SJ300 Series Inverter
Application Note:
Optimizing Vector Control

Please refer also to the SJ300 Inverter
Instruction Manual and the SJ-FB Option
Board Instruction Manual

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Hitachi America, Ltd.

Application Note for Vector Control with the SJ300 Inverter

Contents

This document is a guideline for optimizing motor/inverter performance in vector mode through parameter adjustments. Please note that actual performance of the motor depends on a combination of many parameters, and is difficult to describe concisely. Trial & error is the customary means to achieve good motor performance. Therefore please regard this information as just a guide only.

This document only shows technical issues related to vector control. Please refer to the SJ300 Inverter and SJ-FB manuals for detailed information for installation and operation.

[1] Overview

This engineering note applies when using **SLV**, **0-SLV** and **V2 (closed loop)** control. It is often difficult to get optimized motor performance because many parameters interact. Please refer to this document for getting a rough idea how to achieve good motor performance with above control modes. Please also note that **the performance WILL NOT BE like a servo drive even in the case of V2 mode.**

There are 3 basic modes with which you can get high torque performance with the SJ300 inverter:

(1) SLV control (No SJ-FB is used)

High motor torque performance with open loop can be obtained in the low frequency range (~0.5Hz). Please refer to a standard SLV block diagram in Fig 1 (section 2-2).

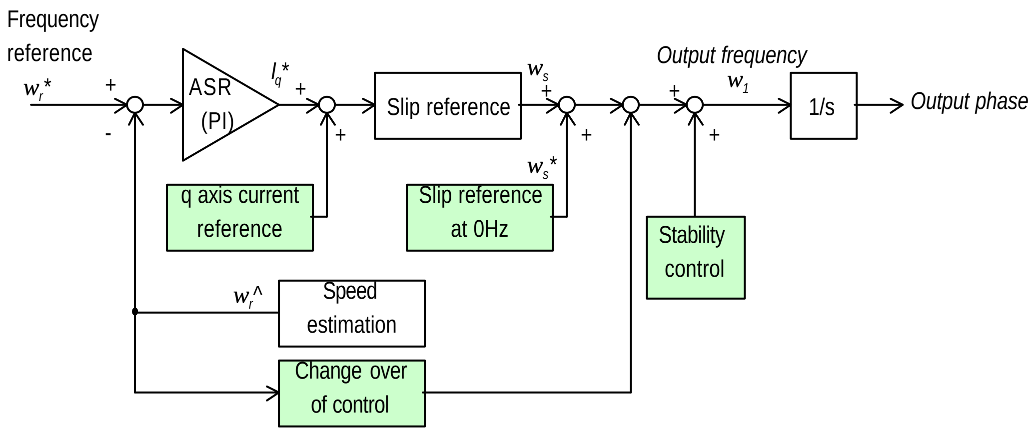
[H***] parameters are mainly adjusted for the control.

(2) 0-SLV control (No SJ-FB is used)

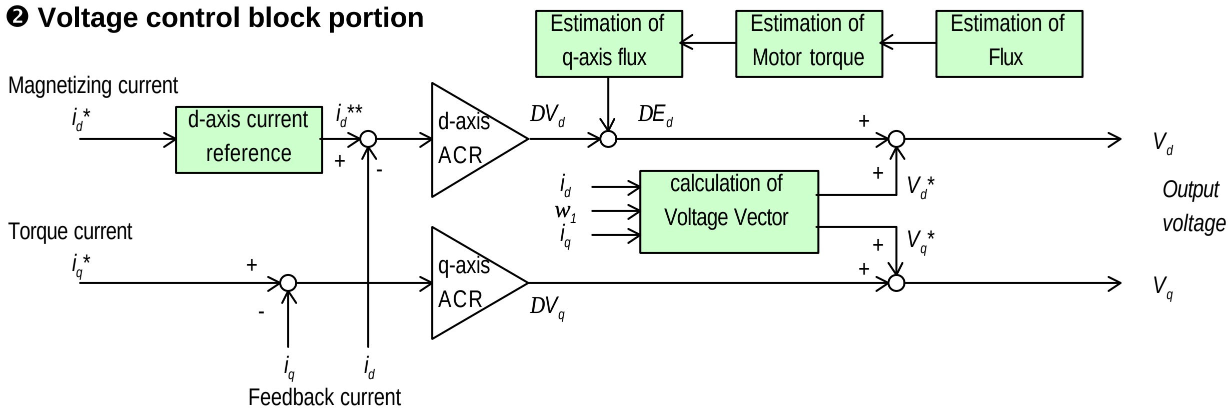
High torque performance can be obtained at around 0Hz. This does NOT mean the motor shaft will be at a standstill. The motor rotates slightly to generate motor torque, since this is not a servo drive. Depending on the application and tuning, you may be able to get full torque with the motor at standstill. This control algorithm is different from SLV control.

[H***] parameters are mainly adjusted for the control.

❶ Frequency control block portion



❷ Voltage control block portion



(3) V2 control (SJ-FB is used)

High torque and stable, accurate motor performance can be achieved with the SJ300 in vector mode. A motor encoder and a feedback option card for SJ300 (SJ-FB) are needed to use this control mode. There are two regulation modes within the V2 control mode: **ASR mode** and **APR mode**.

- ❶ **ASR mode :** Inverter is controlled by speed command input (digitally set, analog input, or RS485)
- ❷ **APR mode :** Inverter is controlled by pulse train input signal

[H***] and [P***] parameters are adjusted for achieving good motor control.

A suitable mode should be selected depending on the application.

[Difference between each control]

➢ Control performance

Item	**SLV mode**	**V2 mode**
Speed linearity	<1 %	<0.01 %
Speed fluctuation	<1 %	<0.01 %
Control range	1 : 50	1 : 100
Speed response	15 rad/s	60 rad/s
Torque control range	1 : 50	1 : 100
Torque response	50 rad/s	500 rad/s

- Note: These are representative values only.
- Percentages are relative to base speed

➢ Torque performance at low speed

Item	**SLV control**	**0-SLV control**	**V2 control**
Down sized motor	150% or more	150% or more	150% or more
Same kW motor	100% or more	100% or more	100% or more

- These are guaranteed minimum values with a Hitachi standard induction motor. Actual capability is greater.

➢ Torque performance at 0Hz

Item	**0-SLV control**	**V2 control**
Down-sized motor	150% or more with a small slip	150% or more with standstill
Same kW motor	100% or more with a small slip	100% or more with standstill

- This has been confirmed using Hitachi standard induction motor and J2 motor (for V2 control).

[2] How to tune each parameter

(2-1) Tuning target of each parameter

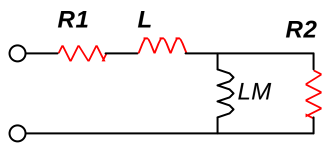
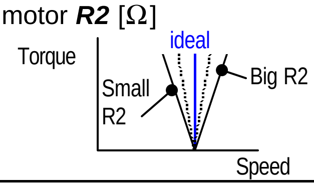
There are many parameters, which influence the motor performance in SLV, 0-SLV & V2 control modes. In some cases auto tuning is not fully sufficient to get the best motor performance because there are various kinds of motors in the world. It is sometimes necessary to adjust by hand after the auto tuning.

Generally the performance of the motor can be determined from two criteria:

- Torque performance at low speed
- Speed response against target speed

Table 1 shows main parameters that influence the motor performance inSLV mode. The concept is the same in 0-SLV and V2 modes as well.

Table 1. Explanation of parameters related to motor performance in SLV mode

Code	Function	Remarks
H001	Auto tuning mode  *Equivalent circuit of one leg of the motor winding*	This determines the method of auto tuning. 00 (NOR) : Auto tuning invalid 01 (NRT) : Auto tuning with motor at standstill 02 (AUT) : Auto tuning with motor rotation Auto tuning determines the following motor constants automatically. (See left figure as well.) • R1 (primary resistance) • R2 (secondary resistance) • L (leakage inductance) • I_O (magnetizing current at base frequency) • J (total load inertia) Normally better motor performance can be obtained by auto tuning with motor rotation with an actual load on the motor. But if the system does not allow rotating the motor, like a lift application for example, auto tuning with motor at standstill can be used.
H002	Motor constant selection	This determines which set of motor parameters is used by the drive. 00 : Motor parameters for a Hitachi standard motor (Uses [H020] ~ [H024]) 01 : Use auto tuning data (Uses [H030] ~ [H034]) 02 : Use auto tuning data with On-line auto tuning On-line auto tuning occurs every time the inverter stops. It measures R1 and R2, the main values that may change due to a motor temperature change. The tuning period is roughly 5 seconds maximum, and if the RUN command is given during the tuning routine, the inverter will start and tuning is aborted.
H003	Motor kW	This sets the motor kW, not a kW of an inverter.
H004	Motor poles	
H005	Speed response factor ***K***	Controls the **speed response** • Large K → Quick response (Too high a value can cause instability.) • Small K → Slow but stable response Value is also dependent on Proportional gain (***P-gain*** : [H050]) and Integration gain (***I-gain*** : [H051]). (*K = f(Kp, Ki)*).
H006	Motor stability control factor	This should be adjusted in case of motor instability. Increase / decrease depends on the situation.
H020 / H030	Primary resistance of the motor ***R1*** [Ω]	Influences mainly the **torque at low speed**. • Large ***R1*** → Higher torque (Too high ***R1*** → Over magnetizing) • Small ***R1*** → Smaller torque
H021 / H031	Secondary resistance of the motor ***R2*** [Ω] 	Influence mainly on the speed change ratio (= **slip compensation**) • Large ***R2*** → Increase speed change ratio (= Actual speed becomes faster than a target speed.) • Small ***R2*** → Decrease speed change ratio (= Actual speed becomes slower than a target speed.)

Code	Function	Remarks
H022 / H032	Leakage inductance of the motor ***L*** [mH]	***L*** does not influence control much compared to other parameters, however a suitable value is recommended to be set.
H023 / H033	Magnetizing current of the motor I_O [A]	Influences mainly the **torque at low speed**. • Large I_O → Bigger torque (Too big I_O → Over magnetizing) • Small I_O → Smaller torque
H024 / H034	Total inertia ***J*** [kgm^2]	Influences mainly speed and torque response performance This should be the total inertia (§***J***) on the motor shaft, including the inertia of the rotor of the motor and the load. See table 2 for information on how to tune in each case. → ***See appendix A for calculation of the total inertia.***
H050	Proportional gain under **PI control mode** (K_p) (% based on [H005])	Fine tuning of proportional portion of speed response factor. • Large K_p →Quick response (Too high K_p can cause instability.) • Small K_p → Slow but stable response
H051	Integration gain under **PI control mode** (K_i) (% based on [H005])	Fine tuning of ***Ki*** portion of speed response factor. • Large K_i → Quick response (Too high K_i can cause instability.) • Small K_i → Slow but stable response
H052	Proportional gain under **P control mode** (K_p) (% based on [H005])	See Remarks for H050
F002	Acceleration time	Acc and Dec time influence the response. Even if optimized tuning parameter values are set, actual motor speed will change according to the set ramp time. If a quick response is required, the ramps should be set as fast as possible. Or, use LAC (LAD cancellation) to make the ramp invalid.
F003	Deceleration time	
A044	Control mode	Control mode should be set to 03 (SLV), 04 (0-SLV) or 05 (V2).
A045	Output gain (*Vgain*)	Output gain scales the duty cycle of PWM output, regardless of the input voltage of the inverter. Decreasing output gain can solve the problem of motor instability, however the output torque will also decrease in this case.
A081	AVR function	AVR function attempts to maintain a stable output voltage by changing the duty cycle of the PWM output in real-time. If the input voltage changes or bus voltage changes due to regeneration, motor sees constant voltage. That means the motor efficiency will be better. In some cases, disabling the AVR function can resolve motor instability problems. AVR function attempts to always mainain constant output voltage. During operation, DC bus voltage is always changing, which means AVR function is always acting to change the duty cycle of PWM output voltage. Since it is an active control function it may lead sometimes motor instability (unstable energy transmission). In such cases, setting AVR OFF can solve the problem.
b022	OL restriction level	Set OL level [b022] as high as possible, or else disable it (set [b021] to "00 "), because a rather high motor current is required in low frequency area in the case of vector control. High torque cannot be achieved if OL restriction is preformed.
b041~b044	Torque limit level	Set torque limit level as high as possible, or else disable it (= assign TL to an intelligent input terminal and leave it OFF), because high motor current is required in the low frequency area in the case of vector control. Maximum torque cannot be achieved if torque limit is triggered.
b083	Carrier frequency	Decreasing carrier frequency can solve the problem of motor instability. This is because the effect of dead time will be reduced.

