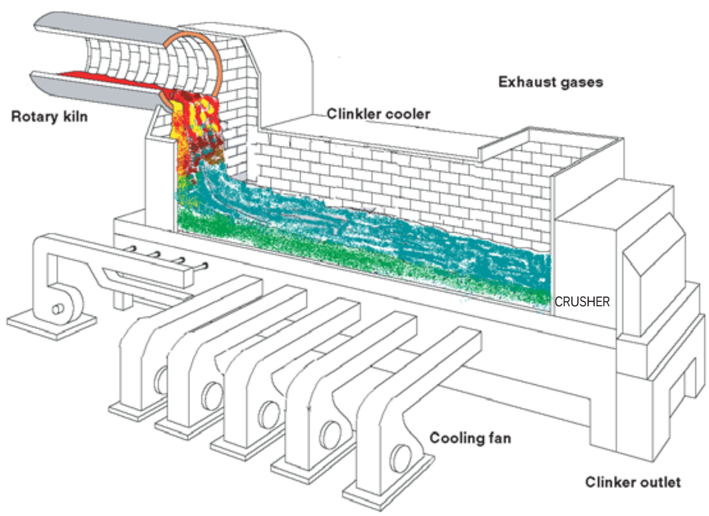
AC drive with PID control loop

In this application note we will configure a DURApulse variable frequency drive for a fan that has to maintain the air flow by means of a PID control loop.

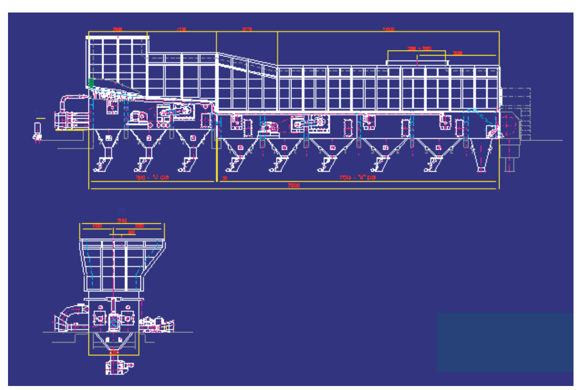
In this case we have to explain the environment where the fan will be working. This is an specific case but it can be extrapolated to any other application using PID control.

On the cement production the rotary kiln produces clinker by calcinating limestone and other grounded raw materials. This raw material is heated up to 1400^{o}C by the rotary kiln, transformed to clinker, which is a material with a granulometry of about 2 inches and below. And, after this is produced at the outlet of the kiln, it has to be cooled by ambient air to a final temperature of 50-70^o C.

Modern plants have capacities of 500 to 3000 metric tons per day (or even higher). The equipment used to cool down the clinker is called a clinker cooler. There are several types of clinker cooler, such as rotary, satellite or grate, the most common being the reciprocating grate cooler, whose diagram is provided on the figure below.



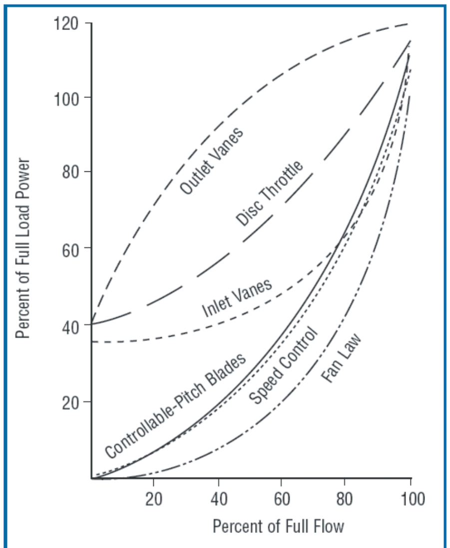
The clinker cooler is separated on sections where fans supply a high flow of ambient air, typically at a temperature from 20 to 50^o C. The oscillations of the grate platform move the clinker bed slowly to the crusher on the outlet side while at the same time the clinker fines falls down through the crate on each segment. See a mechanical section of a real clinker cooler on the adajacent figure



It is necessary however to maintain the maximum flow of air to produce heat exchange which allows the clinker to cool at the most efficient rate, without moving the clinker through the exhaust stack.

