

This Application Note applies to the Unidrive SP

Speed Loop Tuning- Vector Mode

The Unidrive SP has built-in tuning algorithms that address the inner current loop (the more mathematically difficult loop to adjust). The static tune (non-rotational) auto-tune feature measures motor values such as stator resistance and inductance and takes other physical motor data into account such as # of poles etc to obtain a better idea of the inner motor characteristics that the current loop will be driving. The rotating autotune finds the actual motor power factor and another rotating tune can find the motor and attached inertia values. All these factors can assist the drive with finding the appropriate settings for satisfactory drive → motor tuning.

So, as a prerequisite to good speed loop tuning, the inner current loop must first be addressed. As indicated above the internal Auto tune function is used for that bit of work.

In order to perform an autotune the motor shaft must be free (de-coupled) from all influencing load.

Setting up for Vector Mode

The Unidrive SP comes set for Open Loop Pr 0.48 “out of the box”.

With no wires connected to the drive terminal strip and no option modules inserted
Nothing plugged into the Encoder D connector.

Set for Closed Loop Vector by entering 1254 into parameter Pr 0.00 using the drive keypad.

Then go to parameter Pr 0.48 and select “CL VECt” then depress the RED reset button. The drive should now be set for Closed Loop Vector operation. The drive will trip on “th” as it is expecting a motor thermistor connection. If your motor has a thermostat, you could wire it between terminal 8 and common 11 or simply go to Pr 0.21 and set it for Volt then depress the RED reset button.

Entering Motor Data

Below is a typical motor nameplate. We need to enter this data into parameters:

Pr 0.42# of motor poles	Pr 0.45	rated motor speed-rpm
Pr 0.43rated Power Factor	Pr 0.46	rated motor current per wired voltage
Pr 0.44rated motor voltage	Pr 0.47	rated motor frequency

Notes:

poles { 2 pole for a motor whose rated rpm is near 3600 for 60 Hz motor (3000 for 50 Hz)
 #0.42 { 4 pole for a motor whose rated rpm is near 1800 for 60 Hz motor (1500 for 50 Hz)
 { 6 pole for a motor whose rated rpm is near 1200 for 60 Hz motor (1000 for 50 Hz)
 { 8 pole for a motor whose rated rpm is near 900 for 60 Hz motor (750 for 50 Hz)

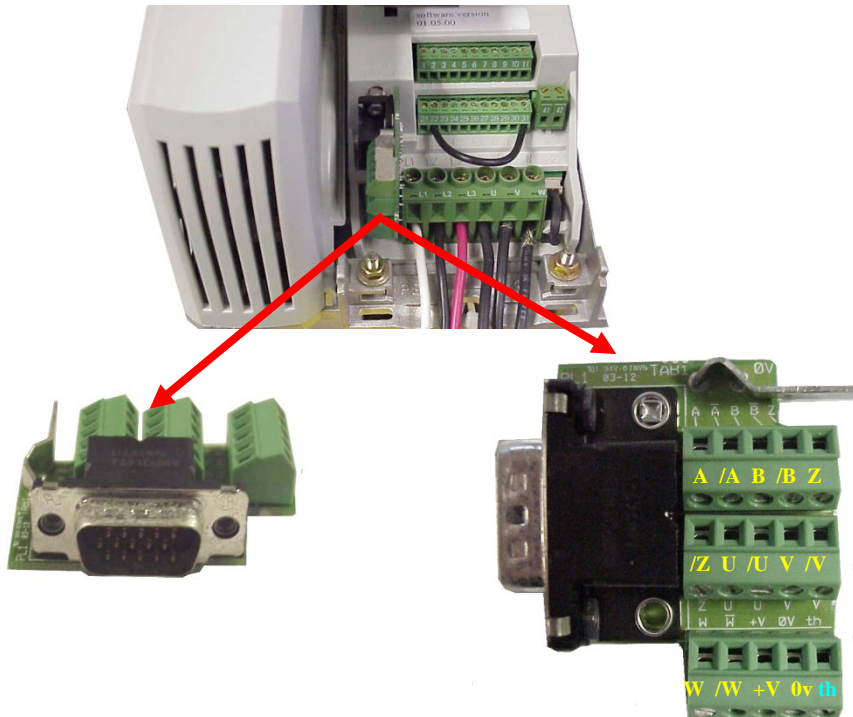
Power Factor is never 1.00 typically 0.95 0.92 for large motors 200-800 HP
 #0.43 0.91- 0.80 for motors 40 -200 HP
 0.85- 0.6 for < 40 HP

