YASKAWA

Technical Note - Permanent Magnet Motor Control

Overview

The popularity of permanent magnet (PM) motors versus induction motors has increased due to the decreasing cost of rare earth magnets. End users are keying on efficiency and size reduction when selecting PM motors. Yaskawa drives offer up to three control methods for PM motors. Open loop vector PM (OLVPM) and advanced open loop vector PM (AOLVPM) does not require the use of an encoder. Closed loop vector PM (CLVPM) requires a feedback option card installed on the drive and the use of an encoder mounted on the motor. The table below lists the PM control methods available for a specific drive series.

Yaskawa Drive	OLVPM (A1-02=5)	AOLVPM (A1-02=6)	CLVPM (A1-02=7)
V1000	✔	✕	✕
A1000	✔	✔	✔
U1000	✔	✔	✔
Z1000	✔	✕	✕
GA800	✔	✔	✔

In this technical note, the focus will be on setting up the open loop vector PM (OLVPM) control method. The setup will include the use of the motor datasheet, auto-tuning (if available) and troubleshooting common fault codes that may be encountered.

Application Features

The table below outlines general specifications for OLVPM control method.

	OLVPM (A1-02=5)	Remarks
General Features	Variable torque application	HVAC Pumps Low dynamics
	Current stabilization algorithm	
	Starting torque 100% @ 5% speed	V1000, Z1000: 50% @ 10% speed
	Speed control range 1:20	V1000, Z1000 1:10
	Speed accuracy ±0.2%	
	Encoder feedback not available	Available in CLVPM
	Torque limit/control not available	Torque limit: AOLVPM, CLVPM Torque control: CLVPM
Motor	SPM & IPM	SPM: surface mounted permanent magnet IPM: interior mounted permanent magnet
Auto-tuning	PM Stationary Back-EMF (rotational)	V1000: auto-tuning N/A (use motor data-sheet) Z1000: use motor datasheet

Application Challenges

Selecting a Yaskawa drive with PM control methods is the first step in achieving success with a PM motor. The next step is obtaining good motor data to successfully control the PM motor. Main motor data can be found on the motor nameplate, but it may not have all of the necessary PM motor constants that must be entered into the drive. If this is the case, the motor manufacturer must be contacted for the complete motor data sheet. The drive's auto-tuning function (if available) can be used to obtain motor constants. Performing a manual tuning process to measure the motor constants is an option, but this will likely require equipment that may not be readily available.

Application Requirements

The table below lists the required drive parameters the PM motor control algorithm needs to successfully control the motor. The control method must first be changed in A1-02=5 (OLVPM) to unlock the E5 parameter group (PM Motor Settings).

Table 1: V/f Pattern for Motor 1

Parameter Number	Description	Unit	Range	Remarks
E1-01	Input voltage setting	V	155 – 255 (200V class) 310 – 510 (400V class)	Drive input voltage
E1-04	Max output frequency	Hz	40.0 – 400.0	Maximum output frequency
E1-05	Max output voltage	V	0.0 – 255.0 (200V class) 0.0 – 510.0 (400V class)	Output voltage at E1-04 frequency
E1-06	Base Frequency	Hz	0.0 – E1-04	Motor rated frequency
E1-09	Minimum output frequency	Hz	0.0 – E1-04	Motor stops below this frequency

Table 2: PM Motor Settings

Parameter Number	Description	Unit	Range	Remarks	Auto-Tuning (A1000, U1000, GA800)
E5-01	Motor code		0000 - FFFF	FFFF for non-Yaskawa motors	
E5-02	Motor rated power	kW	0.4-18.50	Refer to motor name plate	
E5-03	Motor rated current	A	10% to 200% of the drive rated current	Rms current Refer to motor name plate	
E5-04	Motor pole number	pole	2 – 48	Refer to motor name plate	
E5-05	Motor winding resistance	ohm	0.000 – 65.000	Per phase stator resis-tance	✔
E5-06	Motor d-axis inductance	mH	0.00 -300.00	See motor equivalent circuit Per Phase	✔
E5-07	Motor q-axis inductance	mH	0.00 -600.00	See motor equivalent circuit Per Phase	✔
E5-11	Encoder Z-pulse offset	deg	-180.0 -180.0	Only for A1-02=7	✔
E5-09 *	Motor back-emf voltage	mV/(rad/s)	0. 0 -2000.0	Phase peak voltage (mV) per electrical angular speed (rad/s)	✔
E5-24 *	Motor back-emf voltage	mV/(rpm)	0. 0 -2000.0	Line-to-line rms voltage (mV) per mechanical motor speed (r/min)	✔

* Note: An alarm will be triggered if both E5-09 and E5-24 are set to 0, or if neither parameter is set to 0.

Implementation

The table below identifies 6 steps for a general startup with PM motors. Details for steps 2 through 5 are provided after the table.

