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APPLICATION NOTE

Drive Applications Support Library

Application Note	AN-P2-058
Title	Encoder-less Vector Control for 3 Phase Induction Motors
Related Products	P2 Series AC Drives
Level: 3	1 - Fundamental - No previous experience necessary. 2 - Basic - Some basic drives knowledge recommended. 3 - Advanced - Some basic drives knowledge required. 4 - Expert - Good experience in topic of subject matter recommended.

Overview:

The P2 drive incorporates class defining encoder-less vector control technology for high performance, open loop control of standard AC induction motors. The P2 drive packages this technology in such a way to ensure the complex functionality (that provides superior performance) in no way detracts from the P2 drive reputation for ease of use, and fast commissioning. This document is an overview of how best to utilize the P2 drive encoder-less vector technology, including basic set-up procedures and troubleshooting, and is in addition to the information provided in the standard product user guide.

This document should always be used in conjunction with all safety and technical information provided by the product user guide. Optimized performance is obtained by following the advice and procedures provided by this document.

Parameter Overview:

The following parameters are required to be set for successful optimization of the P2 for operation of an induction motor in encoder-less vector mode. Parameters listed in blue are essential for optimum configuration of the encoder-less vector control and need to be set accurately by the commissioning engineer. Parameters in black are less critical but can be configured for improved performance should they be required.

Par.	Description	Range	Units	Default	Explanation
P1-07	Motor Rated Voltage	0, 20 to 250 0, 20 to 500	Volts (rms)	230 400	Rated (nameplate) voltage of the motor
P1-08	Motor rated current	25 - 100% of drive rated current	Amps (rms)	(Drive Rating)	Enter the rated (nameplate) current of the motor. This value is used for overload protection
P1-09	Motor rated frequency	10 - 500	Hz	60	Enter the rated (nameplate) frequency of the motor
P1-10	Motor rated speed	0 - 30,000	Rpm	0	Enter the motor rated (nameplate) speed When non-zero value entered, all speed related parameters are displayed in rpm
P4-01	Control Mode	0-Vector Speed Ctrl 1-Vector Torque Ctrl 2-V/F Speed Ctrl	—	2	Selects the motor control method. Set to '0' for Vector Speed Control, Set to '1' for Vector Torque Control
P4-02	Motor parameter auto-tune	0: Disable 1: Enable	—	0	When set to 1 the drive will perform an auto-tune immediately on exiting the parameter. Values will be written automatically to parameters P7-01 thru P7-05
P4-03	Speed Controller proportional Gain	0.1 - 400	%	50.0	Sets the proportional gain value for the speed controller. Higher values provide better output frequency regulation and response. Too high a value can cause instability and over current trips. For applications requiring best possible performance, the value should be adjusted to suit the connected load.
P4-04	Speed Controller integral time constant	0.010 - 2.000	s	0.050	Sets the integral time for the speed controller. Smaller values provide a faster response in reaction to motor load changes, at the risk of introducing instability. For best dynamic performance, the value should be adjusted to suit the connected load.
P4-05	Motor Power Factor	0.50 - 0.99	—	—	Motor nameplate power factor, which must be entered for encoder-less Vector operation

Par.	Description	Range	Units	Default	Explanation
P4-07	Maximum Torque limit	P4-08 - 500	%	150	When P4-01 = 0, sets maximum torque limit When P4-01 = 1 & P4-06 =0, sets the preset torque reference.
P4-08	Minimum Torque limit	0.0 - P4-07	%	0.0	When P4-01 = 0, sets minimum torque limit When P4-01 = 1 & P4-06 =0, sets the preset torque reference.
P4-09	Maximum generating Torque limit	0.0 - 500	%	100	Sets the maximum regenerating torque limit permitted by the drive.
P7-10	Inertia Ratio	0 - 600	%	10	System Load Inertia to Motor Inertia Ratio. Entered into P7-10 as: $P7\text{-}10 = (J_{Tot} / J_{Mot}) \cdot 10$

The following parameters are set by the drive following execution of the Auto-Tune function. They can be adjusted manually following the Auto-Tune by the user but is not recommended and should only be attempted by experienced applications engineers.