* Second and 3rd functions ([H2**] & [H3**]) have the same meaning for 2nd and 3rd motors.

Refer to Table 3 for standard (default) motor parameter settings for SJ300 series inverter.

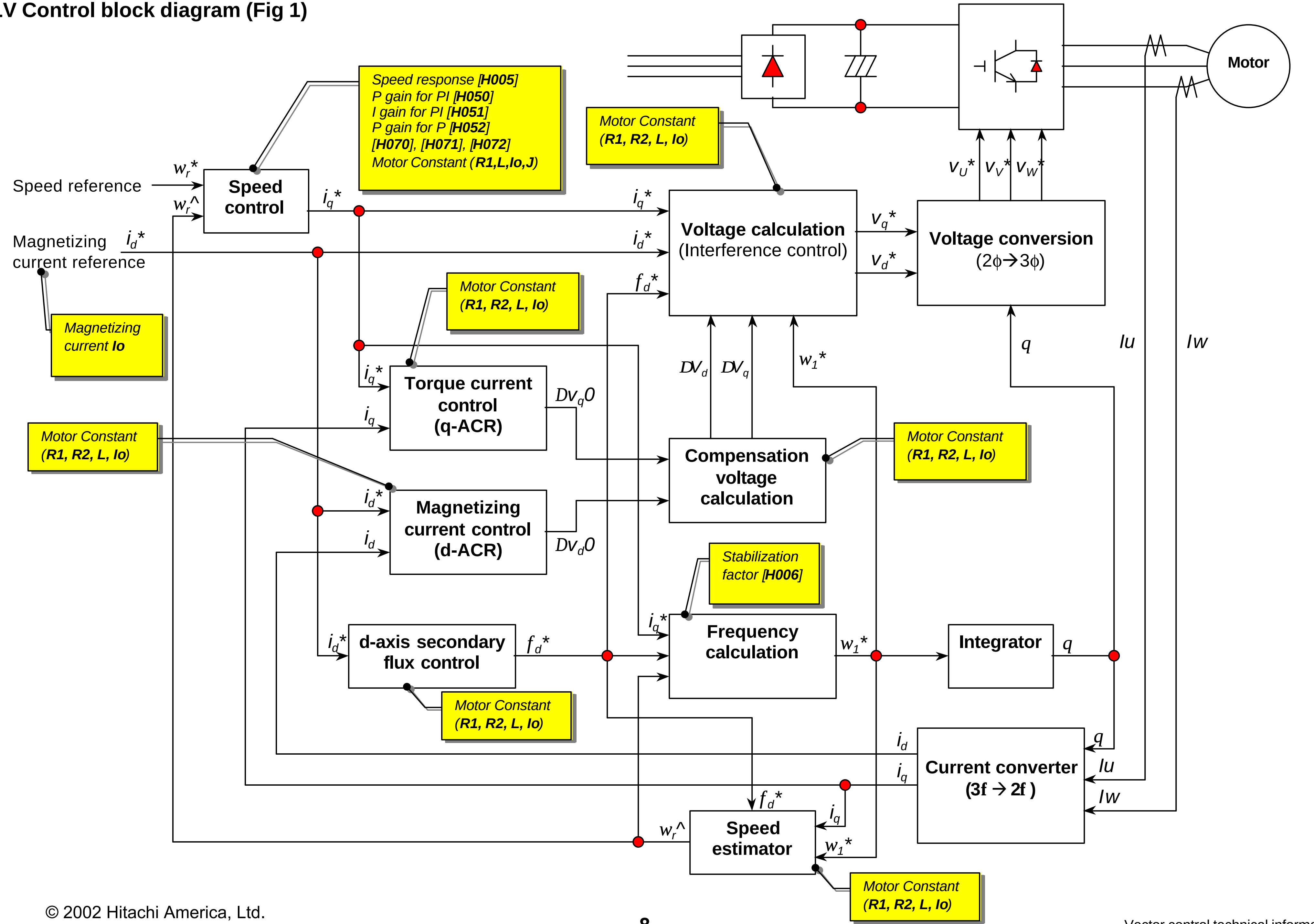
Table 2 shows suggestions for adjusting the SLV and other related parameters to correct various phenomena.

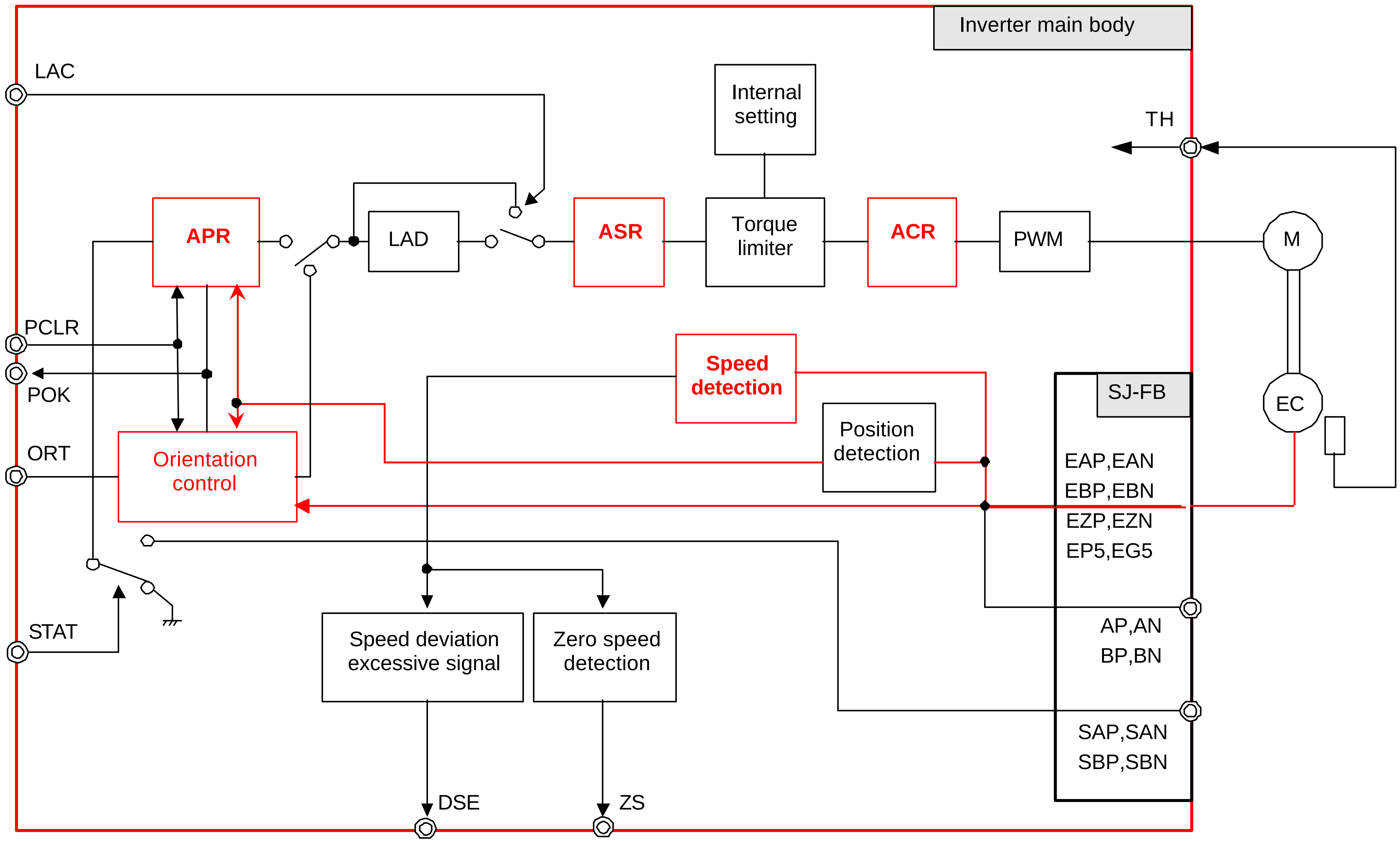
Table 2. Suggestions for tuning

#	Phenomena	Parameter	How to adjust
1	Actual speed is faster than the target speed. (Speed deviation is +)	**H021**	Decrease ***R2*** value (Minimum target is 80% of the preset value)
2	Actual speed is slower than the target speed. (Speed deviation is -)	**H021**	Increase ***R2*** value (Maximum target is 120% of the preset value)
3	Insufficient torque at low speed (~ few Hz)	**H020**	Increase ***R1*** value (Maximum target is 120% of the preset value)
		H023	Increase ***Io*** value (Maximum target is 120% of the preset value)
4	Shock at start	**H024**	Decrease ***J***
5	Unstable motor rotation	**H005**	Decrease ***speed response factor***
		H024	Decrease ***J***
		H006	Increase / decrease ***stability control factor*** (Increase or decrease depends on the situation.)
		A045	Decrease ***output gain***
		A081	Set ***AVR function*** to OFF
		b083	Decrease ***carrier frequency***
6	Insufficient torque at low speed due to torque limit action	**b021, b041 ~b044**	Set; ***Torque limit level*** > ***Overload restriction level***
7	Response is slow	**H005**	Increase ***speed response factor***
		H050	Increase ***P-gain of speed response factor***
		H051	Decrease ***I-gain of speed response factor***
8	Speed overshoot due to too quick response	**H005**	Decrease ***speed response factor***
		H050	Decrease ***P-gain of speed response factor***
		H051	Increase ***I-gain of speed response factor***

***Refer to Table 3 for a standard (default) motor parameter settings for SJ300 series inverter.**

SLV Control block diagram (Fig 1)