If you enter this data via the drives

Encoder Data

In Closed Loop Vector mode the drive relies heavily on accurate motor shaft angular position for both motor velocity and direction. The drive will need to know the power supply requirements for the motor mounted encoder as well as the PPR- pulses per revolution of the encoder.

The encoder must have dual complementary differential outputs A, /A, B, /B as indicated by Encoder Type #3.38 = “Ab” To facilitate wiring we offer an interface option SM-ETC to allow encoder connection to be interfaced to the high density 15pin D connector via screw terminals.



* UVW connections are for Servo motors requiring commutation track information.



The drive defaults to supplying 5 V but the Unidrive SP can provide 8 V and 15 V by setting Pr 3.36

03.38: Ab	Encoder type
03.34: 1024	Lines per rev
03.39: 1	Termination
03.36: 5V	Supply Volts

If the encoder power supply is to be set other than 5 V, set Pr 3.39 =0 **before** setting Pr 3.36 to the requirement Encoder supply voltage. This will remove internal Termination resistors that are sized for 5 V encoders. Failure to do so could permanently damage these internal resistors.

Quick Encoder Feedback Check

Besides obtaining and entering accurate motor nameplate data, encoder feedback is of paramount importance when operating in the Closed Loop Vector mode of operation.

For this reason, it is highly recommended that you perform on quick check on the encoder feedback before attempting to run the motor. This will:

- Verify that the encoder wiring is correct
- Verify the channel outputs
- Verify the PPR is set correctly
- Verify the proper direction for operation

When performing an autotune, the drive is expecting the Encoder Position, Pr 3.29, to count up when the motor shaft is rotated in the clockwise direction. This register should count up to 65535 and roll over in 1 revolution of the encoder. If it counts down, for clockwise rotation, this might actually be the correct direction for the machine. Determine the direction that the motor should go when you command the machine to run forward. If it is indeed counter clockwise then perform the numerically evaluation below but for a CCW direction.

The best way to check is to rotate the encoder until Pr 3.29 is slightly above 0 (say <500 or so) and note the motor shaft position. Then rotate the motor shaft ¼ turn and the display should indicate about 16,000. For ½ turn from the original position, the display should indicate about 32,000 and it should roll over at a full turn. If it does this then the encoder is working and the PPR is set correctly.

If when turned ¼ turn and the display shows about 32000, set Pr 3.34 at 2048 then re-check
If when turned ¼ turn and the display shows about 65000, set Pr 3.34 at 4096 then re-check
If when turned ¼ turn and the display shows about 8000, set Pr 3.34 at 512 then re-check



Not all encoders are power of 2 (512,1024,2048, 4096) however so this may not always be the case

If this works out, you are now ready to perform the Autotune.

In order to perform an autotune the motor shaft must be free (de-coupled) from all influencing load.

Rotational Autotune

If your motor nameplate data is entered and you've performed the Encoder Quick Check, you are now ready to perform the Auto tune.

In order to perform an auto tune the motor shaft must be free (de-coupled) from all influencing load.

