017
3028	6528	6668	3028	3168	4028	0	Output limit pattern setting	018
3029	6529	6669	3029	3169	4029	100	Output limit value	019
3030	6530	6670	3030	3170	4030	0	Soft start/stop setting time	020
3031	6531	6671	3031	3171	4031	0	Position coder method orientation stop position	021
3032	6532	6672	3032	3172	4032	0	Acceleration/deceleration time constant at spindle synchronization control	022
3033	6533	6673	3033	3173	4033	10	Spindle synchronization speed arrival level	023
3034	6534	6674	3034	3174	4034	0	Shift amount at spindle phase synchronization control	024
3035	6535	6675	3035	3175	4035	10	Spindle phase synchronization compensation data	025
3036	6536	6676	3036	3176	4036	0	Feedforward coefficient	026
3037	6537	6677	3037	3177	4037	0	Velocity loop feedforward coefficient	027
3038	6538	6678	3038	3178	4038	0		028
3039	6539	6679	3039	3179	4039	0		029
3040	6540	6680	3040	3180	4040	10	Velocity loop proportion gain on normal operation (HIGH)	030
3041	6541	6681	3041	3181	4041	10	Velocity loop proportion gain on normal operation (LOW)	031
3042	6542	6682	3042	3182	4042	10	Velocity loop proportion gain on orientation (HIGH)	032
3043	6543	6683	3043	3183	4043	10	Velocity loop proportion gain on orientation (LOW)	033
3044	6544	6684	3044	3184	4044	10	Velocity loop proportion gain on servo mode (HIGH)	034
3045	6545	6685	3045	3185	4045	10	Velocity loop proportion gain on servo mode (LOW)	035
3046	6546	6686	3046	3186	4046	30	Velocity loop proportion gain in Cs contouring control (HIGH)	036
3047	6547	6687	3047	3187	4047	30	Velocity loop proportion gain in Cs contouring control (LOW)	037
3048	6548	6688	3048	3188	4048	10	Velocity loop integral on normal operation (HIGH)	038
3049	6549	6689	3049	3189	4049	10	Velocity loop integral on normal operation (LOW)	039

P-□□□
F-□□□

Power Mate	0 No. 1 Spindle	0 No. 2 Spindle	15 No. 1 Spindle	15TT No. 2 Spindle	16	Standard setting data	Contents	Internal data number
3050	6550	6690	3050	3190	4050	10	Velocity loop integral gain on orientation (HIGH)	040
3051	6551	6691	3051	3191	4051	10	Velocity loop integral gain on orientation (LOW)	041
3052	6552	6692	3052	3192	4052	10	Velocity loop integral gain on servo mode (HIGH)	042
3053	6553	6693	3053	3193	4053	10	Velocity loop integral gain on servo mode (LOW)	043
3054	6554	6694	3054	3194	4054	50	Velocity loop integral gain in Cs contouring control (HIGH)	044
3055	6555	6695	3055	3195	4055	50	Velocity loop integral gain in Cs contouring control (LOW)	045
3056	6556	6696	3056	3196	4056	100	Gear ratio (HIGH)	046
3057	6557	6697	3057	3197	4057	100	Gear ratio (MEDIUM HIGH)	047
3058	6558	6698	3058	3198	4058	100	Gear ratio (MEDIUM LOW)	048
3059	6559	6699	3059	3199	4059	100	Gear ratio (LOW)	049
3060	6560	6700	3060	3200	4060	1000	Position gain on orientation (HIGH)	050
3061	6561	6701	3061	3201	4061	1000	Position gain on orientation (MEDIUM HIGH)	051
3062	6562	6702	3062	3202	4062	1000	Position gain on orientation (MEDIUM LOW)	052
3063	6563	6703	3063	3203	4063	1000	Position gain on orientation (LOW)	053
3064	6564	6704	3064	3204	4064	100	Modification rate of position gain on orientation completion	054
3065	6565	6705	3065	3205	4065	1000	Position gain on servo mode (HIGH)	055
3066	6566	6706	3066	3206	4066	1000	Position gain on servo mode (MEDIUM HIGH)	056
3067	6567	6707	3067	3207	4067	1000	Position gain on servo mode (MEDIUM LOW)	057
3068	6568	6708	3068	3208	4068	1000	Position gain on servo mode (LOW)	058
3069	6569	6709	3069	3209	4069	3000	Position gain in Cs contouring control (HIGH)	059

P-□□□
F-□□□

Power Mate	0 No. 1 Spindle	0 No. 2 Spindle	15 No. 1 Spindle	15TT No. 2 Spindle	16	Standard setting data	Contents	Internal data number
3070	6570	6710	3070	3210	4070	3000	Position gain in Cs contouring control (MEDIUM HIGH)	060
3071	6571	6711	3071	3211	4071	3000	Position gain in Cs contouring control (MEDIUM LOW)	061
3072	6572	6712	3072	3212	4072	3000	Position gain in Cs contouring control (LOW)	062
3073	6573	6713	3073	3213	4073	0	Grid shift amount in servo mode	063
3074	6574	6714	3074	3214	4074	0	Origin return speed when Cs contouring/servo mode	064
3075	6575	6715	3075	3215	4075	10	Orientation completion signal detection	065
3076	6576	6716	3076	3216	4076	33	Motor speed limit value on orientation	066
3077	6577	6717	3077	3217	4077	0	Orientation stop position shift value	067
3078	6578	6718	3078	3218	4078	According to sensor installation	MS signal constant	068
3079	6579	6719	3079	3219	4079	0	MS signal gain adjustment	069
3080	6580	6720	3080	3220	4080	According to motor model	Limitation of regenerative power	070
3081	6581	6721	3081	3221	4081	20	Delay time until the motor power is cut off	071
3082	6582	6722	3082	3222	4082	10	Time setting during acceleration/deceleration	072
3083	6583	6723	3083	3223	4083	According to motor model	Motor voltage setting on normal rotation	073
3084	6584	6724	3084	3224	4084	According to motor model	Motor voltage setting on orientation	074
3085	6585	6725	3085	3225	4085	According to motor model	Motor voltage setting on servo mode	075
3086	6586	6726	3086	3226	4086	According to motor model	Motor voltage setting in Cs contouring control	076
3087	6587	6727	3087	3227	4087	115	Overspeed level	077
3088	6588	6728	3088	3228	4088	75	Velocity error excess detecting level on motor restriction	078
3089	6589	6729	3089	3229	4089	200	Velocity error excess detecting level on motor rotation	079