SJ-FB Option Board Block Diagram

Typical Motor Constants

		0.4kW	0.75kW	1.5kW	2.2kW	4kW	5.5kW	7.5kW	11kW	15kW	18.5kW	22kW	30kW	37kW	45kW	55kW	75kW	90kW	110kW	132kW
2p	***R1***	24.584	9.404	3.588	2.368	1.124	0.820	0.512	0.368	0.240	0.192	0.156	0.148	0.088	0.072	0.052	0.032	0.024	0.016	0.012
	R2	6.880	6.048	2.520	1.776	1.032	0.400	0.272	0.236	0.184	0.140	0.112	0.104	0.112	0.084	0.072	0.036	0.040	0.028	0.024
	L	83.28	47.56	24.84	13.64	7.88	6.44	5.28	7.36	5.16	4.12	2.88	2.40	2.28	1.88	1.48	1.00	0.80	0.72	0.60
	Io	0.75	1.17	2.61	2.43	5.10	9.21	11.25	7.97	10.53	12.91	16.18	18.51	21.25	27.00	31.50	35.00	36.17	44.00	47.00
	J	0.003	0.005	0.011	0.012	0.039	0.049	0.059	0.095	0.116	0.126	0.276	0.313	0.551	0.613	0.713	3.001	3.438	4.625	5.625
4p	***R1***	22.800	11.936	4.496	3.604	1.600	0.960	0.608	0.520	0.320	0.204	0.160	0.132	0.104	0.080	0.060	0.036	0.028	0.024	0.016
	R2	11.092	6.392	3.152	1.808	0.996	0.684	0.416	0.300	0.228	0.180	0.148	0.108	0.104	0.080	0.068	0.044	0.032	0.032	0.024
	L	130.56	51.88	25.12	18.64	12.60	11.28	10.40	7.44	5.16	4.12	3.64	2.40	2.32	1.92	1.48	1.00	0.96	0.76	0.68
	Io	0.90	1.26	2.19	4.37	7.64	6.57	8.25	9.91	12.70	16.66	18.51	24.08	28.33	33.33	45.16	50.00	54.33	50.00	57.33
	J	0.005	0.009	0.017	0.027	0.072	0.088	0.111	0.176	0.213	0.413	0.476	0.601	1.038	1.138	1.376	3.001	3.438	6.000	7.000
6p	***R1***	15.332	10.156	5.028	2.804	1.268	1.000	0.872	0.552	0.300	0.268	0.212	0.148	0.112	0.104	0.060	0.044	0.036	0.024	0.020
	R2	7.200	5.496	3.252	2.100	0.880	0.640	0.500	0.308	0.240	0.188	0.156	0.108	0.096	0.076	0.056	0.048	0.048	0.024	0.020
	L	109.16	57.36	37.60	33.04	26.56	24.36	22.88	5.96	5.72	4.76	4.00	2.76	2.32	1.88	1.52	1.16	1.04	0.72	0.68
	Io	1.26	1.78	3.01	4.64	6.30	7.20	8.37	11.16	14.33	16.73	20.25	28.96	33.33	38.90	43.17	58.33	58.00	81.00	68.00
	J	0.009	0.017	0.031	0.062	0.151	0.176	0.276	0.363	0.688	0.813	0.938	1.626	1.876	2.126	4.376	5.251	7.875	9.750	25.625
8p	***R1***	26.668	10.244	3.532	1.708	1.000	0.900	0.804	0.536	0.412	0.320	0.232	0.168	0.092	0.060	0.052	0.040	0.024	0.020	0.016
	R2	15.200	6.632	2.656	1.900	1.260	1.120	1.020	0.392	0.300	0.244	0.188	0.160	0.132	0.080	0.068	0.064	0.040	0.036	0.032
	L	142.84	78.04	59.44	36.36	27.44	25.36	23.44	9.84	6.68	6.00	4.32	3.44	3.00	2.08	1.76	1.44	1.08	0.88	0.72
	Io	1.44	2.34	4.25	6.75	8.40	8.52	8.63	11.97	17.66	19.91	26.73	34.83	33.80	47.50	51.33	59.33	67.00	91.47	109.17
	J	0.017	0.031	0.062	0.126	0.226	0.276	0.363	0.801	0.938	1.626	1.876	2.126	6.376	9.251	12.001	15.001	25.625	25.625	25.625

These parameters are based on EU motors, which have slightly different motor constants than Japanese & US motors.

Therefore the Japanese versions and US versions of SJ300 have slightly different motor parameters as default settings.

(2-5) Example of tuning effects (SLV mode)

This section shows examples of actual effects when changing each parameter by showing motor current waveforms. Please note that **these are just examples**. Actual motor performance will depend on the application.

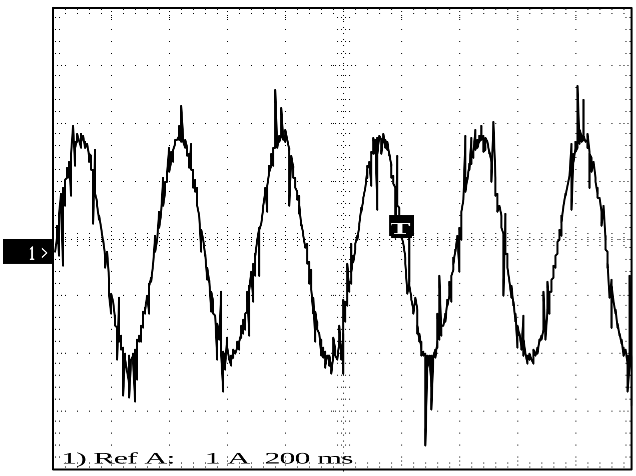
This data is reference only! It is only intended as a guide for obtaining optimal performance.

<Summary of examples>
Common condition

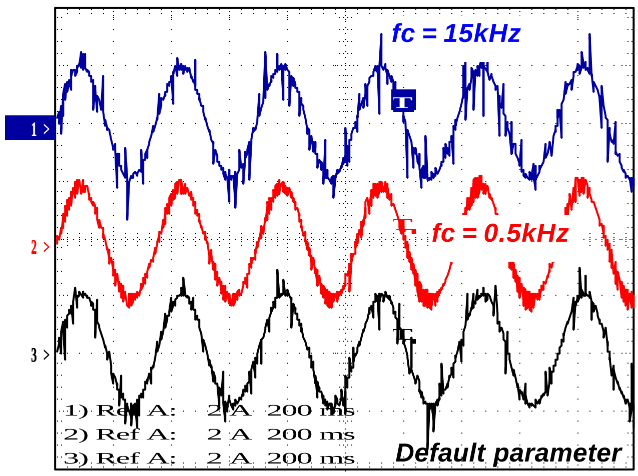
- INV : SJ300-007HFE (rated output current = 2.5A)
- Motor : Hitachi standard induction motor (380V 50Hz 0.75kW 1.9A 4p 1420rpm) **No load** (shaft free)
- Set frequency [F001] = 3.00Hz
- Acceleration time [F002] = 0.01s, Deceleration time [F003] = 0.01s
- **Control mode [A044] = 03 ; SLV mode (open loop)**
- All others are default settings

Parameter	**Default parameter** ***Data00***	comparison	***Data number***	Remarks
b083 : Carrier frequency	**5.0 kHz**	0.5 kHz 15 kHz	***Data01***	
H003 : Motor kW	**0.75 kW**	75kW	***Data02***	
H004 : Motor poles	**4**	8	***Data03***	OC trip
H005 : Speed response factor ***K***	**1.590**	0.100 10.00	***Data04***	
H020 : Motor ***R1***	**11.93 W**	3.000 30.00	***Data05***	
H021 : Motor ***R2***	**6.392 W**	3.000 30.00	***Data06***	
H022 : Motor ***L***	**51.88 mH**	10.00 200.0	***Data07***	Shock at start
H023 : Motor ***Io***	**1.26 A**	0.3 3.0	***Data08***	OC trip
H024 : Total ***J***	**0.009 kgm²**	0.001 0.100	***Data09***	OC trip
H050 : ***P-gain*** of ***K***	**100 %**	1 500	***Data10***	Shock at start
H051 : ***I-gain*** of ***K***	**100%**	1 200	***Data11***	

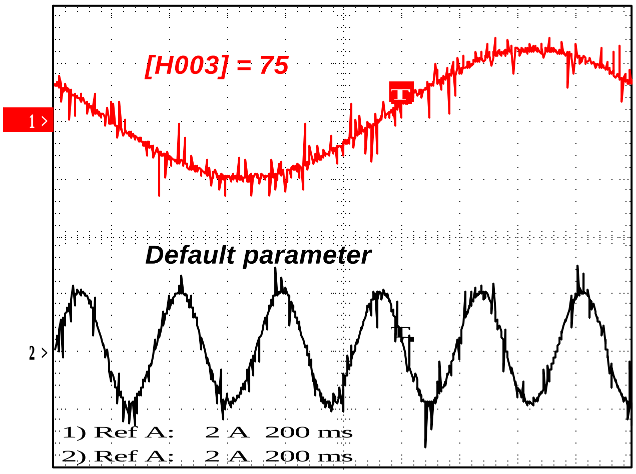
Note - the graphs show steady state operation for comparison purposes only. Response characteristics cannot be determined from this data.



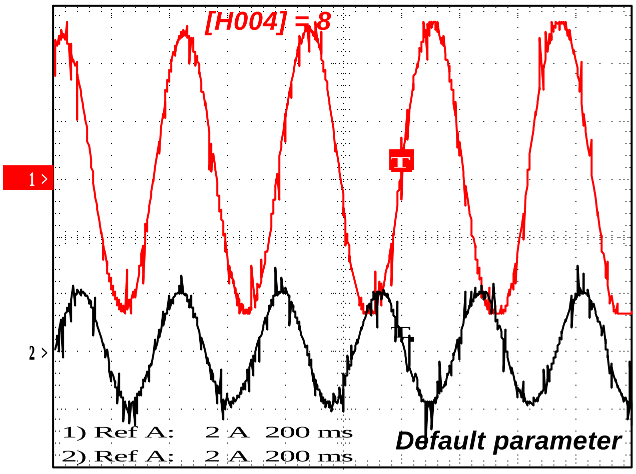
Data00. Default parameter
Actual frequency (average) ***f(ave) = 2.88Hz***
I_M = 1.38Arms



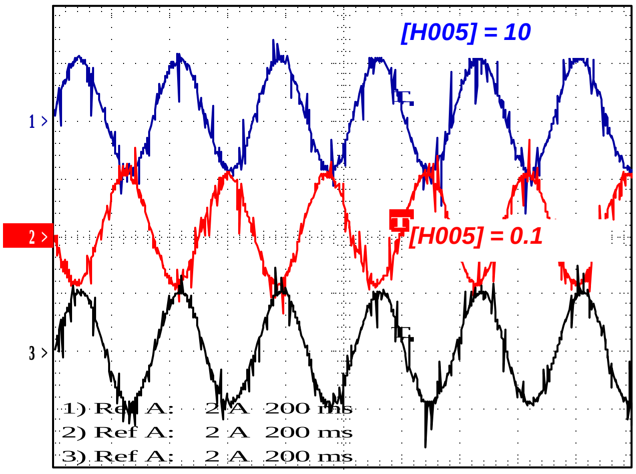
Data01. Carrier frequency 5kHz→0.5kHz / 15kHz
f (ave) = 2.92 Hz / 2.88Hz
I_M = 1.42 Arms / 1.38



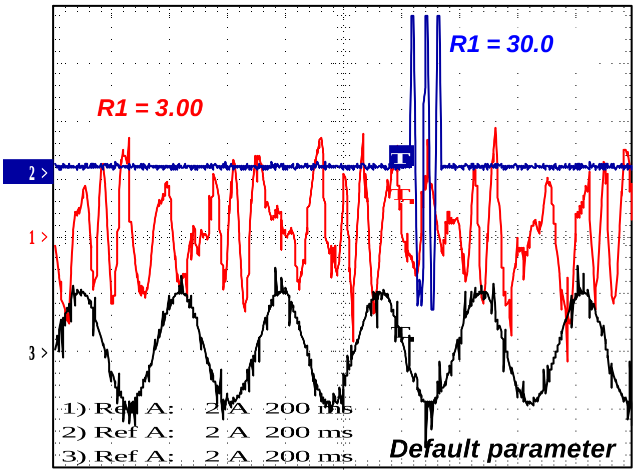
Data02. Motor kW [H003] = 0.75kW → 75kW
f (ave) = 0.87 Hz
I_M = 1.57 Arms



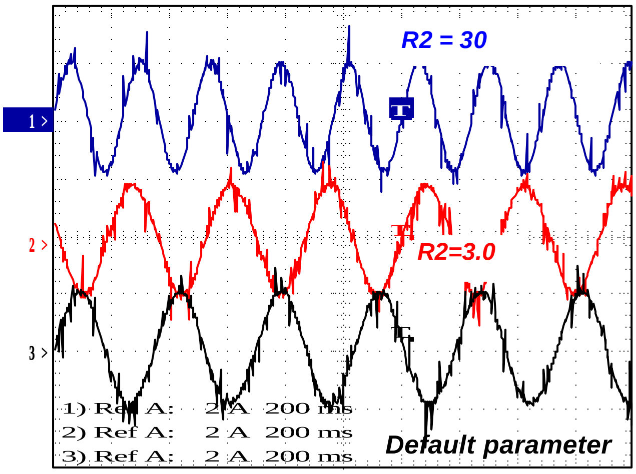
Data03. Motor poles [H004] = 4p→8p
OC trip after few seconds.