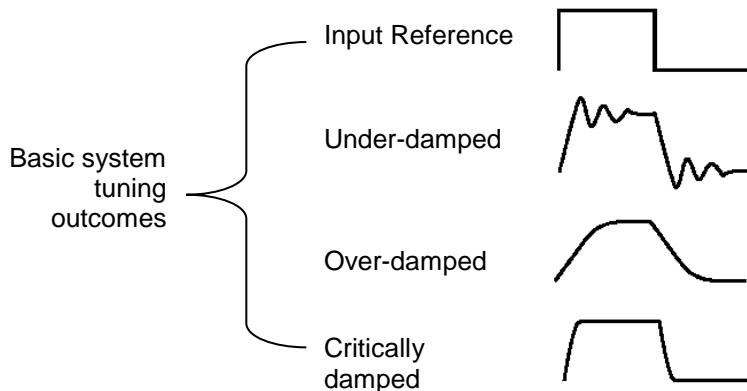
- 1) To perform the auto tune you will need a switch wired between terminal 22 and 31 to enable/disable the drive. It is often necessary to run the auto tune a couple of times or perform one or more of the various auto tunes. After an auto tune the drive will disable internally and you will need to toggle the switch (off to on) in order to re-enable the drive for operation. In addition, this switch will act as a "kill switch" should you need to disable or shut the drive down for any reason during your setup.
- 2) Set Max Speed (parameter Pr 0.02) to the maximum speed you would like your motor to run. Set the Acceleration and Deceleration Rates (Pr 0.03 & Pr 0.04) to reasonable rates for the size of motor – default is 2 seconds from 0 to 1000 rpm which might be a bit to quick for a 500 HP motor on the very first run.
- 3) During this initial commissioning phase we would recommend setting the drive to operate from the Run (green) and Stop (red) buttons on the drive keypad display. This will minimize unnecessary wiring and associate errors/debugging. So set Pr 0.05 = "**Pad**"
- 4) Check the action of the Enable switch- when open the drive should be indicating "**inh**" when closed the drive should be indicating "**rdy**"
Leave the switch in the closed position with the drive indicating "**rdy**"
- 5) Set parameter Pr 0.40 = 2 to perform a rotating auto tune
- 6) If the motor is clear to run and free of shaft load, depress the Run (green) button

The drive should start accelerating the motor up to 2/3 of the Max Speed you set in Step 2 after a short pulse while it performs the static portion of the autotune. The drive will run for about 35 seconds displaying "**ph**" and then coast to a stop. If there are no errors displayed the autotune should have been successful.

You can perform the autotune again if you wish but you will need to toggle (switch the enable to off then back on) then set Pr 0.40 = 2 and again depress the Run button.

After a successful autotune, you can run try running the motor up using the drive keypad. You must toggle the enable- the display should indicate rdy. If so depress the Run (green button) and the display should indicate run. Run the motor up to say ½ speed using the Up arrow on the drive after depressing Run. Test the stopping action- depress the Stop (red button). If all is well depress Run again and take the speed up to the maximum you set into #0.02 or until you feel uncomfortable with that speed. Test the stopping action from this speed- depress the Stop (red button). If all is well, you can exercise the motor by depressing Run then Stop a couple of times letting the motor reach full speed. If all is fine you are ready to couple the motor to the load and perform Speed Loop tuning. Keep in mind that final Speed Loop tuning may not be able to be finalized until the machine is running actual product at the final installation site.

The Speed Loop must deal with the overall motor plus machine/product inertia, associated damping factors such as viscous and frictional components and hopefully little or no discontinuities such as chain slop, gearing backlash, coupling resonance etc. Tuning criteria are often classically characterized as under-damped, over-damped and critically damped. Shown below are the 3 basic categories of tuning which result when a drive is given a step function of speed reference.