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Power Mate	0 No. 1 Spindle	0 No. 2 Spindle	15 No. 1 Spindle	15TT No. 2 Spindle	16	Standard setting data	Contents	Internal data number
3090	6590	6730	3090	3230	4090	90	Overload detecting level	080
3091	6591	6731	3091	3231	4091	100	Reduction rate of position gain in returning to reference point on servo mode	081
3092	6592	6732	3092	3232	4092	100	Reduction rate of position gain in Cs contouring control reference point return	082
3093	6593	6733	3093	3233	4093	0		083
3094	6594	6734	3094	3234	4094	0	Constant of the torque disturbance compensating	084
3095	6595	6735	3095	3235	4095	0	Adjustment of speed meter output voltage	085
3096	6596	6736	3096	3236	4096	0	Adjustment of load meter output voltage	086
3097	6597	6737	3097	3237	4097	0	Spindle speed feedback gain	087
3098	6598	6738	3098	3238	4098	0	Maximum speed of position coder 1 revolution signal detection	088
3099	6599	6739	3099	3239	4099	0	Delay time for motor magnetization	089
3100	6600	6740	3100	3240	4100	According to motor model	Base speed of motor output specifications	090
3101	6601	6741	3101	3241	4101	According to motor model	Limit value for motor output specifications	091
3102	6602	6742	3102	3242	4102	According to motor model	Base speed	092
3103	6603	6743	3103	3243	4103	According to motor model	Magnetic flux down start speed	093
3104	6604	6744	3104	3244	4104	According to motor model	Current loop proportion gain on normal operation	094
3105	6605	6745	3105	3245	4105	According to motor model	Current loop proportion gain in Cs contouring control	095
3106	6606	6746	3106	3246	4106	According to motor model	Current loop integral gain on normal operation	096
3107	6607	6747	3107	3247	4107	According to motor model	Current loop integral gain in Cs contouring control	097
3108	6608	6748	3108	3248	4108	According to motor model	Current loop integral gain zero point	098
3109	6609	6749	3109	3249	4109	According to motor model	Current loop proportion gain speed coefficient	099

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Power Mate	0 No. 1 Spindle	0 No. 2 Spindle	15 No. 1 Spindle	15TT No. 2 Spindle	16	Standard setting data	Contents	Internal data number
3110	6610	6750	3110	3250	4110	According to motor model	Current conversion constant	100
3111	6611	6751	3111	3251	4111	According to motor model	Secondary current coefficient for excitation current	101
3112	6612	6752	3112	3252	4112	According to motor model	Current prediction constant	102
3113	6613	6753	3113	3253	4113	According to motor model	Slip constant	103
3114	6614	6754	3114	3254	4114	According to motor model	Slip compensation constant of high-speed rotation	104
3115	6615	6755	3115	3255	4115	According to motor model	Motor applied voltage compensation constant by dead time	105
3116	6616	6756	3116	3256	4116	According to motor model	Electromotive voltage compensation coefficient	106
3117	6617	6757	3117	3257	4117	According to motor model	Electromotive voltage phase compensation constant	107
3118	6618	6758	3118	3258	4118	According to motor model	Electromotive voltage compensation speed coefficient	108
3119	6619	6759	3119	3259	4119	0	Time constant of voltage filter for electromotive voltage	109
3120	6620	6760	3120	3260	4120	According to motor model	Dead time compensation data	110
3121	6621	6761	3121	3261	4121	5	Time constant of torque change	111
3122	6622	6762	3122	3262	4122	0	Speed detection filter time constant	112
3123	6623	6763	3123	3263	4123	30	Overload detecting time	113
3124	6624	6764	3124	3264	4124	0		114
3125	6625	6765	3125	3265	4125	100	Timer setting for automatic operation	115
3126	6626	6766	3126	3266	4126	1000	Velocity command on automatic operation	116
3127	6627	6767	3127	3267	4127	According to motor model	Load meter display value on maximum output	117
3128	6628	6768	3128	3268	4128	According to motor model	Maximum output limit zero point	118
3129	6629	6769	3129	3269	4129	According to motor model	Secondary electrical current coefficient on rigid tap	119
3130	6630	6770	3130	3270	4130	According to motor model	Electromagnetic voltage phase compensation constant on deceleration	120
3131	6631	6771	3131	3271	4131	0	Speed detection filter time constant (on Cs contouring control)	121
3132	6632	6772	3132	3272	4132	0	V-phase current conversion constant	122
3133	6633	6773	3133	3273	4133	According to motor model	Motor model code	123
3134	6634	6774	3134	3274	4134	0		124,125
3135	6635	6775	3135	3275	4135	0	Grid shift value on Cs contouring control	126,127