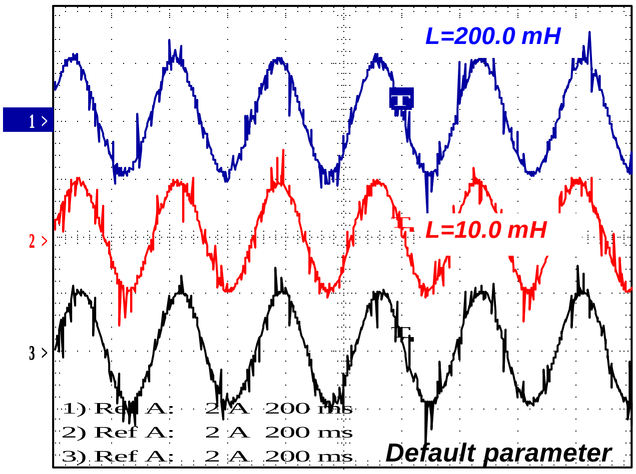
Data04. K [H005] = 1.590 → 0.1 / 10
f (ave) = 3.08 Hz / 2.97 Hz
I_M = 1.38 Arms / 1.38 Arms
K effects on the response so there is almost no difference in steady state current waveform.



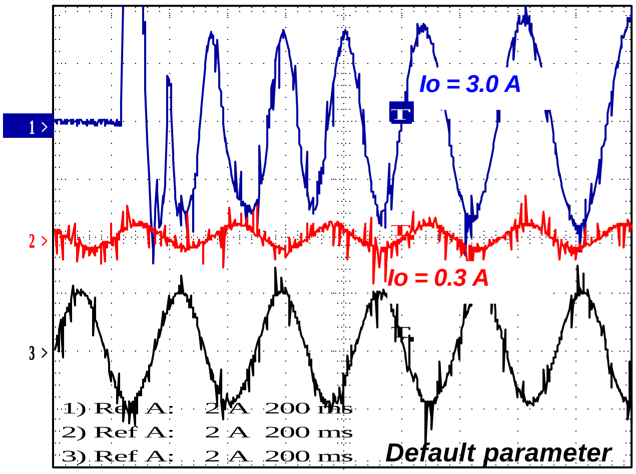
Data05. R1 [H020] = 11.93 → 3.000 / 30.00
R1=3.00 → Bad motor performance
R1=30.0 → OC trip at start



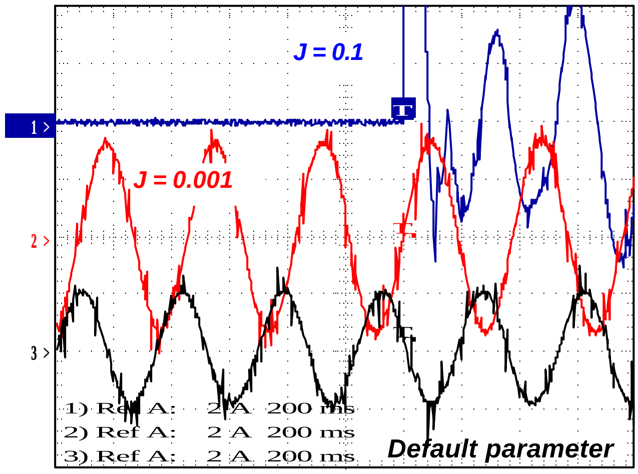
Data06. R2 [H021] = 6.392 → 3.000 / 30.00
f (ave) = 2.94 Hz / 4.25 Hz
I_M = 1.37 Arms / 1.34 Arms



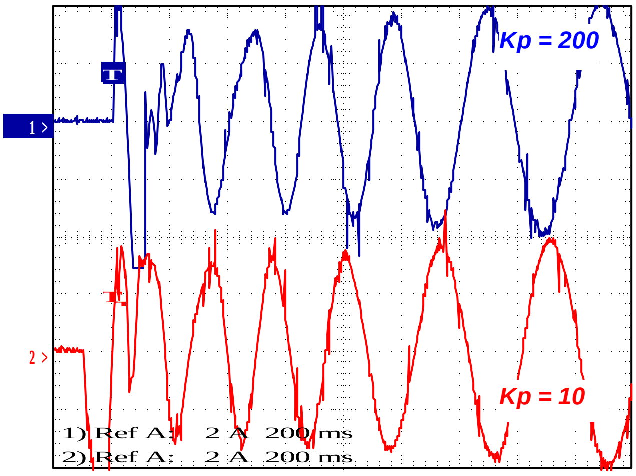
Data07. L [H022] = 51.88 → 10.00 / 200.0
f (ave) = 2.96 Hz / 2.79 Hz
I_M = 1.37 Arms / 1.40 Arms



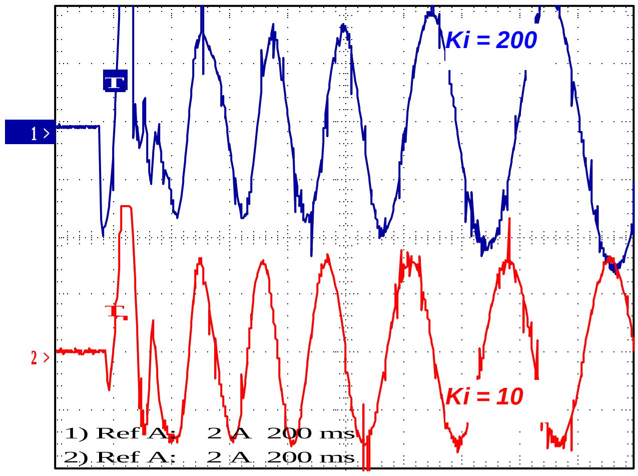
Data08. Io [H023] = 1.26 → 0.30 / 3.00
f (ave) = 2.98 Hz / -
I_M = 0.40 Arms / - (OC trip)



Data09. J [H024] = 0.009 → 0.001 / 0.100
f (ave) = 2.61 Hz / -
I_M = 2.29 Arms / - (OC trip)



Data10. Kp [H050] = 100 → 10 / 200
Shock at start and then OC trip



Data11. Ki [H051] = 100 → 10 / 200
Shock at start and then OC trip

- Note that these plots were made under steady state conditions, i.e. not transient data. Transient response cannot be determined from these plots.
- There is no set procedure or specific order for these tuning steps, because optimal tuning depends on the conditions and situation of the system. Refer to Table 2 in previous section for suggestions for tuning.

[3] Positioning under ASR mode (Orientation function) (V2 mode)

This can be implemented using **SJ-FB (feed back option card)**.

(3-1) Orientation Function

The SJ300 series incorporates a function where the inverter counts the pulses from the motor encoder and stops after a certain number of pulses. It is called the **orientation function**.

The Orientation function is used when an accurate stop position is required.

The SJ300 does not count encoder pulses every time, which means it is different from servo drives. The SJ300 starts counting the encoder pulses only after the Z pulse is given during orientation mode. Therefore the SJ300 can stop the motor at a certain position.

- First, it is necessary to go into the orientation mode. (Turn the "ORT" terminal ON on the logic card.) During orientation period, INV stops the motor after certain pulses from Z pulse is given.

<Example of stopping 7pulses after Z pulse is given>

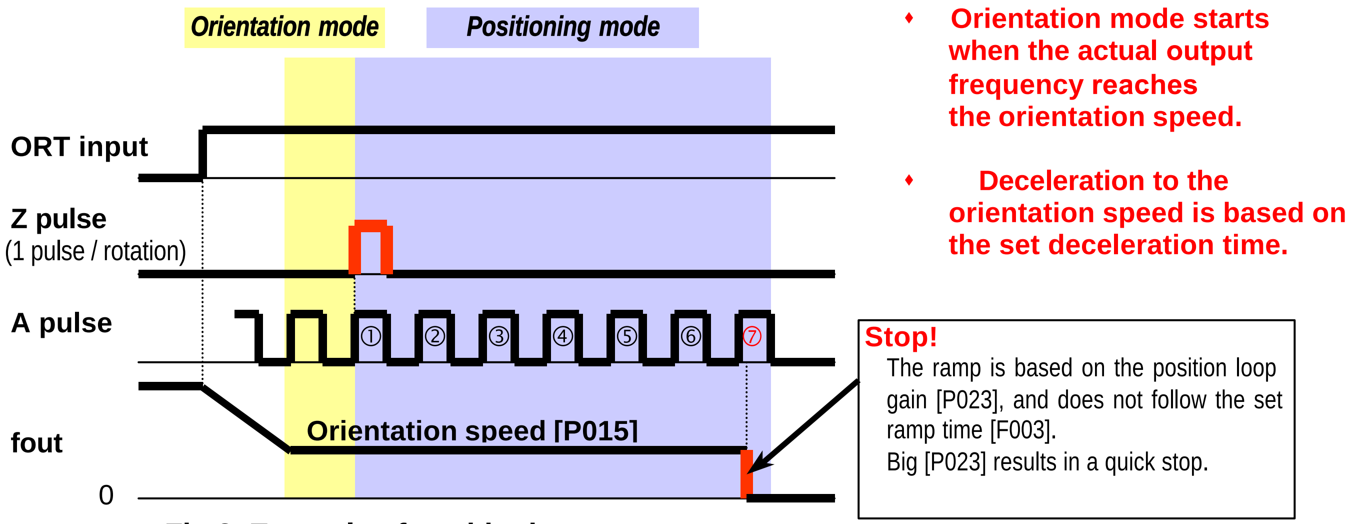


Fig 3. Example of positioning

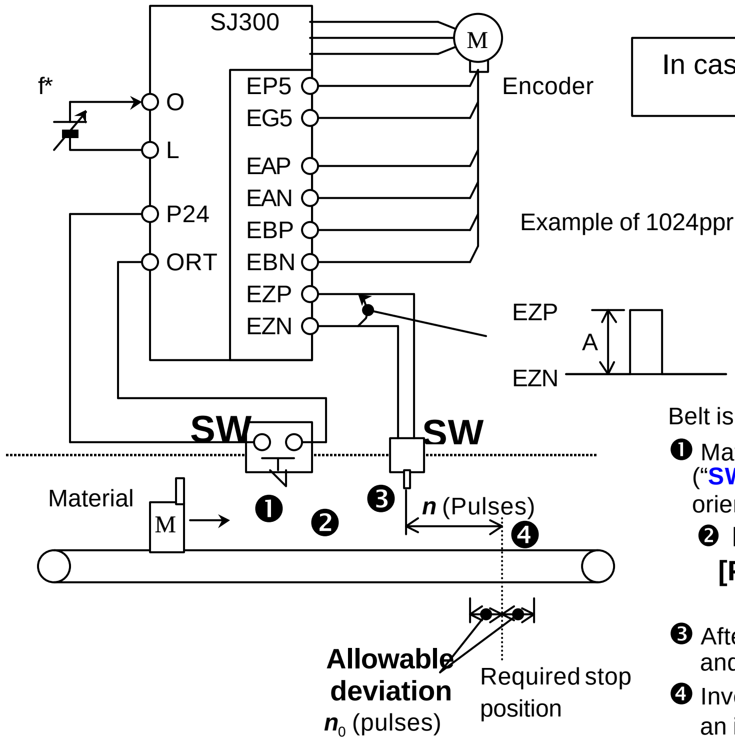
Parameter set for this example under following condition is in table below.