Table 3: Start-up Steps

Step	Action	Note
1	Select Control method (A1-02)	OLV/PM
2	Select PM auto tuning method	Available only for A1000, U1000, GA800
3	Set E1-xx, E5-xx parameters based on the motor name plate data	Manually or by Auto-tuning
4	Set C1-xx and C2-xx	Accel / Decel / S curves
5	Set n8-xx (if necessary)	PM motor control parameters
6	Start	Re-adjust PM motor control parameters if neces-sary

Step 2: Select PM auto-tuning method:

- T2-01 = 14 (rotational auto-tuning)
- Use rotational auto-tuning only when the motor can be uncoupled from the load. The rotational auto-tune must be performed with the motor unloaded. Be sure to secure any couplings, keyways, or other hardware prior to initiating this tuning.
- Auto-tune parameters that need to be entered.

Table 4: Auto-tune Parameters

Auto-Tune Parameters	Parameter Description	Setting Units
T2-01	PM Motor Tune Type	14 (Rotation PM Tune)
T2-03	Motor Type	IPM or SPM
T2-04	Motor Rated Power	kW
T2-05	Motor Rated Voltage	Vac
T2-06	Motor Rated Current	Amps
T2-08	Number Of Motor Poles	--
T2-09	Motor Rated Speed	RPM
T2-15	Tuning Pull-in Current	30%

Note: The PM motor will rotate at 50% of T2-09 in order to measure the back-EMF voltage.

T2-01 = 1 (stationary auto-tuning)

- Use stationary tuning when the load cannot be uncoupled from motor and when accurate motor data is available (via detailed motor data sheet).
- In particular, the Back-EMF voltage must be known (via nameplate or motor data sheet) for this method to be successful.
- T2 auto-tune parameters are the same as rotational auto-tune (in Table 4).
- After a successful auto-tune, change the back-EMF parameter (E5-09 or E5-24) to the motor manufacturer's specified value.

Step 3: Set E1-xx and E5-xx parameters based on the motor name plate data.

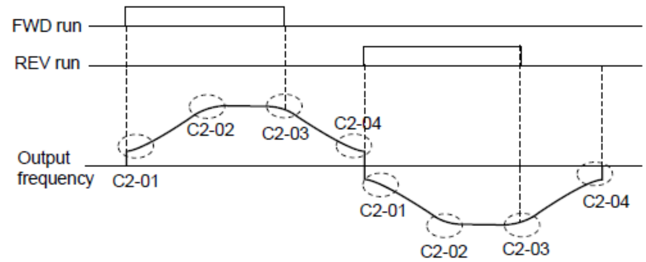
- Reference Tables 1 and 2 for the E1-xx, E5-xx parameters

- With V1000 and Z1000 series products the, E5 PM motor parameters must be manually set. The auto-tuning function does not support PM motors.

Table 5: Acceleration & Deceleration S-curve

	Setting	Range
C1-01	Acceleration Time	0.0 to
C1-02	Deceleration Time	6000.0 Sec
C2-01	S-Curve Characteristic at Acceleration Start	
C2-02	S-Curve Characteristic at Acceleration End	0.00 to
C2-03	S-Curve Characteristic at Deceleration Start	10.00 Sec
C2-04	S-Curve Characteristic at Deceleration End	

Figure 1: S-Curve



Setting the S-curve will increase the acceleration and deceleration times.

Step 4: Set C1-xx and C2-xx

- Setting the accel/decel time and S-curves appropriate for the application can help ensure the motor does not pull out when starting under load or during speed changes

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Step 5: Set n8-xx

- n8-62 (output voltage limit): set to 10% less than the AC supply into the drive

Step 6: Start

- First run motor unloaded to verify there is no vibration or drive faults.
- If drive faults occur, use the troubleshooting section in this document to adjust PM control parameters.
- After successfully running the motor unloaded, connect the load to verify there is no vibration or drive faults.
- If drive faults occur, use the troubleshooting section in this document to adjust PM control parameters.

Troubleshooting

If the drive is unsuccessful in running the PM motor or a fault occurs, adjust the following parameters. Please refer to the selected drive's technical manual for parameter details.

The PM motor stalls at start, drive faults with STO/STPo (motor step-out) or OC (overcurrent) (Table 6).

Table 6:

Parameters	Description	Default	Possible Solution
C1-01	Acceleration Time 1	10.0 sec	Increase setting to reduce output current at start
C2-01	S-Curve Characteristic at Accel Start	0.20 sec	Increase setting to reduce output current at start
n8-51	Accel/Decel Pull-In Current	50%	Increase d axis current to align magnetic poles (used only during accel/decel, increase by 10% steps)
n8-55	Load Inertia	0	Increase setting to change the drive's current regulator gain to adjust the control response
n8-45	Speed Feedback Detection Control Gain	0.80	Decrease setting to lower drive response (decrease by 0.10 steps)
C4-01	Torque Compensation Gain	0.00	Increase setting for higher starting torque (increase by 0.20 steps)

- The PM motor is lightly loaded or at no load, drive faults with STO/STPo (Table 7).