(b) Low speed area parameters for speed range switching function

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Power Mate	0 No. 1 Spindle	0 No. 2 Spindle	15 No. 1 Spindle	15TT No. 2 Spindle	16	Standard setting data	Contents	Internal data number
3136	6900	6940	3280	3500	4136	According to motor model	Motor voltage setting on normal rotation	128
3137	6901	6941	3281	3501	4137	According to motor model	Motor voltage setting on servo mode	129
3138	6902	6942	3282	3502	4138	According to motor model	Base speed of motor output specifications	130
3139	6903	6943	3283	3503	4139	According to motor model	Limiting value for motor output specifications	131
3140	6904	6944	3284	3504	4140	According to motor model	Base speed	132
3141	6905	6945	3285	3505	4141	According to motor model	Initial speed with weakened flux	133
3142	6906	6946	3286	3506	4142	According to motor model	Current loop proportion gain on normal operation	134
3143	6907	6947	3287	3507	4143	According to motor model	Current loop integral gain on normal operation	135
3144	6908	6948	3288	3508	4144	According to motor model	Zero point of current loop integral gain	136
3145	6909	6949	3289	3509	4145	According to motor model	Speed coefficient of current loop proportional gain	137
3146	6910	6950	3290	3510	4146	According to motor model	Current conversion constant	138
3147	6911	6951	3291	3511	4147	According to motor model	Secondary current coefficient for excitation current	139
3148	6912	6952	3292	3512	4148	According to motor model	Current prediction constant	140
3149	6913	6953	3293	3513	4149	According to motor model	Slip constant	141
3150	6914	6954	3294	3514	4150	According to motor model	Slip compensation constant for high-speed rotation	142
3151	6915	6955	3295	3515	4151	According to motor model	Compensation constant for voltage imposed on motor due to dead time	143
3152	6916	6956	3296	3516	4152	According to motor model	Electromotive voltage compensation constant	144
3153	6917	6957	3297	3517	4153	According to motor model	Electromotive voltage phase compensation constant	145
3154	6918	6958	3298	3518	4154	According to motor model	Electromotive voltage compensation speed coefficient	146
3155	6919	6959	3299	3519	4155	0		147

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Power Mate	0 No. 1 Spindle	0 No. 2 Spindle	15 No. 1 Spindle	15TT No. 2 Spindle	16	Standard setting data	Contents	Internal data number
3156	6920	6960	3300	3520	4156	0		148
3157	6921	6961	3301	3521	4157	According to motor model	Time constant of change in torque	149
3158	6922	6962	3302	3522	4158	According to motor model	Maximum output limit zero	150
3159	6923	6963	3303	3523	4159	According to motor model	Secondary electrical current coefficient on rigid tap	151
3160	6924	6964	3304	3524	4160	0	Speed detection signal (SDT) output hysteresis	152
3161	6925	6965	3305	3525	4161	According to motor model	Electromotive voltage phase compensation constant on deceleration	153
3162	6926	6966	3306	3526	4162	0	Velocity loop integral gain on Cs contouring control cutting feed (HIGH)	154
3163	6927	6967	3307	3527	4163	0	Velocity loop integral gain on Cs contouring control cutting feed (LOW)	155
3164	6928	6968	3308	3528	4164	0	V-phase current conversion constant	156
3165	6929	6969	3309	3529	4165	0	Time constant of voltage filter for electromotive voltage compensation	157
3166	6930	6970	3310	3530	4166	According to motor model	Limit of regenerative power	158
3167	6931	6971	3311	3531	4167	0		159
3168	6932	6972	3312	3532	4168	According to motor model	Over load current alarm detecting level (for low speed)	160
3169	6933	6973	3313	3533	4169	According to motor model	Over load current alarm detecting time constant	161
3170	6934	6974	3314	3534	4170	According to motor model	Over load current alarm detecting level (for high-speed)	162
3171	6935	6975	3315	3535	4171	0		163
3172	6936	6976	3316	3536	4172	0		164
3173	6937	6977	3317	3537	4173	0		165
3174	6938	6978	3318	3538	4174	0		166
3175	6939	6979	3319	3539	4175	0	Delay timer at ON of electromagnetic contactor in unit	167

(c) Sub spindle side parameters for spindle selector function

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0 No. 1 Spindle	0 No. 2 Spindle	15 No. 1 Spindle	15TT No. 2 Spindle	16	Standard setting data	Contents	Internal data number
6140	6320	3320	3540	4176	00000000	Bit parameter	168
6141	6321	3321	3541	4177	00000001	Bit parameter	
6142	6322	3322	3542	4178	00000000	Bit parameter	169
6143	6323	3323	3543	4179	00000000	Bit parameter	
6144	6324	3324	3544	4180	00000000	Bit parameter	170
6145	6325	3325	3545	4181	00000000	Bit parameter	
6146	6326	3326	3546	4182	00000000	Bit parameter	171
6147	6327	3327	3547	4183	00000000	Bit parameter	
6148	6328	3328	3548	4184	00000000	Bit parameter	172
6149	6329	3329	3549	4185	00000000	Bit parameter	
6150	6330	3330	3550	4186	00000000	Bit parameter	173
6151	6331	3331	3551	4187	According to motor model	Bit parameter	
6152	6332	3332	3552	4188	According to motor model	Bit parameter	174
6153	6333	3333	3553	4189	According to amplifier model	Bit parameter	
6154	6334	3334	3554	4190	00000000	Bit parameter	175
6155	6335	3335	3555	4191	00000000	Bit parameter	
6156	6336	3336	3556	4192	00000000	Bit parameter	176
6157	6337	3337	3557	4193	00000000	Bit parameter	
6158	6338	3338	3558	4194	00000000	Bit parameter	177
6159	6339	3339	3559	4195	00000000	Bit parameter	
6160	6340	3340	3560	4196	According to motor model	Maximum speed	178
6161	6341	3341	3561	4197	150	Speed arrival level	179
6162	6342	3342	3562	4198	30	Speed detecting level	180
6163	6343	3343	3563	4199	75	Speed zero detecting level	181
6164	6344	3344	3564	4200	50	Setting of torque limit value	182
6165	6345	3345	3565	4201	83	Load detecting level 1	183
6166	6346	3346	3566	4202	0	Output limit pattern setting	184
6167	6347	3347	3567	4203	100	Output limit value	185
6168	6348	3348	3568	4204	0	Position coder method orientation stop position	186
6169	6349	3349	3569	4205	0		187