- 1024 ppr encoder
- 2.0 Hz of orientation speed
- acceptable positioning range is 7±3 pulses
- give frequency command from the analog input (O-L)
- give RUN command from the digital panel

No.	Code	Contents	Set value	Remarks
1	**A044**	Control method	**05**	V2 (closed loop control)
2	**P011**	ppr of the encoder	**1024**	Depends on the encoder
3	**P012**	Control mode	**00**	ASR (Speed command base on speed)
4	P013	Mode of the pulse train input	-	No need to care because this is ASR mode
5	**P014**	Stop position while orientation	**28**	[P014] = 4096 * 7 / 1024 = 28
6	**P015**	Speed while orientation	**2.0**	In case of 2.0Hz for orientation speed.
7	**P016**	Direction of orientation	**00**	In case of FW rotation
8	**P017**	Orientation completion range	**12**	Allowable deviation of positioning. [P017] = ***3*** * *4* (Multiplying 4 is fixed as MCU calculation)
9	A001	Frequency command from;	01	Terminal (O-L input)
10	A002	RUN command from;	02	"RUN" key of the operator
11	F002	Acceleration time	3.0	As short as the system allows.
	F003	Deceleration time	3.0	

(3-2) Example of positioning under speed control mode (ASR) on SJ300 with SJ-FB

(3-2-1) Example of wiring



In case of using external Z pulse

Example of 1024ppr line driver type encoder.

Belt is stopped at a certain position after passing a switch "**SWZ**".

❶ Material M passes "**SWO**" point.
("**SWO**" turns ON which means an inverter is going into an orientation mode.)

❷ **Belt speed will be an orientation speed (set in [P015]), which means it is ready for positioning and wait for a Z pulse.**

❸ After passing **SWZ** point, inverter starts counting the pulses and stops at a certain position (set in [P017]).

❹ Inverter gives out a "positioning completion signal ; POK" from an intelligent output terminal.

Fig 4. Example of wiring

(3-2-2) Example of parameter settings

No.	Code	Contents	Set value	Remarks
1	A044	Control method	05	V2 (closed loop control)
2	P011	ppr of the encoder	1024	Depends on the encoder
3	P012	Control mode	00	ASR (Speed command base on speed)
4	P013	Mode of the pulse train input	-	No need to care because this is ASR mode
5	P014	Stop position while orientation	*	When you want to stop at ***n*** pulses after catching zero-pulse (after AZP/N is given); [P014] = 4096 * ***n*** / [P011] <Regardless the ppr of an encoder> Stop at 300 pulses after Z pulse is given for example; [P014] = 4096 * 300 / 1024 = **<u>1200</u>**
6	P015	Speed while orientation	2.0	In case of 2.0Hz for orientation speed.
7	P016	Direction of orientation	00	In case of FW rotation
8	P017	Orientation completion range	*	Allowable deviation of positioning. [P017] = n_0 * 4
9	A001	Frequency command from;	01	Terminal (O-L input)
10	A002	RUN command from;	02	"RUN" key of the operator
11	F002	Acceleration time	3.0	As short as the system allows.
	F003	Deceleration time	3.0	

Above are the main parameters to get position control. You have to adjust other parameters ([H***] parameters) to get good performance.

(3-2-3) Timing chart

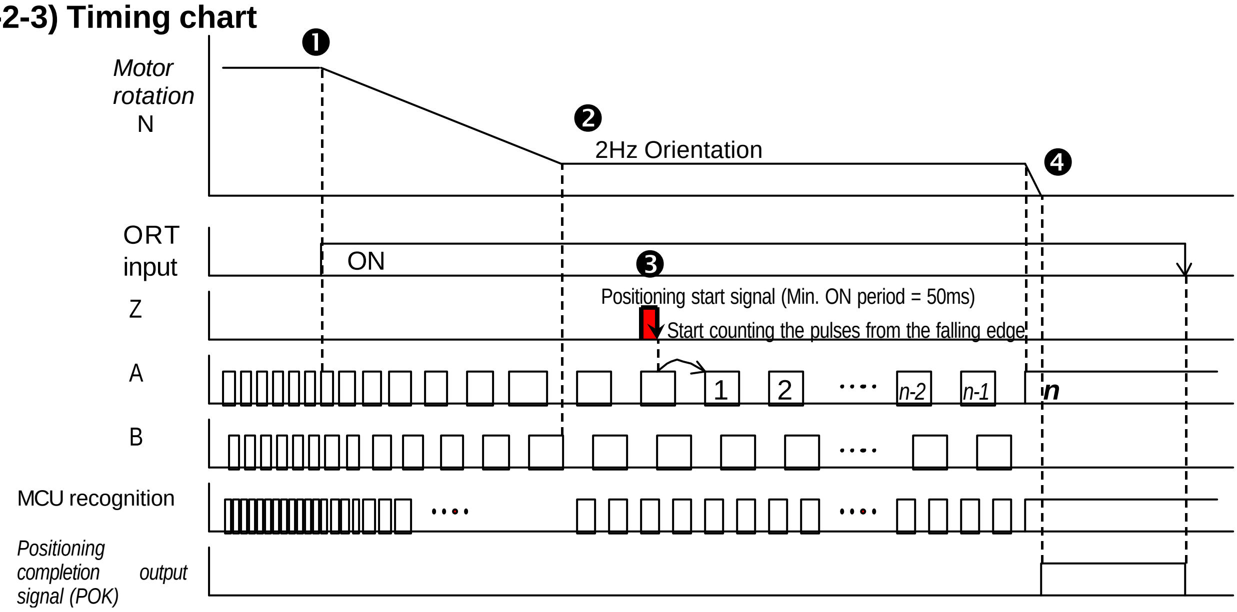


Fig 5. Timing chart of example 3-2

Motor shaft rotates a bit to reverse in case it exceeds the stop position (1 ~ 2 pulses).

<u>Refer to section [2] for adjusting each parameters to get good motor performance.</u>

[4] APR Control

You can control the motor by a pulse train input on SJ300 with SJ-FB.

Make STAT terminal ON to get started. (Inverter starts to accept pulse train input after STAT is turned ON.)

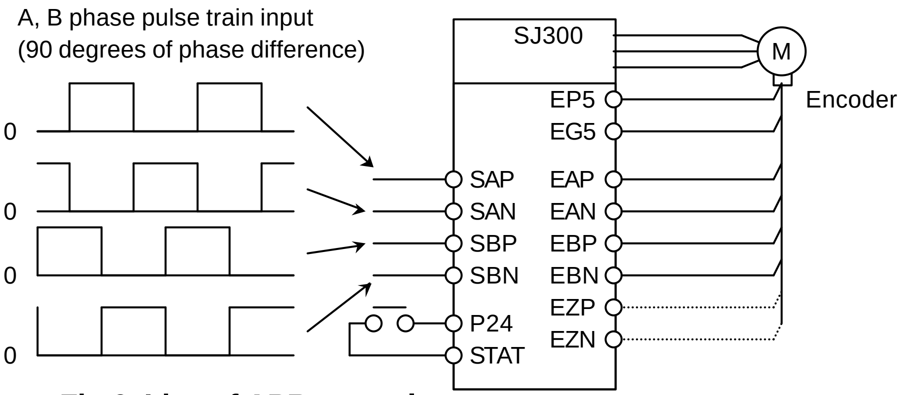


Fig 6. Idea of APR control

SJ300 controls the motor based on the pulse train input to SAP, SAN, SBP, SBN which are 90 degrees phase difference of A, B signals. Please see below for the simplified block diagram of the control.

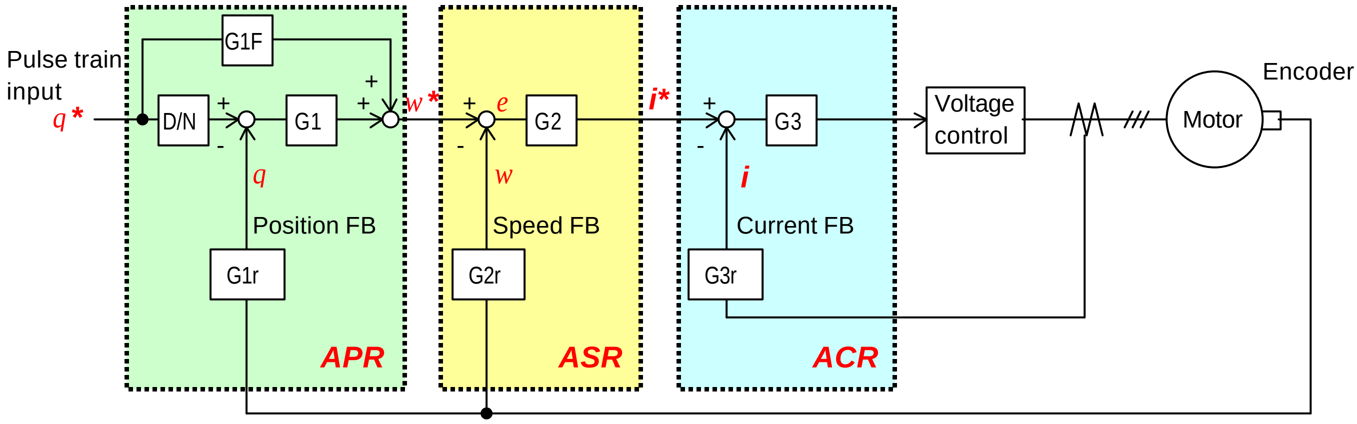


Fig 7. Simplified control block diagram for V2 control

<Explanation of the performance>

If the control system is in a stable state, it performs like figures shown right. Feedback will be 1st order lag against the reference because of PI control. (Ignoring the Overshoot.)

Making STAT signal ON while there is a continuous pulse train input result in a constant increasing of q^*. (q^* will not be a step change because it is a number of pulses.) In this case feedback q will be fixed according to the APR response during t1 period.

In t2 period, feedback q will be stabilized by APR and therefore it will be in a constant increasing mode together with the reference (q^*).

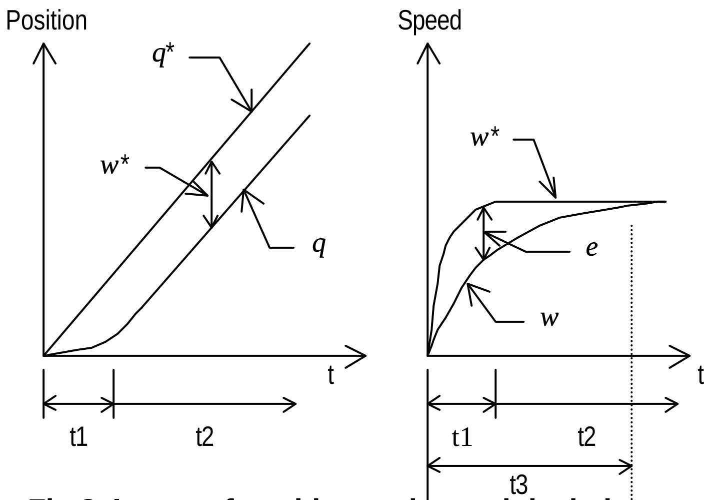


Fig 8. Image of position and speed deviation

Therefore, w (=$G1 \times (q^*-q)$), which is the output or APR block will be in a increasing (not a constant increasing) mode during t1 period and will be stable in t2 period.