Par.	Description	Range	Units	Default	Explanation
P7-01	Motor Stator resistance (Rs)	Drive dependent	Ω Ph-Ph	—	During an Auto-Tune, the drive measures / calculates these parameters to optimise the motor control performance. The values can be adjusted by the user, however this may have a negative effect on the motor behaviour, or can cause unexpected results, and adjustment is not recommended.
P7-02	Motor Rotor resistance (Rr)	Drive dependent	Ω Ph-Ph	—	
P7-03	Stator inductance (Ls)	Drive dependent	mH / µH Ph	—	
P7-04	Magnetizing current (Id rms)	10% to 80% of motor rated Current	A (pH)	—	
P7-05	Leakage coefficient (sigma)	0.025 to 0.250	—	—	

Operating Modes:

There are two modes of encoder-less vector control on the drive, Vector Speed Control and Vector Torque control. The mode of operation is set by parameter P4.01, Control Mode is shown below:

P4-01 = 0 : Speed Control with Torque Limit (vector)
P4-01 = 1 : Torque Control with Speed Limit (vector)

Speed Control with Torque Limit (vector): P4-01 = 0

In Vector speed control mode the reference signal (command) provided to the drive is proportional to the required drive output speed. The full scale range of the reference signal is hence directly proportional to the drive programmed speed range (from minimum speed to maximum speed).The reference to the drive can by provided digitally or through the analog reference and, once enable, the drive will attempt to ramp and then maintain the motor speed in relation to the reference.
Motor voltage and current are optimized by the drive to provided best torque performance within the drives output current limits.

Torque Control with Speed Limit (vector): P4-01 = 1

In Vector torque control mode the reference signal (command) provided to the drive is proportional to the required output torque from the motor (approximately proportional to motor current). The full scale range of the reference signal is hence directly proportional to the drive programmed torque range (from zero to maximum torque set by P4-07 'Maximum motoring Torque limit').
The torque reference to the drive can be provided digitally or through the analog reference and, once enable, the drive will attempt to maintain the requested motor torque in relation to the reference. Torque reference source is set by parameter P4- 06.
Motor output frequency and voltage are optimized in order to provide the required motor torque output.

Set-up Procedure – Encoder-less Vector Control Mode:

The following procedure should be followed to ensure correct parameterization of the drive and optimum performance from the Induction motor when using encoder-less vector control mode.

Step 1: Returning the Drive to Factory Default Settings.

This application note assumes set-up from default condition. The drive is returned to factory default by holding the up, down, start, and stop buttons on the drive keypad simultaneously.

Plus
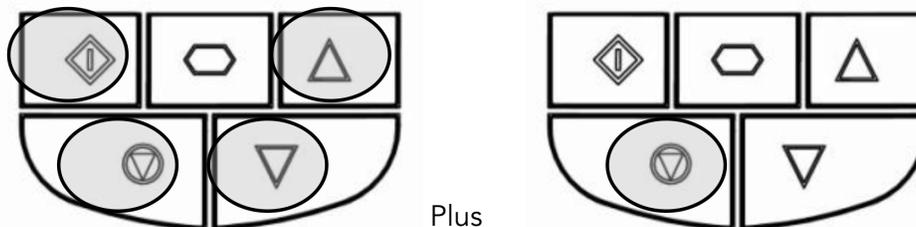
Step 2: Entering Security Code for Extended Menu Parameter Access.

In order to select encoder-less vector motor control method and to enter associated parameters a dedicated access code must be entered into parameter P1-14. The code for extended parameter access is '201'. Once this value is set in parameter P1-14 parameter P4-01 will allow selection of Vector Speed or Torque Control and parameter group 2 thru 7 will be available for edit.

Step 3: Entering basic motor parameters.

Note: Accurate entry of data for parameters P1-07 thru P1-10 and P4-05 is very important for optimum performance.