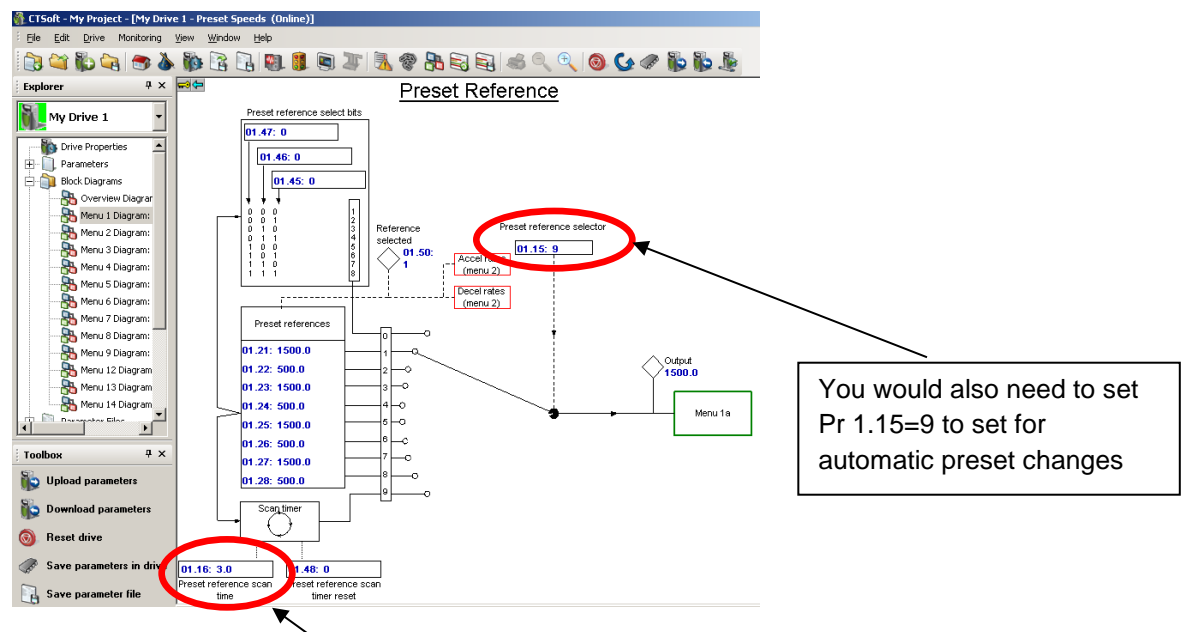


Speed Loop tuning is a rather subjective matter. Different applications may dictate a different kind of tuning. Some applications such as positioning and other forms of rapid “motion control” typically require a rather hot/crisp speed loop tuning response-perhaps a cross between critical and under-damping as shown above. Other general applications such a conveyor control, extruders and their accompanying melt pumps would require a more docile yet accurate tuning criteria-perhaps a cross between critical and over-damping as shown above. Then there are compromises that may need to be considered depending on the stiffness of the mechanical linkage that result in the best overall system performance. The primary adjustments to achieve this tuning are the **Proportional, Integral and Derivative Gains** of the Speed Loop. In the UnidriveSP these are parameters Pr 3.10, Pr 3.11 & Pr 3.12 respectively.

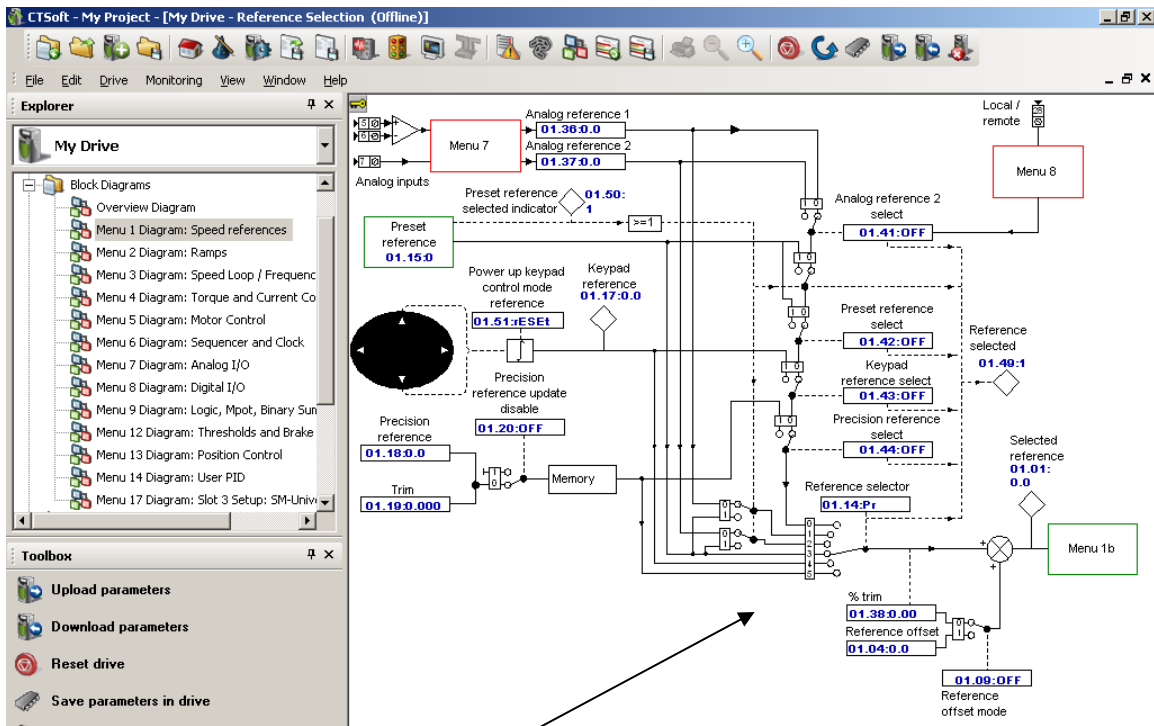
In any case, this tuning is usually performed by the technician who is taking into account these considerations. In a steady state speed situation, performance of the speed loop may appear fine. It won't be until an external disturbance is introduced that instability will become noticeable. In order to achieve the desired speed loop tuning, it is necessary to create such disturbances but in a controlled repetitive manner so that one can make adjustments and observe the outcome. This application note will outline a simple method of using a built-in feature of the Unidrive to assist with the tuning process when operating in a closed loop mode- (Vector or Servo)