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0 No. 1 Spindle	0 No. 2 Spindle	15 No. 1 Spindle	15TT No. 2 Spindle	16	Standard setting data	Contents	Internal data number
6170	6350	3350	3570	4206	10	Velocity loop proportion gain on normal operation (HIGH)	188
6171	6351	3351	3571	4207	10	Velocity loop proportion gain on normal operation (LOW)	189
6172	6352	3352	3572	4208	10	Velocity loop proportion gain on orientation (HIGH)	190
6173	6353	3353	3573	4209	10	Velocity loop proportion gain on orientation (LOW)	191
6174	6354	3354	3574	4210	10	Velocity loop proportion gain on servo mode (HIGH)	192
6175	6355	3355	3575	4211	10	Velocity loop proportion gain on servo mode (LOW)	193
6176	6356	3356	3576	4212	10	Velocity loop integral gain on normal operation	194
6177	6357	3357	3577	4213	10	Velocity loop integral gain on orientation	195
6178	6358	3358	3578	4214	10	Velocity loop integral gain on servo mode	196
6179	6359	3359	3579	4215	0		197
6180	6360	3360	3580	4216	100	Gear ratio (HIGH)	198
6181	6361	3361	3581	4217	100	Gear ratio (LOW)	199
6182	6362	3362	3582	4218	1000	Position gain on orientation (HIGH)	200
6183	6363	3363	3583	4219	1000	Position gain on orientation (LOW)	201
6184	6364	3364	3584	4220	100	Modification rate of position gain on orientation completion	202
6185	6365	3365	3585	4221	1000	Position gain on servo mode (HIGH)	203
6186	6366	3366	3586	4222	1000	Position gain on servo mode (LOW)	204
6187	6367	3367	3587	4223	0	Grid shift value on servo mode	205
6188	6368	3368	3588	4224	0		206
6189	6369	3369	3589	4225	0		207

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0 No. 1 Spindle	0 No. 2 Spindle	15 No. 1 Spindle	15TT No. 2 Spindle	16	Standard setting data	Contents	Internal data number
6190	6370	3370	3590	4226	10	Orientation completion signal detection level	208
6191	6371	3371	3591	4227	33	Motor speed limit value on orientation	209
6192	6372	3372	3592	4228	0	Orientation stop position shift value	210
6193	6373	3373	3593	4229	According to sensor installation	MS signal constant	211
6194	6374	3374	3594	4230	0	MS signal gain adjustment	212
6195	6375	3375	3595	4231	According to motor model	Limitation of regenerative power	213
6196	6376	3376	3596	4232	20	Delay time until the motor power is cut off	214
6197	6377	3377	3597	4233	10	Time setting during acceleration/deceleration	215
6198	6378	3378	3598	4234	0		216
6199	6379	3379	3599	4235	0		217
6200	6380	3380	3600	4236	According to motor model	Motor voltage setting on normal rotation	218
6201	6381	3381	3601	4237	According to motor model	Motor voltage setting on orientation	219
6202	6382	3382	3602	4238	According to motor model	Motor voltage setting on servo mode	220
6203	6383	3383	3603	4239	100	Reduction rate of position gain in returning to reference point on servo mode	221
6204	6384	3384	3604	4240	0	Feedforward coefficient	222
6205	6385	3385	3605	4241	0	Velocity loop feedforward coefficient	223
6206	6386	3386	3606	4242	0		224
6207	6387	3387	3607	4243	0		225
6208	6388	3388	3608	4244	0		226
6209	6389	3389	3609	4245	0		227
6210	6390	3390	3610	4246	0		228
6211	6391	3391	3611	4247	0		229
6212	6392	3392	3612	4248	0		230
6213	6393	3393	3613	4249	0		231
6214	6394	3394	3614	4250	0		232
6215	6395	3395	3615	4251	0		233
6216	6396	3396	3616	4252	0		234
6217	6397	3397	3617	4253	0		235
6218	6398	3398	3618	4254	0		236
6219	6399	3399	3619	4255	0		237

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0 No. 1 Spindle	0 No. 2 Spindle	15 No. 1 Spindle	15TT No. 2 Spindle	16	Standard setting data	Contents	Internal data number
6220	6400	3400	3620	4256	According to motor model	Base speed of motor output specifications	238
6221	6401	3401	3621	4257	According to motor model	Limit value for motor output specifications	239
6222	6402	3402	3622	4258	According to motor model	Base speed	240
6223	6403	3403	3623	4259	According to motor model	Initial speed with weakened flux	241
6224	6404	3404	3624	4260	According to motor model	Current loop proportion gain on normal operation	242
6225	6405	3405	3625	4261	According to motor model	Current loop integral gain on normal operation	243
6226	6406	3406	3626	4262	According to motor model	Current loop integral gain zero point	244
6227	6407	3407	3627	4263	According to motor model	Current loop proportion gain speed coefficient	245
6228	6408	3408	3628	4264	According to motor model	Current conversion constant	246
6229	6409	3409	3629	4265	According to motor model	Secondary current coefficient for excitation current	247
6230	6410	3410	3630	4266	According to motor model	Current prediction constant	248
6231	6411	3411	3631	4267	According to motor model	Slip constant	249
6232	6412	3412	3632	4268	According to motor model	Slip compensation constant of high-speed rotation	250
6233	6413	3413	3633	4269	According to motor model	Compensation constant for voltage imposed on motor due to dead time	251
6234	6414	3414	3634	4270	According to motor model	Electromotive voltage compensation constant	252
6235	6415	3415	3635	4271	According to motor model	Electromotive voltage phase compensation constant	253
6236	6416	3416	3636	4272	According to motor model	Electromotive voltage compensation speed coefficient	254
6237	6417	3417	3637	4273	5	Time constant of torque change	255
6238	6418	3418	3638	4274	According to motor model	Load meter display value on maximum output	256
6239	6419	3419	3639	4275	According to motor model	Maximum output limit zero point	257
6240	6420	3420	3640	4276	According to motor model	Secondary electrical current coefficient on rigid tap	258
6241	6421	3421	3641	4277	According to motor model	Electromagnetic voltage phase compensation constant on deceleration	259
6242	6422	3422	3642	4278	0	Speed detection filter time constant	260
6243	6423	3423	3643	4279	0		261
6244	6424	3424	3644	4280	0	Time constant of voltage filter for electromotive voltage compensation	262
6245	6425	3425	3645	4281	0		263
6246	6426	3426	3646	4282	0		264
6247	6427	3427	3647	4283	0		265

(d) Low speed area parameters on SUB spindle both with spindle selector function and with speed range switching function