P1-07: Motor Rated Voltage
Motor rated voltage (UM), often referred to just as rated voltage (Ur). Its value can be taken directly from the motor data plate.

P1-08: Motor Rated Current
Rated phase current (Ir) of the motor often referred to as the motor nominal current (IN). Its value can be taken directly from the motor data plate.

P1-09: Motor Rated Frequency
Rated operating frequency (Fr) of the motor often referred to as the motor base frequency. Its value can be taken from the motor data plate.

P1-10: Motor Rated Speed
Rated output speed (nr) of the motor shaft often referred to as the motor base speed. Its value can be taken from the motor data plate.

P4-05: Motor Power Factor
Rated motor power factor (P.F.) often referred to as the Cos φ value. Its value can be taken from the motor data plate.

Step 4: Selecting Speed or Torque Vector motor control.

Set parameter P4-01, drive control method, to a value of 0 to enable Vector Speed control or to a value of 1 to enable Vector Torque Control.

Step 5: Fix System criteria that will Effect Auto-Tune.

The following system criteria will have an effect on the accuracy of the Auto-Tune function and should be established as per the final application prior to carrying out the auto-tune procedure.

- Motor – Ensure connected motor is correct motor to be used in the application
- Motor – Ensure star / delta connection is established correctly within the motor terminal housing
- Motor Cabling – Ensure cable type, length and connection is as per final application
- Motor Parameters – Motor parameters (Step 2) have been accurately entered
- Control Mode – Correct Vector control mode established in step 3
- Switching Frequency – Output switching frequency selected in parameter P2-24

If any of the above criteria change prior to finalization of the application then the auto-tune function must be repeated.

Step 6: Auto-tune for Encoder-less Vector motor control.

Motor inductance and resistance values, programmed into drive menu 7, can be configured manually or derived by the drive software using the auto-tune function.

It is always recommended, for optimum performance and ease of set-up, that the auto-tune procedure is completed regardless of whether motor values for parameter menu 7 are already known.

To activate auto-tune function set parameter P4-02 to value '1' and exit the parameter. Auto-tune begins immediately on exit.

During auto-tune the drive will display '*Auto-t*' or Auto-Tune on the drive display, returning to its normal state once auto- tune is complete.

Auto-tune is a non-rotational function although some small rotation of the motor shaft may occur. It is not necessary to disconnect the motor from the driven load for this function to be completed successfully but the rotor should not be locked such that motion is prevented.

Step 7: Setting Application ramp Rates.

Parameter P1-03 sets acceleration ramp rate and parameter P1-04 sets deceleration ramp rate. If adjusting speed controller gains (P4-03 & P4-04) always set required ramps rates prior to tuning these values. Ensure ramp rate setting and acceleration / deceleration cycle does not result in the drive operating excessively in the over-current (>100%) region or in excessively braking energy being returned to the drive such that nuisance trips occur.

P2 drive encoder-less Vector motor configuration is now complete.

Advanced Settings for Encoder-less Vector Control Mode:

Following basic configuration of the encoder-less Vector control, more advanced optimization can be carried out by completing the following procedure. For the majority of applications the default settings for the following parameters are sufficient and should only be adjusted by experienced drives engineers should the application require further performance improvement.

Step 1: Check menu 7 motor values.

If auto-tune function (P4-02) was completed then the following values will be measured and entered automatically by the P2 drive. The measured values can be viewed in the listed parameters for reference.

P7-01	Motor Stator resistance (Rs)	Phase to Phase
P7-02	Motor Rotor resistance (Rr)	Phase to Phase
P7-03	Stator inductance (Ls)	Phase
P7-04	Magnetising current (Id rms)	Amps
P7-05	Leakage coefficient (sigma)	—

If manufacturer data for the motor is available then these auto-tune values can be checked against the manufacturer's data. If the values measured are significantly different than the motor data then this suggests an issue with the motor cabling or configuration that will require further investigation (see troubleshooting). If

the values are reasonably well matched then always use values generated by the auto-tune as these are measured values, as opposed to the design values specified in the motor data (subject to tolerances and build variations).