One of the easiest ways to create system disturbances is to vary the speed reference to the drive during operation. If the drive has a speed pot, one could merely ask an assistant to rotate the speed pot back and forth over a range while the technician adjusts and observes the results. This would work but can become tiresome for the assistant and put the speed pot thru undue wear and tear.

The UnidriveSP has a 8 pre-settable speeds and built-in feature that will step from Preset Speed 1 to 8 at regular intervals set as X.X seconds. To use this feature you would determine a modest center speed that the system can be run at. For example, if the drive has a speed pot, you would just adjust the speed to some reasonable level where you would feel comfortable to begin tuning (top speed would not be my first choice). For my example, I selected to modulate the Speed Reference about 1000RPM – between 500 and 1500 RPM. For a first time however, you may wish to start out with a small change say 800- 200 rpm – you can always extend to larger speed swings after you have arrived at satisfactory settings at these smaller swings successfully. You can place these speeds into the Preset Speed registers in an alternating fashion- see below. (**Note- these speeds are in RPM as expected for Vector or Servo mode operation**)



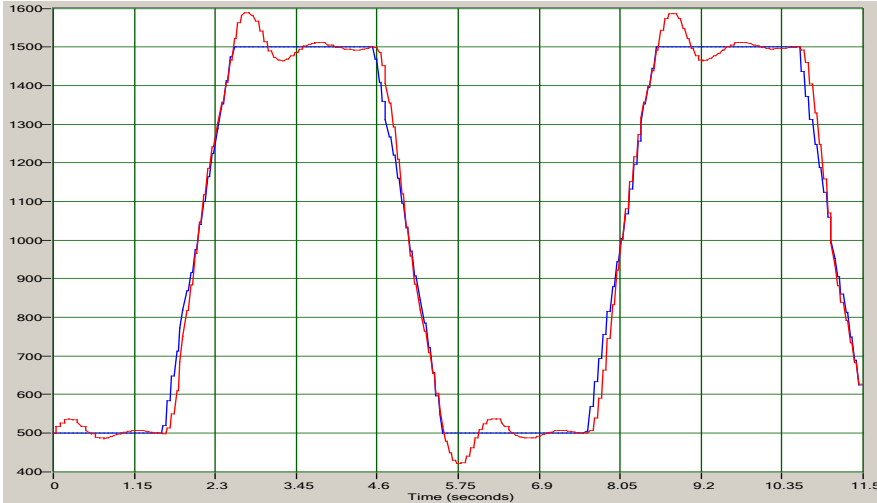
In order to activate the Automatic Preset Speed interval feature, you would set the Time Interval in parameter Pr 1.16 (3.0 or 3 seconds would be a good starting point).