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0 No. 1 Spindle	0 No. 2 Spindle	15 No. 1 Spindle	15TT No. 2 Spindle	16	Standard setting data	Contents	Internal data number
6248	6428	3428	3648	4284	According to motor model	Motor voltage setting on normal rotation	266
6249	6429	3429	3649	4285	According to motor model	Motor voltage setting on servo mode	267
6250	6430	3430	3650	4286	According to motor model	Base speed of motor output specifications	268
6251	6431	3431	3651	4287	According to motor model	Limit value for motor output specifications	269
6252	6432	3432	3652	4288	According to motor model	Base speed	270
6253	6433	3433	3653	4289	According to motor model	Initial speed with weakened flux	271
6254	6434	3434	3654	4290	According to motor model	Current loop proportion gain on normal operation	272
6255	6435	3435	3655	4291	According to motor model	Current loop integral gain on normal operation	273
6256	6436	3436	3656	4292	According to motor model	Current loop integral gain zero point	274
6257	6437	3437	3657	4293	According to motor model	Current loop proportion gain speed coefficient	275
6258	6438	3438	3658	4294	According to motor model	Current conversion constant	276
6259	6439	3439	3659	4295	According to motor model	Secondary current coefficient for excitation current	277
6260	6440	3440	3660	4296	According to motor model	Current prediction constant	278
6261	6441	3441	3661	4297	According to motor model	Slip constant	279
6262	6442	3442	3662	4298	According to motor model	Slip compensation constant of high-speed rotation	280
6263	6443	3443	3663	4299	According to motor model	Compensation constant for voltage imposed on motor due to dead time	281
6264	6444	3444	3664	4300	According to motor model	Electromotive voltage compensation coefficient	282
6265	6445	3445	3665	4301	According to motor model	Electromotive voltage phase compensation constant	283
6266	6446	3446	3666	4302	According to motor model	Electromotive voltage compensation speed coefficient	284
6267	6447	3447	3667	4303	5	Time constant of torque change	285
6268	6448	3448	3668	4304	According to motor model	Maximum output limit zero point	286
6269	6449	3449	3669	4305	According to motor model	Secondary electrical current coefficient on rigid tap	287

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0 No. 1 Spindle	0 No. 2 Spindle	15 No. 1 Spindle	15TT No. 2 Spindle	16	Standard setting data	Contents	Internal data number
6270	6450	3450	3670	4306	According to motor model	Electromotive voltage phase compensation constant on deceleration	288
6271	6451	3451	3671	4307	According to motor model	Limit of regenerative power Time constant of voltage filter for electromotive voltage compensation	289
6272	6452	3452	3672	4308	0		290
6273	6453	3453	3673	4309	According to motor model	Motor model code	291
6274	6454	3454	3674	4310	0		292,293
6275	6455	3455	3675	4311	0		294,295
6276	6456	3456	3676	4312	0		296
6277	6457	3457	3677	4313	0		297
6278	6458	3458	3678	4314	0		298
6279	6459	3459	3679	4315	0		299
6280	6460	3460	3680	4316	0		300
6281	6461	3461	3681	4317	0		301
6282	6462	3462	3682	4318	0		302
6283	6463	3463	3683	4319	0		303
6284	6464	3464	3684	4320	0		304
6285	6465	3465	3685	4321	0		305
6286	6466	3466	3686	4322	0		306
6287	6467	3467	3687	4323	0		307
6288	6468	3468	3688	4324	0		308
6289	6469	3469	3689	4325	0		309
6290	6470	3470	3690	4326	0		310
6291	6471	3471	3691	4327	0		311
6292	6472	3472	3692	4328	0		312
6293	6473	3473	3693	4329	0		313
6294	6474	3474	3694	4330	0		314
6295	6475	3475	3695	4331	0		315
6296	6476	3476	3696	4332	0		316
6297	6477	3477	3697	4333	0		317
6298	6478	3478	3698	4334	0		318
6299	6479	3479	3699	4335	0		319

P-□□□
F-□□□

0 No. 1 Spindle	0 No. 2 Spindle	15 No. 1 Spindle	15TT No. 2 Spindle	16	Standard setting data	Contents	Internal data number
6300	6480	3480	3700	4336	0		320
6301	6481	3481	3701	4337	0		321
6302	6482	3482	3702	4338	0		322
6303	6483	3483	3703	4339	0		323
6304	6484	3484	3704	4340	0		324
6305	6485	3485	3705	4341	0		325
6306	6486	3486	3706	4342	0		326
6307	6487	3487	3707	4343	0		327
6308	6488	3488	3708	4344	0		328
6309	6489	3489	3709	4345	0		329
6310	6490	3490	3710	4346	0		330
6311	6491	3491	3711	4347	0		331
6312	6492	3492	3712	4348	According to motor model	Over load current alarm detecting level (for low-speed)	332
6313	6493	3493	3713	4349	According to motor model	Over load current alarm detecting time constant	333
6314	6494	3494	3714	4350	According to motor model	Over load current alarm detecting level (for high-speed)	334
6315	6495	3495	3715	4351	0	Current detection offset compensation	335

1. The parameter data given in this table consists of standard values. It is necessary to reset according to the machine system.

APPENDIX 5 MONITORING INTERNAL DATA OF THE SERIAL SPINDLE

5.1 Overview

Because all the data items on the serial spindle (such as velocity information) are processed by software, they cannot be monitored with the oscilloscope.
There is a function that can output the internal data of the serial spindle to the LM (load meter) and SM (speedometer) terminals using a voltage output circuit to get analog output of these meters.
This section describes the method for using the function to monitor the internal data of the serial spindle with the oscilloscope.

5.2 Major Properties

Item	Properties
Output voltage range	0 to +11 V
Output voltage resolution	Approx. 43 mV step (11 V/256)
Input impedance of the external measuring instrument	10 kΩ min.

5.3 Monitoring

5.3.1 Outline

Start up the system for normal operation.
When the system is started up:
- The speed (min^{-1}) of the spindle motor is output to the five-digit indicator.
- The load meter output (maximum output plus 10 V) is output to the load meter terminal (LM).
- The voltage for the motor speed (+10 V for the maximum speed) is output to the terminal (SM) of the speedometer.