It is generally recommended for optimum performance and ease of set-up that the auto-tune procedure is used to complete these values and that they are not entered manually.

Step 2: Setting Torque limits

Note: is Vector Torque mode the torque reference for the drive is variable and the torque reference value is taken from the source selected in parameter P4-06. In Vector Speed mode the torque limits are fixed at the levels set in the following parameters. These values generally do not require adjustment.

Vector Speed Mode

Parameter P4-07 sets maximum torque limit and P4-08 the minimum torque limit for the motor. The P2 drive has an additional parameter (P4-09) that can be used to adjust the maximum torque limit when the motor is generating.

Peak torque values for the motor are available from the motor technical data sheet and if less that 200% of the nominal torque value then torque limit values can be adjusted to provide peak torque protection to the motor. If system mechanics do not permit 200% (default) torque to be generated safely then the torque limit(s) can be adjusted down.

Adjustment of minimum torque is not required in the majority of applications. Adjusting this value from zero can cause unexpected motor behavior and must only be attempted by experienced drive users.

Vector Torque Mode

For Vector Torque Mode Parameter P4-07, maximum torque limit, is only used when P4-06 (Torque reference source select) is set to 0 (preset value). With these setting P4-07 provides a direct set-point to the torque controller. This value should be set to protect either the motor or system from excessive torque levels. Parameter P4-08, minimum torque reference, can be used to prevent the rotor from locking when the torque reference set- point to the drive is very low. Care should be taken in adjusting this parameter as too high a value can cause the motor to 'take off' (rapidly accelerate) or run at very high speeds. In general, this parameter should only be used in specific applications, where a minimum torque level must always be applied, and it is safe to do so.

If the analog input is used to vary the torque reference, the torque will be scaled linearly in proportion to the analog input in the range of P4-08 (minimum torque limit) to P4-07 (maximum torque limit).

For all torque control applications, the maximum speed of the motor can never exceed the speed limit set in P1-01.

Step 3: Entering Motor / Load Inertia Ratio

Parameter P7-10 allows the inertia ratio between the motor and connected load to be entered into the drive. This value can normally be left at the default value (10); however it is used by the drive control algorithm as a feed forward term in order to provide optimum torque / current to accelerate the load. Hence accurate setting of the inertia ratio will produce better system response and dynamics. If value is unknown then leave value set to default (10).

The value entered into P7-10 is given as; P7-10 = $(J_{Tot} / J_{Mot}) . 10$

Where; J_{Tot} is Total Inertia (including motor, load, and any coupling)

J_{Mot} is Motor Inertia

Motor inertia will be given by the motor manufacturer as part of their standard motor data. Total inertia must either be known from the system design or measured.

Step 4: Setting baseline values for speed loop gains.

Note Speed loop gains are only in effect when the drive is in Vector speed mode (P4-01 = 0), they have no effect when operating in Vector Torque Mode (P4-01=1).

The Default gains values for the speed controller are generally suited to standard induction motor control. If changes are required to the speed controller tuning parameters then they should be made very gradually with close observation of the resulting effect on the system response.
Tuning needs to be carried out with the motor and load configured as per the completed drive application. If the system criteria or mechanics are changed then auto-tune should be repeated.

Ensure ramp rates (P1-03 and P1-04) have been set prior to carrying out tuning of the speed loop gains.

P4-03: Speed Controller proportional Gain
The proportional gain is used to change the output to the motor as a proportional of the error in the speed loop controller (difference between commanded and actual speed). The proportional response of the drive is adjusted by multiplying the error by a constant called the proportional gain that is set in parameter P4-03. Increasing the value in parameter 4.03 decreases drive response times and improves system dynamics.
If proportional gain is set too low the system response will be poor (slow) however if set too high the system will oscillate and could grow unstable.