You would also need to set Pr 1.14= "Pr" to allow the drive to follow these Speed Preset values. If the drive was already running by the pot at 1000 RPM for instance, these parameter changes would begin taking affect causing automatic speed changes between 1500 & 500 rpm at 3 second intervals.

Keep in mind that you may need to adjust the accel and decel (Pr 2.11 and Pr 2.21 respectively) to lower values to allow more of a step or abrupt speed changes but within practical limits of your attached machinery. Remember that accel rates are in seconds per 1000 rpm – so in the above setup with 1000rpm delta (1500-500), the drive will attempt to accomplish this speed change in 1 second.

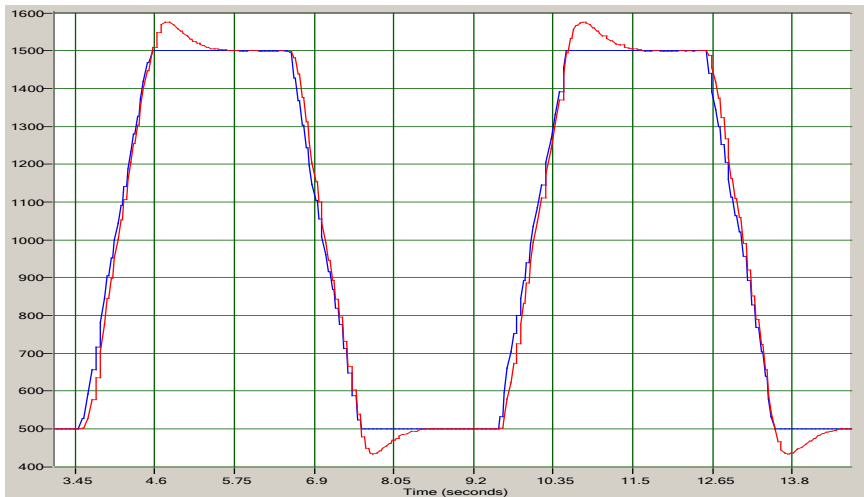
Shown below is a screen shot of the Speed Reference (Pr 3.01 blue trace) vs the Speed Feedback (Pr 3.02 red trace) of a motor operating in Vector mode. The shot below was taken using our CTScope program for a PC. CTScope is a complimentary software available from our website.



Speed Loop Gains were at the default settings:

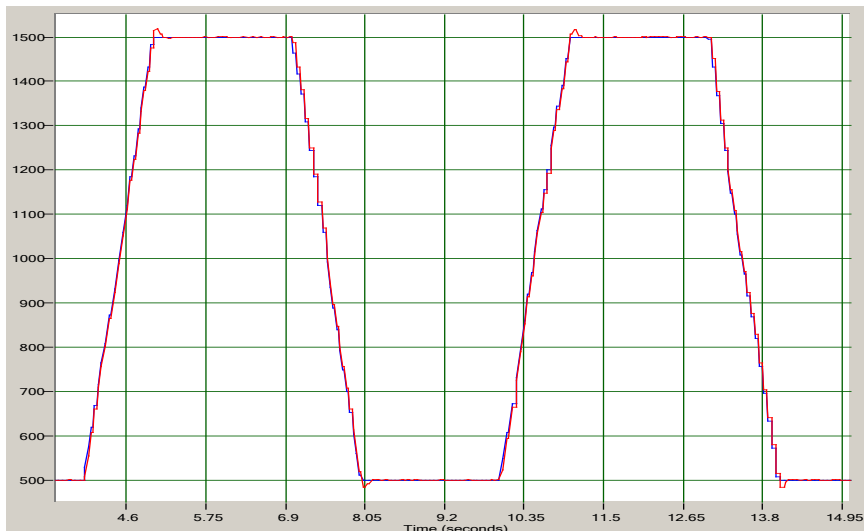
Proportional Pr 3.10=0.03
Integral Pr 3.11=0.1
Derivative Pr 3.12=0