Set data using the four setting switches on the serial spindle control circuit. This function will then be able to output the internal data of the serial spindle to the indicator and the LM and SM terminals.
When power is turned off, data items which have been set are automatically cleared.
To check the signals on the LM and SM terminals, set pins S2 and S3 to B.
After data monitoring is completed, reset the pins to A.

Pin	Set to A	Set to B
S2, S3	The filter circuit is added while voltage is output.	The filter circuit is not added while voltage is output.

5.3.2 Specifying data to be monitored

(1) Press the four setting switches at the same time for at least a second. "FFFFF" will be displayed on the indicator.

(2) Turn off the switches and press the "MODE" switch. "d-00" will be displayed on the indicator and the system will enter the mode for monitoring internal data.
In this mode, the motor can be operated normally.

(3) Press the "UP" or "DOWN" switch while holding down the "MODE" switch. The indicator display will change in the range of "d-00" to "d-12".

(4) The following shows the correspondence between the destinations of the internal data of the serial spindle and addresses d-01 to d-12.
   d-01 to d-04: Specifies the amount of data to be output to the indicator, data shift, and output format (decimal or hexadecimal).
   d-05 to d-08: Specifies the amount of data to be output to the LM terminal, data shift, and whether an offset is provided.
   d-09 to d-12: Specifies the amount of data to be output to the SM terminal, data shift, and whether an offset is provided.

(5) Select address d-xx in the procedure for setting data described in (3).

(6) Turn off the "MODE" switch. "d-xx" will disappear 0.5 second later, and the data will be displayed for a second.
Change the set data using the "UP" or "DOWN" switch within the second the data is displayed.

(7) When more than a second elapses without pressing the "UP" or "DOWN" switch, data cannot be changed.
If the "MODE" switch is turned on or off, however, setting can be started from the beginning of the step in item (6).

5.4 Description of Addresses

[Output to the indicator]

Address	Description	Initial value
d-01	Specifies a data number.	0
d-02	Shift at data output (0 to 31 bits)	0
d-03	Data shift direction 0: Data is shifted right. 1: Data is shifted left.	0
d-04	Display format 0: Decimal notation 1: Hexadecimal notation (0 to F)	0

[Output to the LM terminal]

Address	Description	Initial value
d-05	Specifies a data number.	132
d-06	Shift at data output (0 to 31 bits)	0
d-07	Data shift direction 0: Data is shifted right. 1: Data is shifted left.	0
d-08	Offset 0: Not provided 1: Provided	0

[Output to the SM terminal]

Address	Description	Initial value
d-09	Specifies a data number.	131
d-10	Shift at data output (0 to 31 bits)	0
d-11	Data shift direction 0: Data is shifted right. 1: Data is shifted left.	0
d-12	Offset 0: Not provided 1: Provided	0

5.5 Principles in Outputting the Internal Data of the Serial Spindle

The length of data is 32 bits (BIT31 TO BIT00) unless it is described as 16 bits.

BIT31	• • • • •	BIT03	BIT02	BIT01	BIT00

5.5.1 Example of output to the indicator

(Example 1) Displaying data in decimal

When the number of digits to shift data (d-02) = 0 and display format (d-04) = 0 (decimal notation): The last 16 bits of data (BIT15 to BIT00) are converted into decimal (0 to 65535 max.) and displayed.

BIT15	• • • • •	BIT01	BIT00

16 bits

↓ Converted into decimal data and displayed

Indicator

X	X	X	X	X

(Example 2) Displaying data in hexadecimal

When the number of digits to shift data (d-02) = 0 and display format (d-04) = 1 (hexadecimal notation): The last 16 bits of data (BIT15 to BIT00) are converted into hexadecimal (0 to FFFFF max.) and displayed.

BIT15	• • • • •	BIT01	BIT00

16 bits

↓ Converted into hexadecimal data and displayed

Indicator

	X	X	X	X

(The fifth digit is blank.)

(Example 3) Shifting data left

When the number of digits to shift data (d-02) = 3, the shift direction is left (d-03 = 1), and display format (d-04) = 1 (hexadecimal notation): Data in BIT12 to BIT00 and the last three bits of data (= 0) are converted into hexadecimal (0 to FFFFF max.) and displayed.

BIT12	·····	BIT01	BIT00	0	0	0

|←—— 16 bits ——→|

↓ Converted into hexadecimal data and displayed

Indicator		X	X	X	X	(The fifth digit is blank.)

(Example 4) Shifting data right

When the number of digits to shift data (d-02) = 5, shift direction is right (d-03 = 0), and display format (d-04) = 0 (decimal notation): Data in BIT20 to BIT05 is converted into decimal (0 to 65535 max.) and displayed.

BIT12	·····	BIT06	BIT05

|←—— 16 bits ——→|

↓ Converted into decimal data and displayed

Indicator	X	X	X	X	X

(Example 5) Shifting data right when the data length is 16 bits

When the data length is 16 bits, data shift (d-02) = 5, shift direction is right (d-03 = 0), and display format is decimal notation (d-04 = 0): The first five bits of data and data in BIT15 to BIT05 are converted into decimal and displayed.

0	0	0	0	0	BIT15	···	BIT05

|←—— 16 bits ——→|

↓ Converted into decimal data and displayed

Indicator	X	X	X	X	X

5.5.2 Example of output to the LM terminal

When the internal data of the serial spindle is output to the LM terminal, the data is set in the 8-bit D/A converter.
When the set data is 0, the D/A converter outputs 0V. When the set data is 255 (maximum value), the converter outputs +11 V.
The unit resolution of the D/A converter is therefore 11V/255 (about 43 mV).

(Example 1) Data set
When the number of digits to shift data (d-06) = 0 and when no offset is provided (d-08 = 0): The last eight bits of data (BIT07 to BIT00) is set in the D/A converter of the LM terminal.

BIT07	BIT06	BIT05	BIT04	BIT03	BIT02	BIT01	BIT00

↓

Set in the D/A converter for LM terminal output

(Example 2) Shifting data left
When the number of digits to shift data (d-06) = 3, shift direction is right (d-07 = 1), and no offset is provided (d-08 = 0): Data in BIT14 to BIT00 and the last three bits of data (= 0) are set in the D/A converter.