P4-04: Speed Controller integral time constant
The integral time constant is an 'accumulated' gain based on both the magnitude of the error in the speed controller and the time the error has existed, essentially working to eliminate prolonged and steady state error in the system.
Parameter P4-04 is set as a time (in ms). The smaller the time (integration time) the more responsive the drive output, at the possible expensive of system stability.
Small changes of integral time constant can have a significant effect on reaction times and stability of the speed controller.

General practice with tuning a PI system is to set the integral value (P4-04) to its highest possible setting (1.0 sec) and tune the proportional value (P4-03) for optimum performance. When proportional gain has been set / optimized then the integral gain (P4-04) can then be adjusted to eliminate steady state speed errors.

Troubleshooting:

Trip codes and fault diagnostic information is provided in the standard drive user manual. Below is further troubleshooting information specific to encoder-less Vector control.

Symptom		Solution / Advice
No parameter access beyond Menu 1		Extended menu access code not entered in P1-14. Value '201' required.
Auto-tune failure *At-F01* *At-F02* *At-F03* *At-F04* *At-F05*	*At-F01*	Measured motor stator resistance varies between phases. Ensure the motor is correctly connected and free from faults. Check the windings for correct resistance and balance.
	At-F02	Measured motor stator resistance is too large. Ensure the motor is correctly connected and free from faults. Check that the power rating corresponds to the power rating of the connected drive
	At-F03	Measured motor inductance is too low. Ensure the motor is correctly connected and free from faults
	At-F04	Measured motor inductance is too large. Ensure the motor is correctly connected and free from faults. Check that the power rating corresponds to the power rating of the connected drive
	At-F05	Measured motor parameters are not convergent. Ensure the motor is correctly connected and free from faults. Check that the power rating corresponds to the power rating of the connected drive
Poor Torque Performance at low speed		Check Auto-Tune performed Successfully – See Set-Up procedure
		Check System criteria effecting auto-tune have not change. See step 4 in standard set-up procedure. If any of these setting have changed then the Auto-tune procedure must be repeated.
Too much current causing motor to heat up		Check parameter P1-07, motor nominal voltage is set correctly
		Check parameter P1-08, motor nominal current is set correctly
		If running for sustained periods at low speed check adequate cooling is provided to the motor. If no ventilation is provided for the motor then it may be necessary to provide ventilation. If motor shaft mounted ventilation is provided then this can be ineffective at low speed and may need to be replaced with forced (fixed speed) ventilation. Always consult with the motor manufacturer on issues of suitability and adequate motor cooling.
Motor Stalled		Check motor connection
		Check values entered into motor parameters (P1-07 to P1-10 & P4-05)
		Check Auto-Tune performed Successfully – See Set-Up procedure
		Reduce the load

| Symptom	Solution / Advice
	Increase acceleration / deceleration time
	Increase drive and motor rating
Unstable motor speed / poor speed regulation	Check values entered into motor parameters (P1-07 to P1-10 & P4-05)
	Check Auto-Tune performed Successfully – See Set-Up procedure
	Check appropriate tuning of speed loop controller, reduce gains as required
Poor motor dynamics, slow response times	Check values entered into motor parameters (P1-07 to P1-10 & P4-05)
	Check Auto-Tune performed Successfully – See Set-Up procedure
	Check appropriate tuning of speed loop controller, increase gains as required
O-I Trip Occurring	Check the motor and motor connection cable for phase-phase and phase-ground short circuits
	Check the load mechanically for a jam or stalled condition, or shock loads
	Check values entered into motor parameters (P1-07 to P1-10 & P4-05)
	Check Auto-Tune performed Successfully – See Set-Up procedure
	Increase the ramp up time in P1-03
	Check appropriate tuning of speed loop controller, reduce gains as required
I_t-trP Trip Occurring	Increase acceleration rate or reduce the load
	Check motor cable length is within specified limits
	Check values entered into motor parameters (P1-07 to P1-10 & P4-05)
	Check Auto-Tune performed Successfully – See Set-Up procedure
	Check the load mechanically to ensure it is free, and no jams, blockages or other mechanical faults exist
Motor parameters in menu 7 differ significantly to published motor data after Auto-tune	Check motor connection
	Check values entered into motor parameters (P1-07 to P1-10 & P4-05)
	Check Auto-Tune performed Successfully – See Set-Up procedure
	Check motor condition / windings for damage

Encoder-less Vector Quick set-up:

The quick start is intended as a basic first step to successfully running the motor. For Optimum performance the full programming and optimization procedure should be followed.