Since the clinker is not distributed on a fixed pattern, the pressure under the grate changes in time due to the permeability of the moving layer of clinker. Also, the total air flow shall depend on the rate of clinker per hour being produced. It is then necessary to continuously maintain the proper flow. There are several options to control the flow and one of them is to change the speed of the fan. Obviously an operator cannot control this flow manually in an efficient mode. In this note we selected to control the fan speed with the controller that continuously corrects the fan's speed, known as PID control.

For this reason the system will have on each fan a flow control loop whose process variable is detected by venturi devices, that measure the pressure drop thru them, typically on the range of 0 to 2 inches of water column. The fan speed set point is individually set but all the set points are affected by the rate of which the clinker flow changes. Each fan PID loop will receive the flow setpoint from another controller. This is called cascade. If the flow should change on a relative small segment (fan speed of about 60 to 90% with upset conditions that can reach up to 100%), the flow can be considered linear, which is a requirement for a PID control loop.



Relative Power Consumption Among Flow Control Options

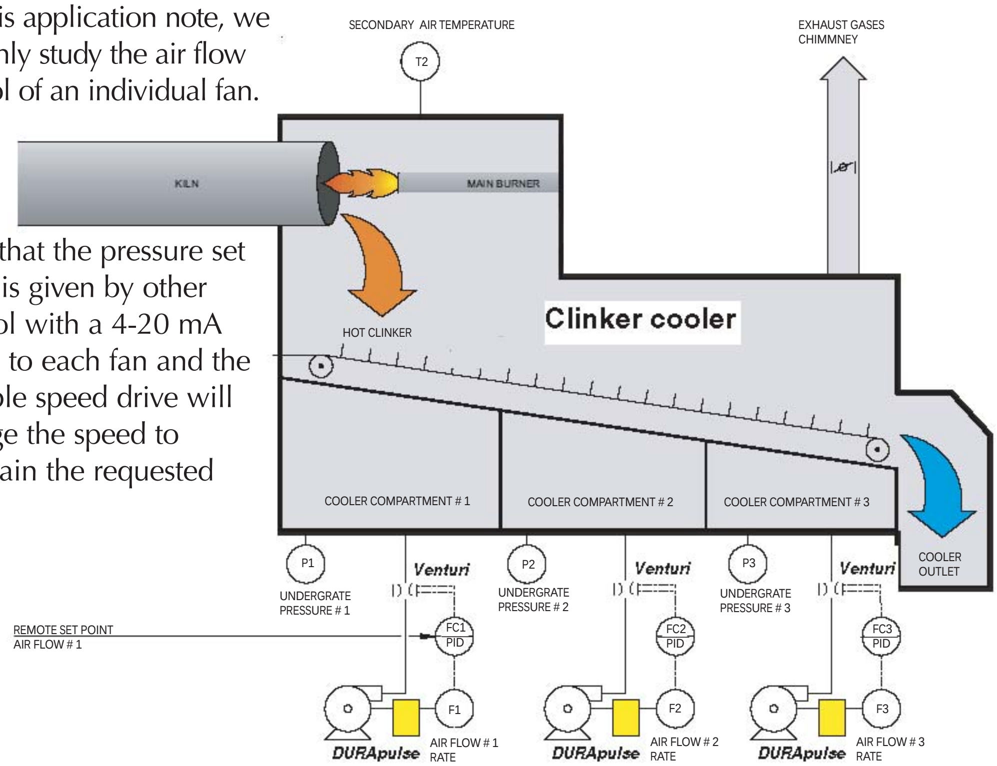
The flow of a fan varies as the square of the pressure drop on the venturi; the flow can be measured with a differential pressure transmitter with square root function. The output of the transmitter is proportional to the air flow under certain conditions of temperature and pressure, which is enough for the accuracy needed.

Please see in the next figure the PID loop control for compartment 1, as generic control:

The figure shows partially the control concept. There is a central control room where the control of the complete clinker cooler system is located.

On this application note, we will only study the air flow control of an individual fan.

Note that the pressure set point is given by other control with a 4-20 mA signal to each fan and the variable speed drive will change the speed to maintain the requested flow.