Table 7:

Parameters	Description	Default	Possible Solution
n8-55	Load Inertia	0	Increase setting to change the drive's current regulator gain to adjust the control response
E5-24	Back-EMF	Auto-tune	Fine tune back-EMF value of motor datasheet or auto-tune result (increase/decrease by 5% steps)
n8-62	Output voltage limit	200V/400V	Decrease if output voltage is at n8-62 and E1-04 setting (decrease by 10V steps)

- The PM motor is hunting, output frequency is unstable (Table 8).

Table 8:

Parameters	Description	Default	Possible Solution
n8-55	Load Inertia	0	Increase setting to change the drive's current regulator gain to adjust the control response
n8-45	Speed Feedback Detection Control Gain	0.80	Change drive response for speed compensation (increase/decrease by 0.10 steps)
n8-48	Light Load Pull-In Current	30%	Increase setting at light Iq level of 0% to n8-74 setting (increase by 10% steps)
C4-01	Torque Compensation Gain	0.00	Increase setting for applications with high starting torque(increase by 0.20 steps)
C4-02	Torque Compensation Time Delay	100 ms	Increase for light load conditions, decrease for high starting torque (increase by 10 times or decrease by 0.10 times)

- The PM motor requires a fast acceleration or impact loading is possible, drive faults with STO/STPo (Table 9).

Table 9:

Parameters	Description	Default	Possible Solution
n8-55	Load Inertia	0	Increase setting to change the drive's current regulator gain to adjust the control response
C2-01	S-Curve Characteristic at Accel Start	0.20 sec	Decrease setting to reduce decel rate at start
n8-51	Accel/Decel Pull-In Current	50%	Increase d axis current to align magnetic poles (used only during accel/decel, increase by 10% steps)
n8-45	Speed Feedback Detection Control Gain	0.80	Increase drive response for speed compensation (increase by 0.10 steps)
n8-62	Output voltage limit	200V/400V	Decrease if output voltage is at n8-62 and E1-04 setting during impact load (decrease by 10V steps)

- The PM motor is rotating at start, drive faults with STO/STPo, OC or OV (overvoltage) (Table 10).

Table 10:

Parameters	Description	Default	Possible Solution
b2-02	DC Injection Braking Current	50%	Increase setting to help stop the motor before run (increase by 10% steps)
b2-03	DC Injection Braking Time at Start	0.00 sec	Increase setting to enable function (increase up to 0.50 sec)
b2-12	Short Circuit Brake Time at Start	0.00 sec	Increase setting to enable function (increase up to 1.00 sec)

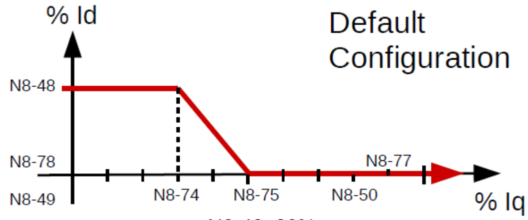
Note: Use either DC Injection Braking or Short Circuit Braking, not in combination, to stop the load prior to the output frequency ramp up.

- The PM motor is unstable or stalls during constant speed, or faults with STO/STPo (Table 11 & Figure 2).

Table 11:

Parameters	Description	Default	Possible Solution
n8-48	Light Load Pull-In Current	30%	Increase setting at light Iq level of 0% to n8-74 setting (increase by 10% steps)
n8-78	Middle Load Pull-In Current	0%	Setting is dependent on PM motor characteristics, increase/decrease at middle Iq level of n8-74 to n8-75 (change by 10% steps)
n8-49	Heavy Load Pull-In Current	0%	Setting is dependent on PM motor characteristics, increase/decrease at heavy Iq level > n8-77 (change by 10% steps)

Figure 2:



- N8-48: 30%
- N8-49: 0%
- N8-50: 80%
- N8-74: 30%
- N8-75: 50%
- N8-77: 90%
- N8-78: 0%

Adjustment of the Id level (N8-48, N8-78, and N8-49) may be required to maintain motor synchronization for varying Iq load points (N8-74, N8-75, N8-50, and N8-77). The N8 parameters listed above allow the Id current to be tailored for various Iq levels . If motor pull-out is encountered at a specific load current (Iq level), identify and then adjust the applicable Id level to eliminate the pull-out.