ASR block receives the w^* and controls the system to make e (= w^* - w) to be 0. (see above figure.) and output of this block will be forwarded to next block.

(4-1) Example of the parameter settings

Main parameters to be set for APR control.

No.	Code	Contents	Set value	Remarks
1	**A044**	**Control method**	**05**	**Closed loop control mode**
2	**P011**	**ppr of the encoder**	*****	**Depends on an encoder**
3	**P012**	**Control mode**	**01**	**APR mode**
4	**P013**	**Mode of the pulse train input**	*****	**Depends on an encoder. See manual of SJ-FB the mode.**
5	P014	Stop position while orientation	-	No need to set since this is not positioning.
6	P015	Speed while orientation	-	
7	P016	Direction of orientation	-	
8	P017	Orientation completion range	-	
9	P018	Delay time for orientation completion	-	
10	**P019**	**Position of an electronic gear**	*****	**Depends**
11	**P020**	**Numerator of an electronic gear**	*****	**Depends**
12	**P021**	**Denominator of an electronic gear**	*****	**Depends**
13	**P022**	**Feed forward gain (FFWG)**	*****	**Depends**
14	**P023**	**Position loop gain (G)**	*****	**Depends**

(4-2) How to adjust control parameters for APR control

There are only two parameters to be adjusted to get good performance under APR control mode, which are feed forward gain (P022) and position loop gain (P023).

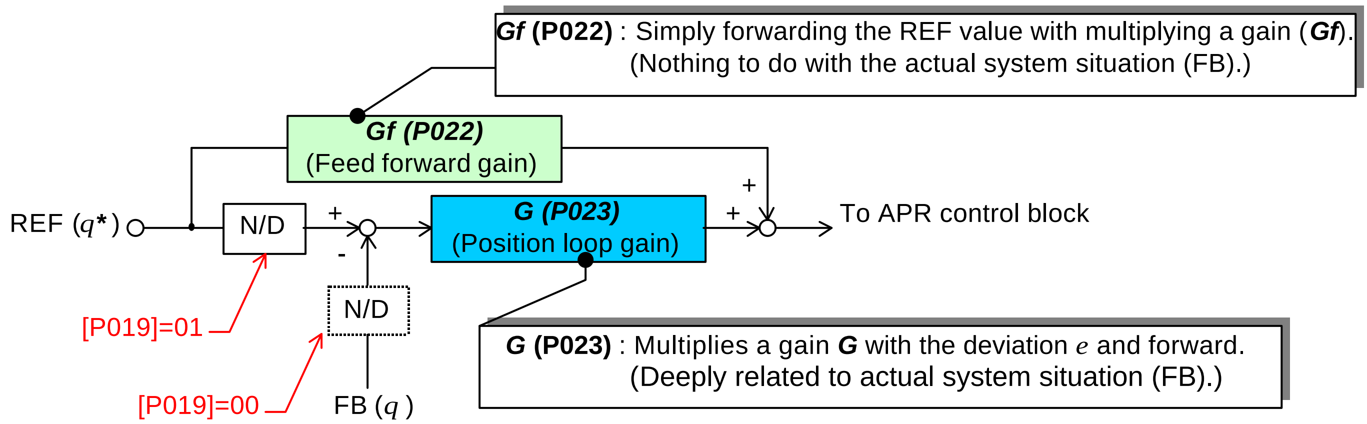


Fig 9. Block diagram of position control loop

Other parameters shown in section [2] should also be adjusted to get overall good performance.

[5] Master Slave Control

With combination of ASR and APR control, we can achieve master-slave control, which means the slave motor follows the master motor.

SJ-FB has pulse train signal output terminals (AP, AN, BP, BN) so that he can give them to pulse train input terminals of another SJ-FB. The output signal is the same as motor encoder feedback signal of the motor belonging to him.

Master inverter can be either ASR or APR mode, however the slave inverter should be in APR mode because the slave inverter is controlled by pulse train input from the master.

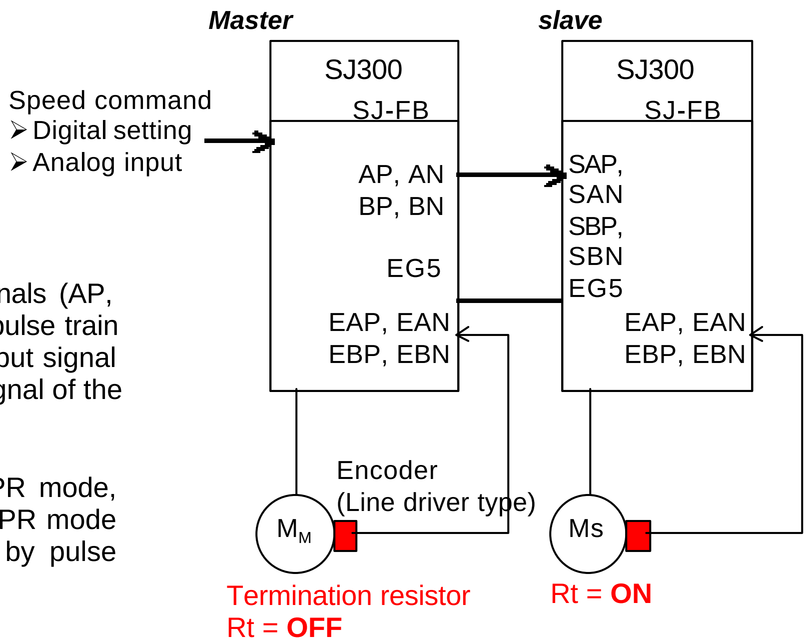


Fig 10. Idea of Master-Slave control

(5-1) Example of parameter settings for Master-Slave control

<How to achieve speed 5 : 1 between master and slave>

Code	Function	Set value		Remarks
		Master	Slave	
[A044]	Main Control mode	05 (V2)	05 (V2)	
[P011]	Encoder pulse (ppr)	1,024	1,024	
[P012]	Vector control mode	00 (ASR)	01 (APR)	
[P013]	Mode of the pulse train input	*	*	Depends on the encoder
[P014]	Stop position while orientation	60	-	15 pulses * 4 = 60
[P015]	Speed while orientation	3.00 Hz	-	
[P016]	Direction of orientation	00 (FW)	-	
[P017]	Orientation completion range	20	-	5 pulses * 4 = 20
[P019]	Position of an electronic gear	-	01 (REF side)	*(Note 1)*
[P020]	Numerator of an electronic gear	-	1,024	*(Note 1)*
[P021]	Denominator of an electronic gear	-	5,120	1,024 * 5 *(Note 1)*
[P022]	Feed forward gain (FFWG)	-	Depends	
[P023]	Position loop gain (G)	-	Depends	

(Note 1)

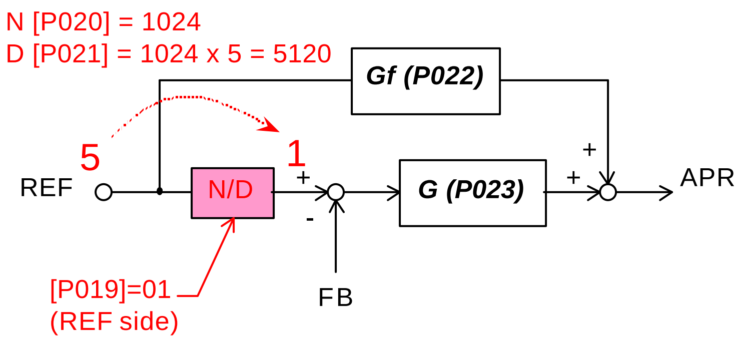


Fig 11. Electronic gear of APR control

Common condition :

- Encoder = 1,024 ppr for both master and slave motor
- Master is driven by ASR
- Master is stopped by positioning (3Hz of orientation speed)
- Master stops 15 pulses after a Z pulse is given during orientation (3 pulses for the slave)
- Both master and slave motors stop at the same time.
- Orientation completion range is 5 pulses

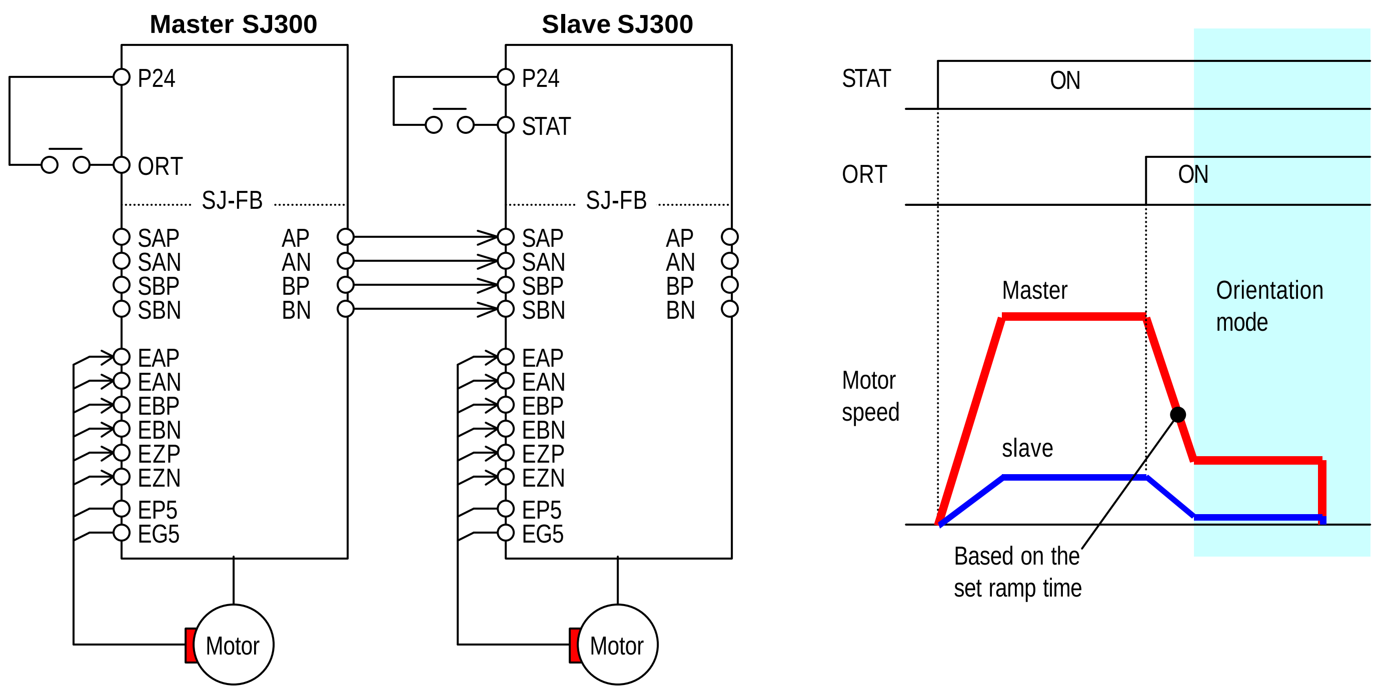


Fig 12. Wiring and timing chart example of Master-Slave control

(5-2) How many slaves can be connected?

There are two ways of connecting slave SJ300 to one master SJ300.