BIT04	BIT03	BIT02	BIT01	BIT00	0	0	0

↓

Set in the D/A converter for LM terminal output

(Example 3) Shifting data right
When the number of digits to shift data (d-06) = 10, shift direction is right (d-07 = 1), and no offset is provided (d-08 = 0): Data in BIT17 to BIT10 is set in the D/A converter.

BIT17	BIT16	BIT15	BIT14	BIT13	BIT12	BIT11	BIT10

↓

Set in the D/A converter for LM terminal output

(Example 4) Shifting data right when the data length is 16 bits

When the data length is 16 bits, data shift (d-06) = 10, shift direction is right (d-07 = 0), and no offset is provided (d-08 = 0): The first two bits of data (= 0) and data in BIT15 to BIT10 are set in the D/A converter.

0	0	BIT15	BIT14	BIT13	BIT12	BIT11	BIT10

↓

Set in the D/A converter for LM terminal output

(Example 5) If an offset is provided

When the number of digits to shift data (d-06) = 10, shift direction is right (d-07 = 0), and an offset is provided (d-08 = 1): Data in most significant bit BIT17 (to which 1 is added) and data in BIT16 to BIT10 are set in the D/A converter.

BIT17 + 1	BIT16	BIT15	BIT14	BIT13	BIT12	BIT11	BIT10

↓

Set in the D/A converter for LM terminal output

When an offset is specified for the output of the D/A converter it is only 5.5 V, half of 11 V. This is because 1 is added to the data in the most significant bit.

5.5.3 Example of output to the SM terminal

Output to the SM terminal is the same as that to the LM terminal.

However, the addresses for setting data (d-09 to d-12) are different from those for output to the LM terminal.

Setting velocity information in the LM terminal and the number of errors in the SM terminal enables simultaneous monitoring of the change in each data item using the two channels.

5.6 Data Numbers

5.6.1 Main data

Data No.	Description	Data length (unit: bit)	Remarks
16	Motor speed command	32	The 12th bit (BIT12) indicates a units in min^{-1}.
19	Motor speed	32	The 12th bit (BIT12) indicates a units in min^{-1}.
25	Motor speed deviation (speed command - motor speed)	32	The 12th bit (BIT12) indicates a units in min^{-1}.
4	Move command	32	Number of command pulses for ITP (usually 8 ms)
9	Positioning error	32	Number of erroneous pulses (Cs contouring control, spindle synchronous control, rigid tapping)
27 or 90	Torque command	16	0 to ±16384
131	Speedometer data	16	LM terminal
132	Load meter data	16	
136	Positioning error	32	Number of erroneous pulses (Position coder method orientation)

5.6.2 Data to be transmitted between the serial spindle and the CNC

Data No.	Description	Data length (unit: bit)	Remarks
2	Control bit signal 1	16	Command bit sent from the CNC to the spindle
3	Control bit signal 2	16	Command bit sent from the CNC to the spindle
5	Speed command data	16	±16384 for the maximum speed command
6	Spindle control signal	16	Command bit sent from the PMC to the spindle
10	Load meter data	16	0 to 32767 (maximum)
11	Motor speed data	16	±16384 for maximum speed
12	Spindle status signal	16	Status bit sent from the spindle to the PMC

5.6.3 Others

Data No.	Description	Data length (unit: bit)	Remarks
51	U-phase current command	16	
52	V-phase current command	16	
53	W-phase current command	16	
112	Position coder data	16	Number of the pulses that return to the position coder for ITP (usually 8 ms)

5.7 Example of Monitoring Data

5.7.1 Example of monitoring a positioning error using the LM terminal

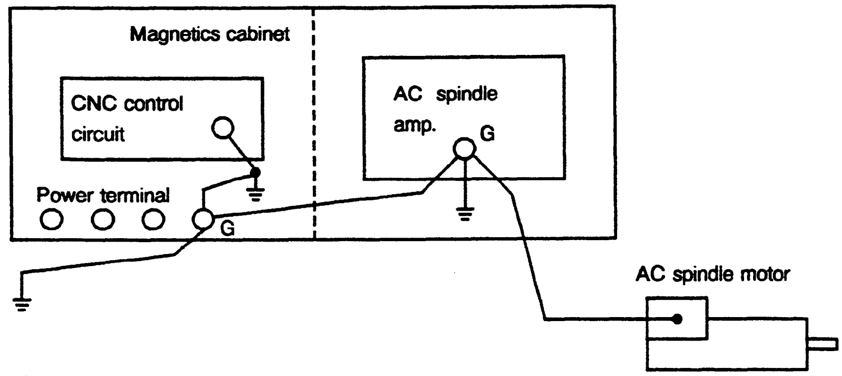
Address	Description	Set data			
d-05	Data number	9	9	9	9
d-06	Data shift	0	1	1	2
d-07	Data shift direction	0	0	1	1
d-08	Offset	1	1	1	1
Data unit for the LM terminal		256p/11V	512p/11V	128p/11V	64p/11V

5.7.2 Example of monitoring a motor speed using the SM terminal

Address	Description	Set data		
d-09	Data number	19	19	19
d-10	Data shift	13	12	11
d-11	Data shift direction	0	0	0
d-12	Offset	0	0	0
Data unit for the SM terminal		$512 min^{-1}/11V$	$256 min^{-1}/11V$	$128 min^{-1}/11V$

When an offset is specified, the output is +5.5 V at 0 min^{-1}.

APPENDIX 6 GROUNDING



① Connect the G terminal of the AC spindle amp. to the G terminal of the power terminal.
② Connect the G terminal of the AC spindle motor to the G terminal of the AC spindle amp.
③ Connect the G terminal of the AC spindle amp. close to the position of the magnetics cabinet. Place the G terminal close to the cabinet as much as possible to get more effective grounding.

(Note 1) Connect the G terminal of the magnetics cabinet to the ground terminal according to the technical standard authorized.

(Note 2) For connecting the G terminal of the CNC to the ground terminal, the ground terminal to the ground plate and the ground terminal to the G terminal of the power terminal of the magnetics cabinet, use the thick cable and connect it close to each other.