- STO/STPo Fault Detection Conditions (STO/STPo Causes) (Table 12).
  - The drive's output current is 200% of the motor rated current for more than 1 second.
  - The drive's output current is 190% of the drive rated current for more than 1 second.
  - The back-EMF compensation output is over 50% of the output voltage for more than 1 second.
  - The stall prevention during acceleration is active for more than 5 seconds.
  - If the drive is in stall prevention during acceleration and accel/decel is repeated more than 10 times.

Table 12:

Parameters	Function	Description	Range	Default	Remarks
L8-20	Control fault detection selection	0: Disable 1: Enable	0 ~ 1	1	
L8-51	STO/STPo current detection level	STO/STPo fault detection level using the output current. The detection level is determined by the drive is set to 0%.	0.0 ~ 150.0%	0.0%	100% = motor rated current
L8-52	STO/STPo integral detection level	STO/STPo fault detection level. Incorrect motor constants (Ld, Lq and back-EMF) can cause integration to increase.	0.1 ~ 2.0	1.0	Increase to allow for a higher peak current. Decrease to reduce peak current for fault (can create nuisance fault if set too low).
L8-53	STO/STPo integral detection time	Sets the time for STO/STPo condition to exist to trigger the fault	1.0 ~ 10.0 sec	1.0 sec	Monitors output current to check if there is an error with Id feedback and reference. Increase to monitor for longer period before fault. Decrease for a responsive Id error fault.
L8-54	STO/STPo Id deviation detection (Id error detection)	0: Id error detection disable 1: Id error detection enable	0 ~ 1	1	The difference between Id reference (U6-12) and Id feedback (U6-02) is greater than motor rated current (E5-02). It may be helpful to disable when back-EMF is unstable

Manual Tuning Procedure to Measure PM Motor Data

Not all motor information can be measured:

1) Motor data still required:
   - Motor rated power
   - Motor rated current
   - Motor rated speed
   - Motor rated poles
2) Measureable Motor Characteristics:
   - Motor stator resistance
   - PM motor d-axis and q-axis inductance
   - PM motor back-EMF voltage

Stator Resistance:

- The drive requires a per phase resistance value

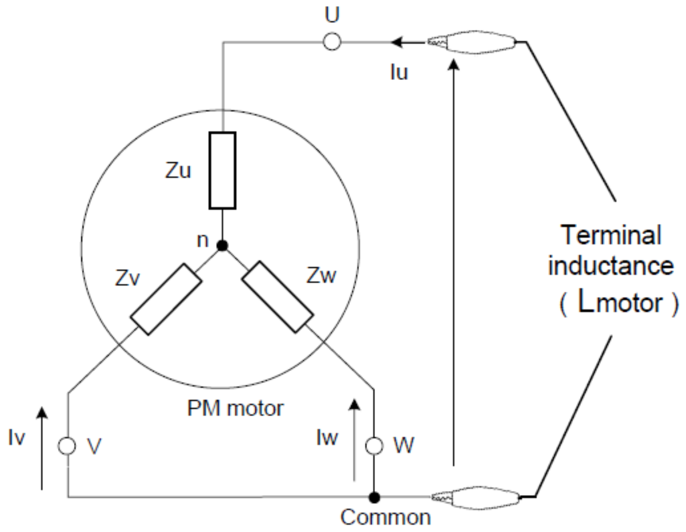
1) Measure phase to phase resistances
   - Resistance from T1/U to T2/V
   - Resistance from T2/V to T3/W
   - Resistance from T1/U to T3/W
2) Take the average of the measured terminal resistance
3) Take half of the average terminal resistance to obtain per phase stator resistance
4) Enter stator resistance in parameter E5-05

d-Axis and q-Axis Inductances

- The drive requires a per phase inductance value for the d-axis and q-axis

1) Connect a LCR meter to the PM motor as shown in Figure 3 below. Set the test signal frequency of the LCR meter close to the rated frequency of the PM motor.
2) Measure the motor inductance at various rotor positions.
   - Min inductance values = d-axis
   - Max inductance values = q-axis
   - SPM: d-axis = q-axis; IPM: d-axis ≠ q-axis
3) Enter d-axis and q-axis inductances in parameters E5-06 and E5-07
   - E5-06 = d-axis min * 2/3
   - E5-07 = q-axis max * 2/3

Figure 3:



Back-EMF Voltage

- The drive requires a per phase peak voltage for back-EMF

1) Rotate the PM motor using another motor as the prime mover
   - Disconnect PM motor's leads from power source
2) Measure the motor's line-to-line back-EMF voltage at rated speed
   - If rated speed is not possible, make note of the prime mover's speed
3) Repeat measurements to ensure a correct measurement
4) Back-EMF parameter unit is V/Krpm, ratio voltage measurement to Krpm
   - A measurement taken at 1000 rpm can be entered directly into back-EMF parameter (E5-24)
   - Not all motors can be run up to 1000 rpm
5) Enter back-EMF in parameter E5-24