Motor 20 HP 460 Vac Vector
Mode 1024PPR
Coupled Inertia $\approx 1.5x$ AC motor



Speed Loop Gains were at the default settings:

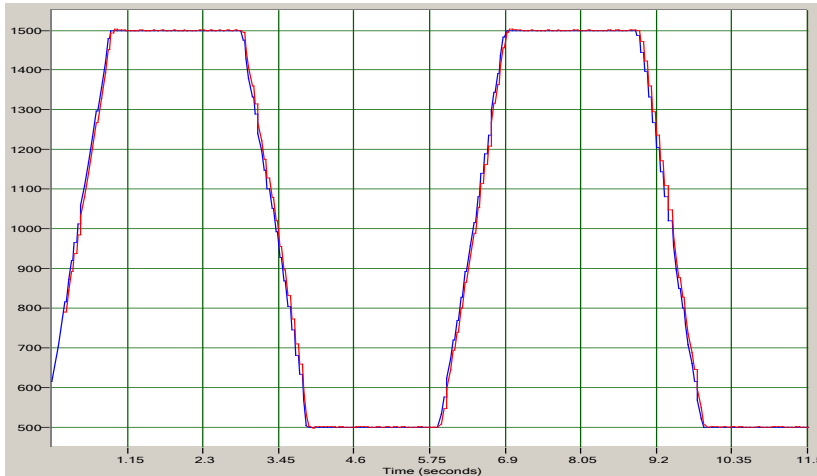
Proportional Pr 3.10=0.03
Integral Pr 3.11=0.5
Derivative Pr 3.12=0



Speed Loop Gains were at the default settings:

Proportional Pr 3.10=0.08
Integral Pr 3.11=1.4
Derivative Pr 3.12=0

For most application this previous last tuning shot was good enough but with the application of a little Derivative the motor could be made to follow the reference with little to no error.



Speed Loop Gains were at the default settings:

Proportional Pr 3.10=0.08
Integral Pr 3.11=1.4
Derivative Pr 3.12=0.02

One must use caution when adding a derivative term. Derivative can introduce rather large step disturbances during changes since derivative is a “rate of change” term. Add derivative using least significant digits.

It should be emphasized that all tuning adjustments were done use the Drive keypad. Do NOT use CTSOft to make changes to PI & D adjustments. Reason being, first of all your will need your communication channel to observe the results of your adjustments on CTScope, secondly CTSOft makes changes only after you depress Apply or Enter. These changes could be too abrupt and may kick the system into a very unstable situation. By using the drive keypad, all adjustments are acted upon immediately but most importantly, you can move the adjustment position using the right and left arrow to a digit position of lower significance to avoid large changes. In this manner, you can make small changes and observe whether things are getting better or worse immediately as you make changes.

I could have continued to adjust further but this performance was more than satisfactory for my application so I was pleased with the critically damped performance of the last screen shot.

In practice one may wish to perform additional tuning at higher speeds and perhaps with larger steps and quicker interval changes. This can easily be accomplished using the Automatic Preset Speed interval feature as described previously. Once the desired tuning performance is achieved one would need to at least change Pr 1.14 back to the original setting before performing a store so that the alternating speed presets are not in the picture any more. If the preset speeds are going to be used in the final application, these tuning speeds could be removed altogether and don't forget about Pr 1.15 – set if back to its' original setting as a 9 will make the drive auto step thru the presets.

Tuning the speed loop gains using an oscilloscope

Connect the oscilloscope to analog output 1 to monitor the speed feedback.

Give the drive a step change in speed reference and monitor the response of the drive on the oscilloscope.

The proportional gain should be set up initially - the value should be increased up to the point where the speed overshoots and then reduced slightly.

The integral term should then be increased up to the point where the speed becomes unstable and then reduced slightly.

If a derivative gain is required the value should be increased up to the point where the system response becomes unstable and then reduced slightly.

It may now be possible to increase the proportional gain to a higher value and the process should be repeated until the system response matches the ideal response shown below.

The diagram below shows the effect of incorrect P and I gain settings as well as the ideal response.