APPENDIX 7 CUSTOMER RECORDS

Customer records for spindle motor / serial interface spindle amplifier Issued on Jan. 10, 1989

Date: Drawn by:

Customer		Machine model	
Machine type	Lathe (No. of spindle motor =) / MC / Other ( )		
CNC device	FANUC Series		

1. Spindle Motor

Motor type				
Mounting direction	Horizontal / Output shaft vertical downward / Other ( )		Air exhaust	Front / Rear
Sensor	C axis detector / Built-in sensor / Usual sensor		No. of pulses	128p / 256p / 512p/rev.

Model	Specification No.	Basic speed / Max. speed	Continuous rating / 30min. rating / %ED	Special condition
	A06B- -	/ min^{-1}	/ / kW	

2. Spindle Amplifier

Model	Specification No.	C axis detection circuit	Special condition
	A06B- -H #H	Required / Not required	

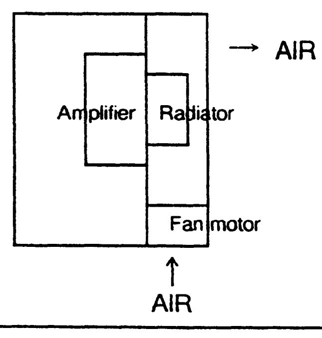
3. Installation Condition and Cooling Amplifier

Input power voltage	AC200V / 230V / 380V / 415V / Other (V AC)	Frequency	50 Hz / 60 Hz
Ambient temperature	Motor: approx. °C - °C, Amplifier: approx. °C - °C		
Ambient humidity	Approx. % - %		
Cooling system	Designed by machine tool builder / Specifications for FANUC unit adaptor		

Cooling conditions for designed by machine tool builder	
Fan motor	Max. air flow: m^3/min., Max. static pressure: mmAg, Number of motors: units
Cooling air circulation system	Magnetics cabinet internal circulation / Air direct cooling (Air filter: Provided / Not provided)

Cooling Configuration Drawing
(See below diagram / Attached sheet)
Duct size: (W) × (D) × (H)

[Example]
Duct size: 50 (W) ×20 (D) ×100 (H) mm



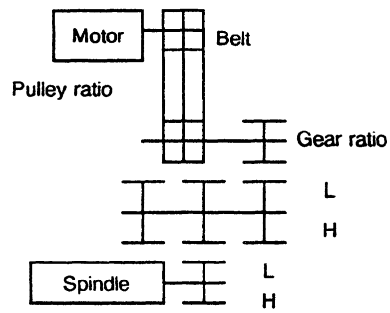
4. C Axis Detector

Detector spec. No.	Drum Outer Dia.	Preamplifier spec. No.	Detection circuit spec. No.	Special condition
	ϕ65 / ϕ97.5 / ϕ130 / ϕ195			
Detector rotation direction	Same direction as motor / Reverse direction as motor			

5. Spindle Configurations

Driving system	Belt drive / Gear drive / Belt & Gear drive / Direct drive / Other ( )
Gear	1 gear / 2 gears / 3 gears / 4 gears Backlash:
Belt	Type: , Length (Perimeter): mm, Quantity: pcs., V belt / Timing belt
Brake	Used / Unused , Brake pressure: 1 step / 2 steps / 3 steps

Gear ratio / Pulley ratio	Spindle: Motor	Load inertia converted to motor shaft unit	Rotation direction of spindle and motor	Target acceleration time 0 to Max. min^{-1}.	Max. spindle speed
HIGH	:	$kg \cdot cm, sec^2$	Same / Reverse	sec	min^{-1}
MEDIUM	:	$kg \cdot cm, sec^2$	Same / Reverse	sec	min^{-1}
MEDIUM	:	$kg \cdot cm, sec^2$	Same / Reverse	sec	min^{-1}
LOW	:	$kg \cdot cm, sec^2$	Same / Reverse	sec	min^{-1}



6. Function

Item	Description
C axis control function	Used / Unused Application: Cutting / Spindle index / Other ( )
Rigid tapping function	Used / Unused Target specification: [Example] 2000 min^{-1} for M2
Spindle orientation function	Magnetic sensor system / Position coder system (Position coder / Built-in sensor) Application: ATC / Spindle index (required index workpiece) / Other
Constant surface speed control function	Used / Unused
Output control function	Used / Unused Application:
Torque control function	Used / Unused Application: Gear change / Other ( )

7. Cs Contour Cutting Conditions

Item	Description
Workpiece material	Iron / Stainless steel / Aluminum / Brass / Others
Cutting radius	mm
Tool	End mill, Diameter: ϕ mm, Number of flutes: , Others ( )
Tool speed	rpm
Depth of cut	mm
Cutting feedrate	mm/min., deg/min
Cutting figure	

INDEX

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Revision Record

AC SPINDLE MOTOR series (SERIAL INTERFACE) DESCRIPTIONS (B-65042E)

Edition	Date	Contents	Edition	Date	Contents
04	July '92	• The descriptions of improved spindle amplifier models 1S to 3S, small models 6S, 15S, and 30S have been added. • The description of the differential control function has been added. • The sequences of the descriptions in the parts on output switching and spindle switching have been changed. • The part describing the signal conversion circuits for model 0.5S has been added. • The description of the spindle orientation function to be externally set with the incremental command has been added. • The description of spindle orientation control requiring the shortest time using the position coder system has been added.			
03	Nov. '91	Retrofit type • Added descriptions of spindle servo unit models 6S to 26S. • Added section on the switching unit. • Added section on the high-resolution position coder. • Added descriptions of models 0.5S, 8P/8000, 12P/8000, and 15P/8000.			
02	Jan. '91	• Added the descriptions of models 1S, 1.5S, 2S, 3S, 30S, 40S and 60P. • Added the parts of the high-resolution magnetic pulse coder and spindle switching function.			
01	Sep. '89	————————	05	Jan. '94	• Added descriptions of motor LIQUID-COOLED series. • Added descriptions of motor IP65 series.
Edition	Date	Contents	Edition	Date	Contents