Quick Step 1: Default Drive parameter settings.

Quick set up instructions are dependent on drive being in a default state.
Default drive by holding the following keys on the drive keypad simultaneously for 2 seconds.

plus
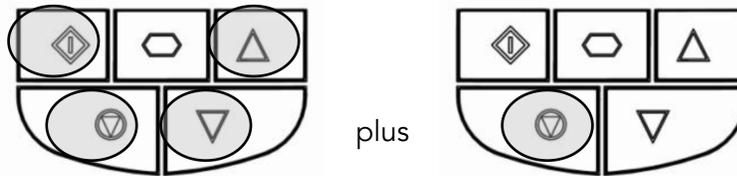
Quick Step 2: Setting of the required parameters

Set the following parameters in the sequence they are listed.
P1-07: Nominal back emf (rms Phase-Phase)-   -   = Motor Dependent
P1-08: Motor rated current (rms Phase)   -   -   = Motor Dependent
P1-09: Motor rated frequency (Hz)   -   -   -   = Motor Dependent
P1-10: Motor rated speed (rpm)   -   -   -   = Motor Dependent
P4-05: Motor Power Factor   -   -   -   = Motor Dependent   P1-12 = 0
P1-14: Parameter access code   -   -   -   = 201   P1-13 = 1

For Vector Speed Mode: P4-01: Control Mode = 0
For Vector Torque Mode: P4-01: Control Mode = 1

1	+24V Output
2	Input 1: O: Stop (Disable) C: Run (Enable)
3	Imput 2:
4	Input 3:
5	+10V Output
6	Analog Speed / Torque Ref
7	0V
12	Safe Torque Off Input
13	Safe Torque Off 0V

Enable

Quick Step 3: Complete Auto-tune function

Note: The Safe Torque Off input (terminal 12 and 13) needs to be connected in order to enable the safe torque off function and allow auto- tune and motor control. See connection diagram.

Set the following parameter. Drive will perform auto-tune on exit of parameter entry.
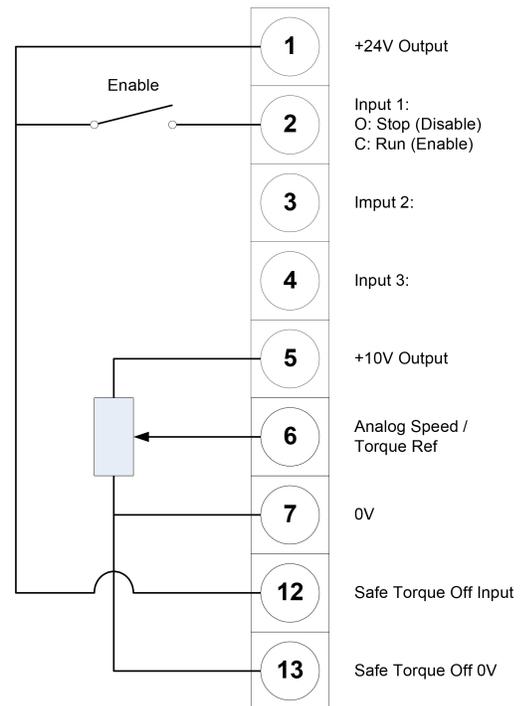
       P4-02: Auto-tune Function = 1

Wait for completion of auto-tune.

Quick Step 4: Check motor operation

Apply enable and speed set-point inputs to the drive. Default configuration is shown right.

Vary speed set-point and check smooth operation of the motor.

Values should be optimized following on from the quick start procedure.

Revision History			
Version	Comments	Author	Date
1.00	Document Creation	RL / JP	02/24/2012
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