As an alternative to observing the results using the “soft-scope”, one could use an actual oscilloscope by placing at least one channel of a 2 Channel scope on pin 9 of the Unidrive. The default for this Analog output is a voltage proportional to the Speed feedback .

If it is desired to see both Reference and Feedback on a 2 Channel scope, you could change Pr 7.22 to 1.01 in order to bring out the Speed Reference on pin 10.

Shown below is an extract from the Unidrive Manual under Optimization and with the description of parameters Pr 3.10-Pr 3.12 Speed Loop PID gains.


Dynamic performance

Closed-loop only

The following parameters affect the dynamic performance of the Drive when it is operating in a closed-loop mode:

- 0.07** Speed-loop proportional gain
- 0.08** Speed-loop integral gain
- 0.09** Speed-loop derivative gain

Procedure



Caution Inappropriate values entered in the parameters for the speed-loop PID gains can cause the control system to become unstable.

The default values of the speed-loop PID gains can be used for undemanding applications. Use the following procedure when the performance is to be improved in speed or torque control:

1. Connect the load to the motor.
2. Start and stop the Drive as required.
3. Set the motor running at the required speed.
4. To increase the speed of response to a change in speed demand, or to a change in load, increase **0.07** Speed-loop proportional gain. Set **0.07** just below the value that causes the motor to vibrate. It is common for the vibration to be worse at zero speed. An excessive proportional gain can result in instability.
5. To improve the ability of the Drive to maintain a speed or torque demand under steady-state or slowly-changing conditions, increase **0.08** Speed-loop integral gain.
A high value of **0.08** can cause the motor speed to vary sinusoidally around the speed demand. This effect can be minimized by increasing the value of **0.07** Speed-loop proportional gain.
6. To reduce overshoot when the speed demand or the load on the motor is suddenly changed, increase **0.09** Speed-loop derivative gain. Excessive derivative gain will cause noise in the motor.

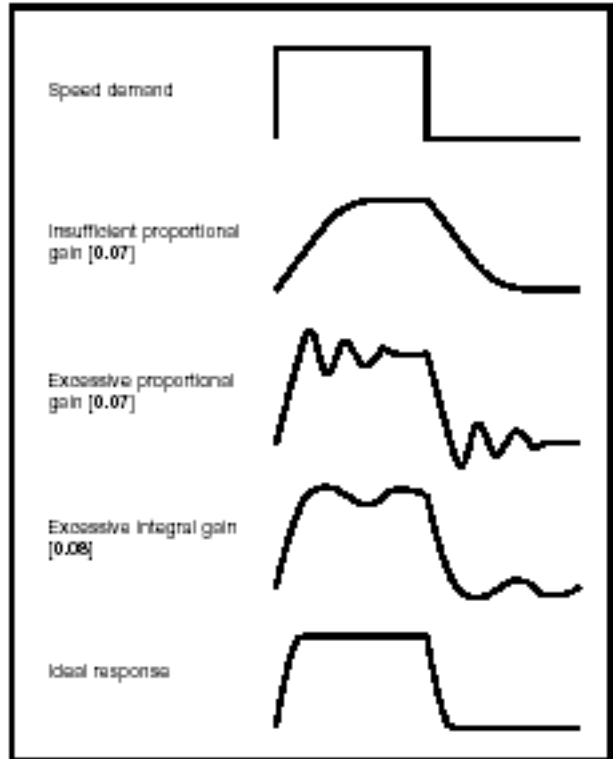


Figure 2-9 Response to a step-change in speed demand when the speed-loop PID gains are adjusted

Default values and range

Pr	Default value	Range
0.07	200	0 ~ 32000
0.08	100	0 ~ 32000
0.09	0	0 ~ 32000

Summary

The waveforms shown in Figure 2-9 represent the signals that would appear at terminal 9 of the signal connector when the speed demand applied to terminals 5 and 6 (or terminal 7) is a square-wave.



All for dreams

Resources: can be found on our website: www.controltechniques.com

For help contact techsupport.cta@mail.nidec.com, or
call Technical Support at 952-995-8000, 24/7/365