(5-2-1) Parallel connection

Maximum 10 slaves can be connected to a master based on RS422B EIAJ US. Actual capability is 32 units.

In this case, every slave follows the master with a minimum delay.

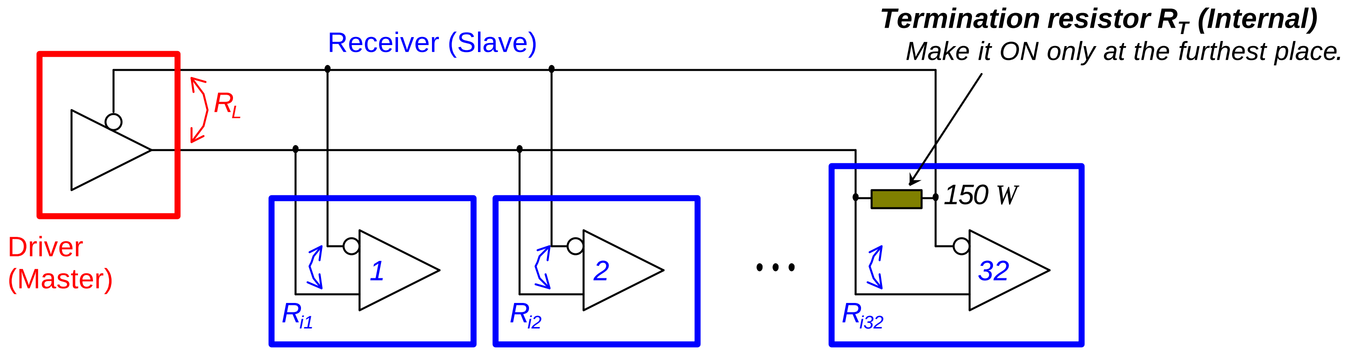


Fig 13-1. Parallel connection of Master-Slave control

- **RS422 standard**
  Load impedance of the driver $R_L > 100\,\Omega$
  Input impedance of the receiver $R_{in} > 4\,k\Omega$
- **Actual spec of SJ-FB**
  Load impedance of the driver $R_L > 100\,\Omega$
  Input impedance of the receiver $R_{in} = 12\,k\Omega$

In case of 32 slaves with SJ300;
$RL = (12\,k\Omega\ /\ 32)\ //\ R_T$
$= 107\,\Omega > 100\,\Omega$

∴ **Capability is 32 units**

(5-2-2) Series connection

Any numbers of slaves can be connected to a master theoretically.

Delay in response will be bigger at far end.

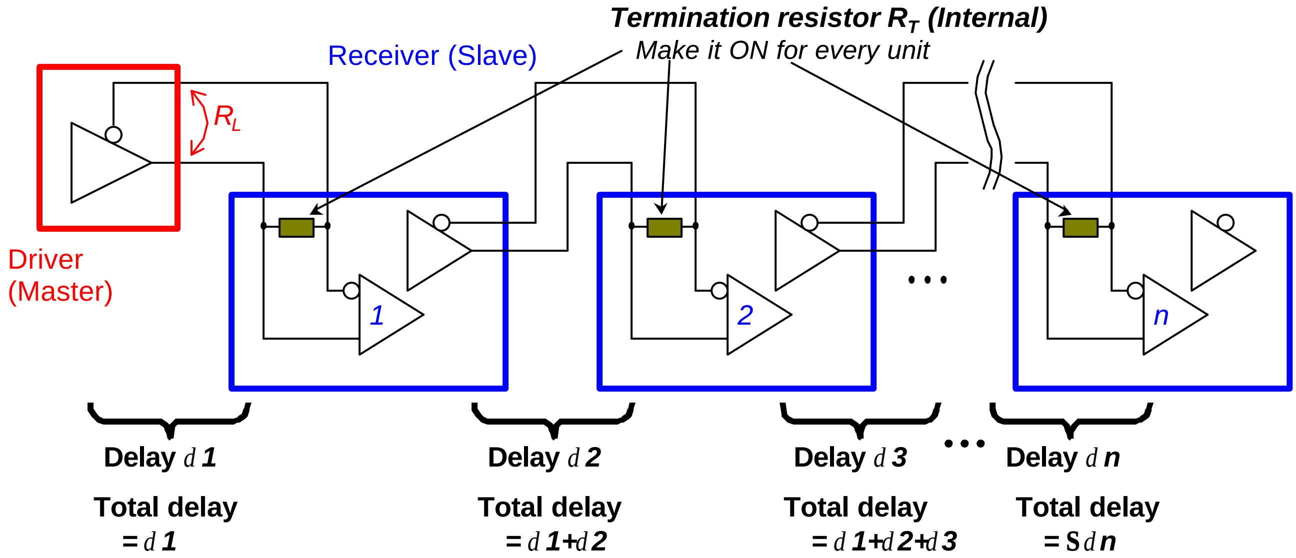


Fig 13-2. Series connection of Master-Slave control

(5-3) Explanation of each P parameter

[P001], [P002]
What to do in case of an option error

"00" : Make inverter trip when an option error.
"01" : Make inverter ignore the error.

[P001] is for option slot 1, and [P002] is for option slot 2.

[P010]
Function display selection related to SJ-FB under user parameter [U*] mode**

"00" : Parameters related to SJ-FB do not appear on the panel.
"01" : Parameters related to SJ-FB appear on the panel.

This is nothing to do with the actual performance of the motor control. It is only a display issue.

[P011]
Pulse numbers of the encoder (ppr)

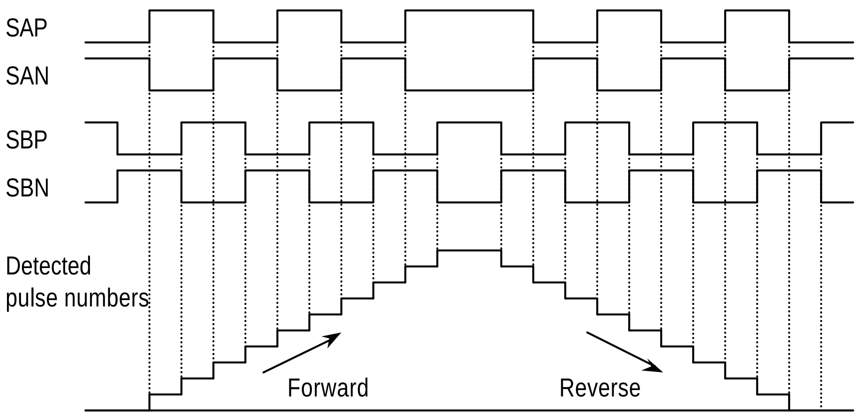
Suitable number should be set depending on the encoder to be used.

[P012]
SJ-FB control mode under V2 control mode

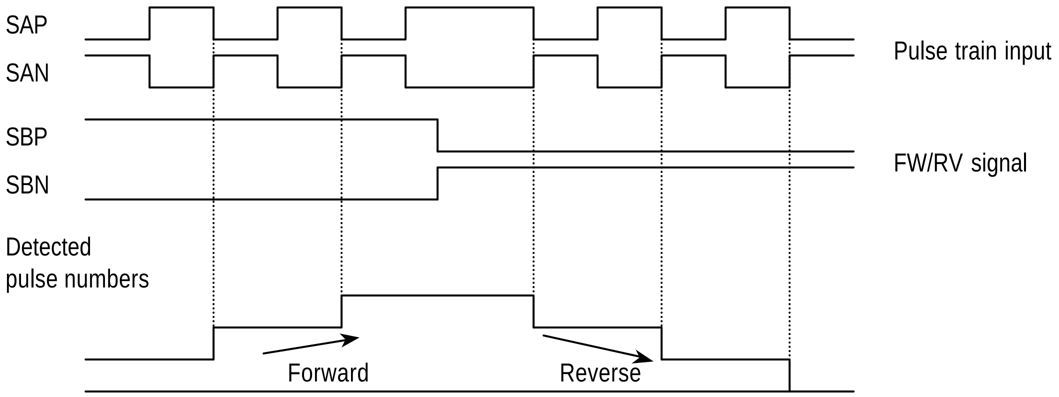
"00" : ASR (Speed control) mode
"01" : APR (Position control) mode

[P013]
Pulse train mode of the encoder

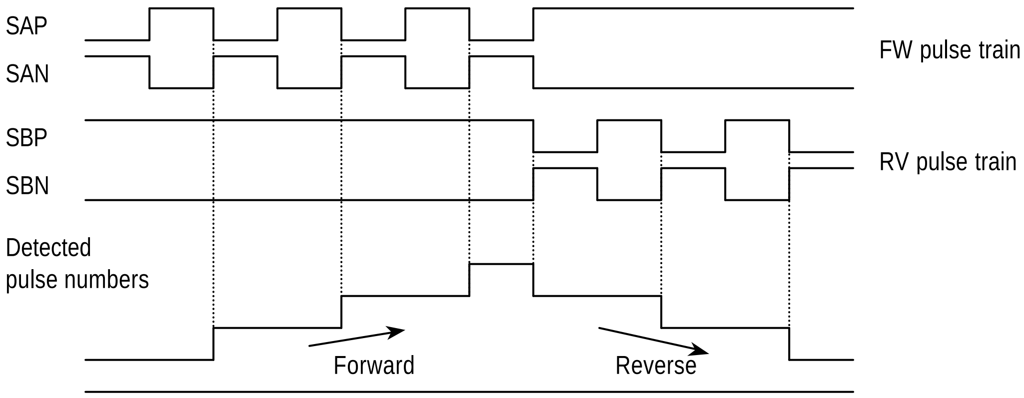
"00" : 90° of phase difference pulse train input



"01" : FW/RV pulse and pulse train



"02" : FW pulse train and RV pulse train



[P014]
Stop position during orientation

Input value is 4 time of the requested stop position (pulse numbers).

<Example>
If you want to stop the motor at 15 pulses after Z pulse is given;

[P014] = 15 * 4 = **60**

[P015]
Orientation speed

Low frequency is recommended to be set (1~few Hz for example), so to get stable performance of stopping.

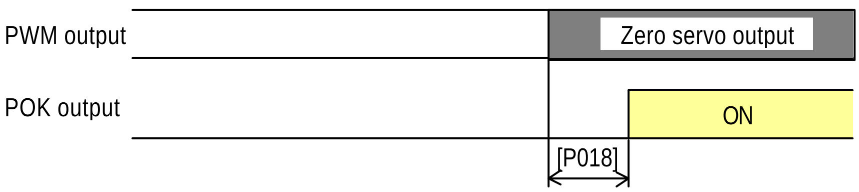
[P016]
Orientation direction

Set the direction during orientation.

[P017]
Completion range of positioning

SJ300 keep performing positioning until the actual stop position is inside this range.

[P018]
Delay time between Completion of positioning and output of the completion signal (POK)



- This is nothing to do with the actual motor performance, but just a delay time of POK output signal issue.

Fig 14. Timing chart of POK output

[P019]
Position of an electronic gear

[P020]
Numerator of the electronic gear

[P021]
Denominator of the electronic gear

Refer to section (4-2) and (5-1) for an information.

[P022]
Feed forward gain for APR control mode

[P023]
Position loop gain for APR control mode

Refer to section (4-2) for an information.

[P025]
Secondary resistance compensation

"**00**" : No compensation
"**01**" : With compensation

① Connect a motor thermistor between TH and CM1 terminal of the control card.

② Set [b098] to a suitable value
- "00" : Thermistor input invalid
- "**01**" : **PTC type**
- "**02**" : **NTC type**

③ Set the resistance value [Ω] you want to make it trip.

④ Set gain adjustment by [C085]

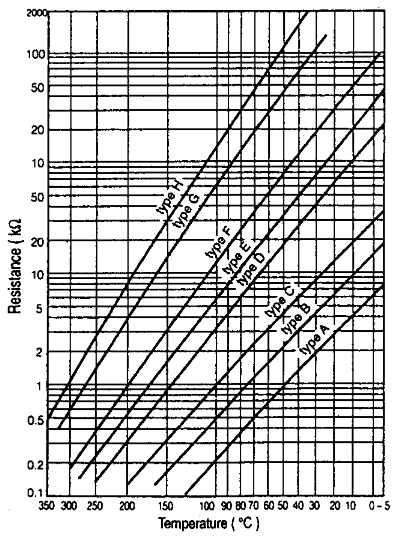
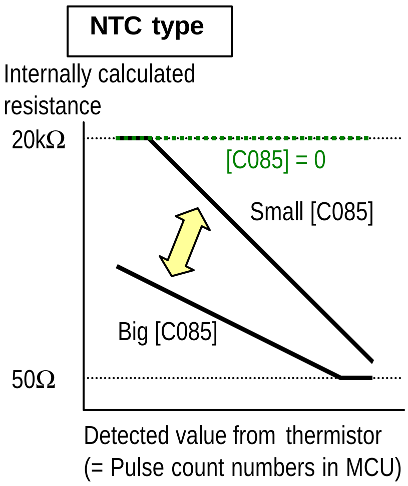
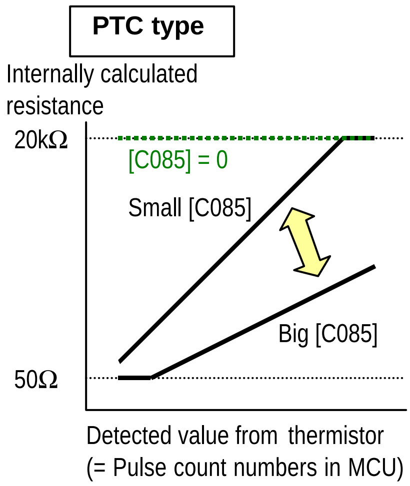


Fig 15. Example of thermistor characteristics





[P026]
Over speed trip level (%) setting

Inverter trips with over speed (***E 61*** or ***E 71***) when a deviation between actual speed and target speed exceeds the level of ***(Maximum frequency set) x [P026]***.

This can happen by an overshoot caused by incorrect settings of ***J ([H024]/[H034])*** and/or ***K([H005])*** value.

[P027]
Over deviation detection level (Hz) setting

Inverter gives out warning (***DSE output***) from an intelligent input terminal when the speed deviation exceeds this level. The calculation is based on a ***deviation*** *e* in **Fig 7** and **Fig 8**.

① Zero speed detection : ZS (21)

SJ300 gives out this signal when;

- **Actual rotation of the motor** becomes less than a set value of **[*C063*] under V2 mode**.
- **PWM output frequency** becomes less than a set value of **[*C063*] under other than V2 mode.**

② Speed deviation excessive : DSE (22)

DSE signal turns ON when an actual motor speed exceeds the set value of **[*P027*]** under V2 mode.

③ Positioning completion : POK (23)

POK signal turns ON when the motor stop position comes to a set range of **[*P017*]** during positioning. Once it goes out of this range the signal turns OFF and perform positioning again.

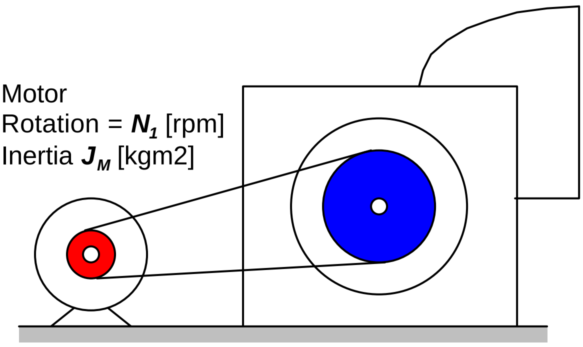
Appendix A Calculation of total inertia (reflected to the motor shaft)

(A-1) Ventilation Fan

- Inertia of a motor = J_M [kgm²]
- Inertia of a fan = J_L [kgm²] : Contact a fan manufacturer for the J_L value.

Total inertia $S\ J = J_M + J_L$

(Note) If there is a pulley inbetween them, calculation will be as follows.



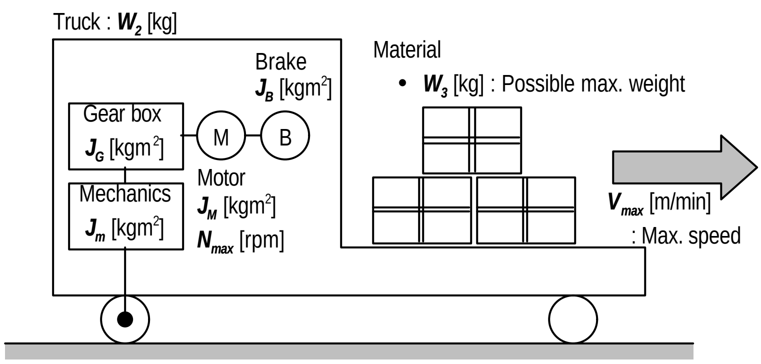
	Inertia	Rotation	Converted Inertia
Motor	J_M	N_1	J_M
Pulley 1	J_1	N_1	J_1
Pulley 2	J_2	N_2	$J_2 \cdot \left(\frac{N_2}{N_1}\right)^2$
Fan	J_L	N_2	$J_L \cdot \left(\frac{N_2}{N_1}\right)^2$
Total	-	-	$J_1 + J_M + J_2 \cdot \left(\frac{N_2}{N_1}\right)^2 + J_L \cdot \left(\frac{N_2}{N_1}\right)^2$

(A-2) Truck

- Maximum speed = V_{max} [m/min]
- Maximum motor rotation = N_{max} [rpm]

- Inertia of a gear box = J_G [kgm²] (*)
- Inertia of mechanics = J_m [kgm²] (*)
- Inertia of a motor = J_M [kgm²] (*)
- Inertia of the load = J_L [kgm²]

(*) Contact each manufacturer for each J [kgm²] value.



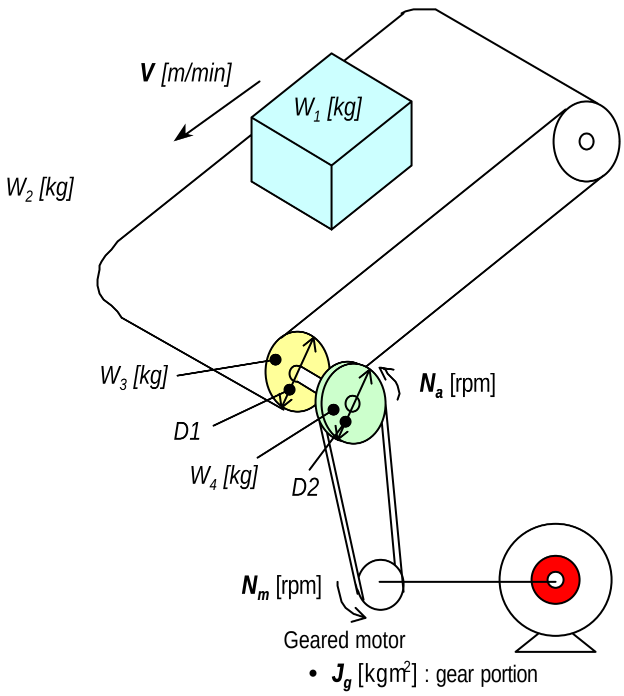
Total inertia $S\ J = J_G + J_m + J_M + J_L$

- $J_L = \frac{W_1 \cdot V_{max}^2}{4 \cdot p^2 \cdot N_{max}^2}$ [kgm²]

$W_1 = W_2 + W_3$ [kg] : Total weight

Refer to **Appendix B** for calculation of load inertia.

(A-3) Conveyor



- *Material*
  $Ja = (W_1 \times V^2)/(4\pi \times N_a^2)$
- *Belt conveyor*
  $Jb = (W_2 \times V^2)/(4\pi \times N_a^2)$
- *Drum for the belt conveyor (2 pcs)*
  $Jc = (1/8) \times (W_3 \times D1^2) \times 2$
- *Sprocket*
  $Jd = (1/8) \times (W_4 \times D2^2)$

Total inertia converted to a motor shaft ΣJ_m ;

$$\Sigma J_m = (Ja+Jb+Jc+Jd) \times (Na/Nm) + Jg$$

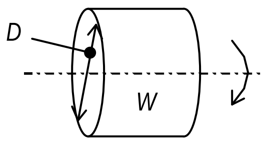
Jg ; Inertia for the gear portion

Appendix B Calculation of load inertia

(B-1) A column

$$J = (1/8) \cdot W \cdot D^2 \ [kg \cdot m^2]$$

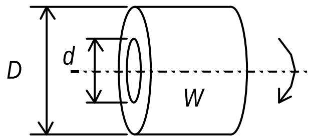
W [kg] : Weight
D [m] : Diameter



(B-2) A cylinder

$$J = (1/8) \cdot W \cdot (D^2 + d^2) \ [kg \cdot m^2]$$

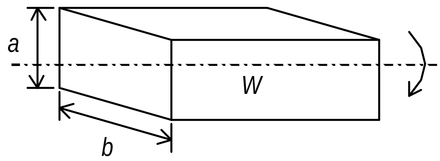
W [kg] : Weight
D [m] : Outer diameter
d [m] : Inner diameter



(B-3) A rectangular solid

$$J = (1/12) \cdot W \cdot (a^2 + b^2) \ [kg \cdot m^2]$$

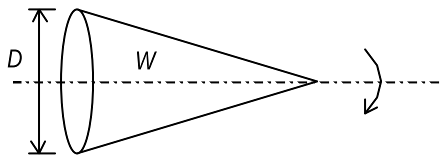
W [kg] : Weight
a [m] : Length
b [m] : Length



(B-4) A Cone

$$J = (3/40) \cdot W \cdot D^2 \ [kg \cdot m^2]$$

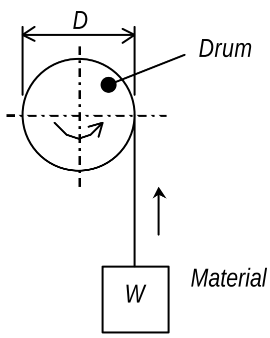
W [kg] : Weight
D [m] : Diameter



(B-5) Wind up (vertical linear motion)

$$J = (1/4) \cdot W \cdot D^2 \ [kg \cdot m^2]$$

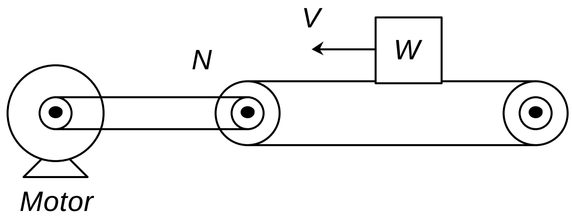
W [kg] : Weight of the material
D [m] : Diameter of a drum



(B-6) Horizontal linear motion

$$J = (W \cdot D^2) / (4\pi^2 \cdot N^2) \ [kg \cdot m^2]$$

W [kg] : Weight of the material
V [m/min] : Speed of the material
N [rpm] : Rotation of the converted shaft



Refer also to appendix **(A-3)** for detailed explanation.

Refer to Hitachi Inverter Technical Guide Book for further detailed information of inertia.