Application requirements

- The drive must control a 460 Volt, 75 horsepower, 1800 rpm motor.
- The motor must accelerate to the maximum speed in 10 seconds. The motor must coast to a stop.
- The operation of the system (start, stop, etc.) will be controlled by a PLC.
- The frequency of the VFD will be set by the embedded PID, whose output will try to maintain the air flow (process variable PV) as close to the flow set point.
- The analog signal input of the VFD will indicate the flow set point. This signal comes from another control loop, not detailed here. The example shows mainly the PID control configuration.
- The fan will coast to a stop, not controlled by the VFD. Some other fans may be already running and this might cause a backward rotation. The fan start shall overcome the reverse rotation.The fan can have up to 40% backward resistive torque and 50% speed.
- The system will detect an overtorque condition if this condition last over 10 second.

We will use a motor of 75 HP, 1800 rpm. The closest we have is a 75 HP, 1785 rpm. We sell several different inverter duty type 75 HP motors. We select the Marathon inverter duty motor E212, BlueChip with 86A of rated current at 460 Volt.

The corresponding drive is the GS3-4075 with 110A rated current. We do not need a braking resistor.

We will select the Volt/Hz method of control,with variable torque method. The fan has an inertia (WK2) of 308 lb-ft^2, under the NEMA standard value.

The motor heating calculation is not necessary, because the motor will normally work under the rated power, except on upset conditions, where it can run with up to 110 A (128% more than the rated current) for short periods.

The line reactor to be used is the GS-4075-LR, for 460 Volt, and the fuse kit including the fuses is the GS-4075-FKIT. Please note that the fuse is sized for 400A, 600 Volt and is fast blow type, to protect the drive and not the cable that feeds the drive. In general the cable fuse or circuit breaker has a lower rating than the fuse sized to protect the AC drive.

For start up, after verifying that the drive runs with the keypad control, the motor is running in the right direction, the analog and discrete signals in and out of the PLC and the DURApulse are operating (for example, that the PV signal is working), it is necessary to set the parameters as shown on the following pages.

Some of the parameters should be readjusted and the most important of them are the proportional gain and the integral value of the PID controller. Probably the Derivative factor will be left as default.

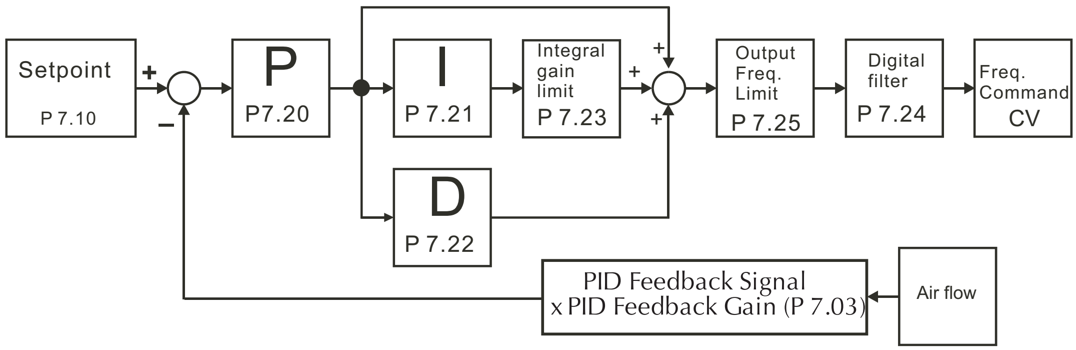
On the next figure we will show the PID control loop and what it does and how it relates to the specific application. Right after that, we will show the wiring diagram.

After reviewing the wiring diagram there is a short procedure to systematically find the proper values of P and I, to be set on parameters P7.20 and P7.21. If necessary the D value can be also adjusted in the same way.

Recall that the PID control loop receives the pressure setpoint from other control loop input in the terminal AI2 (defined in P7.10). The process variable, the air flow, is measured with a differential pressure tranducer. This transducer generates an output of 4-20mA, that reflects the flow from 0 to 100% (in reality CFM) that is the process variable PV. The control loop shall have the proper values of P, I, and D to generate the control output CV, which is the frequency command to the drive.

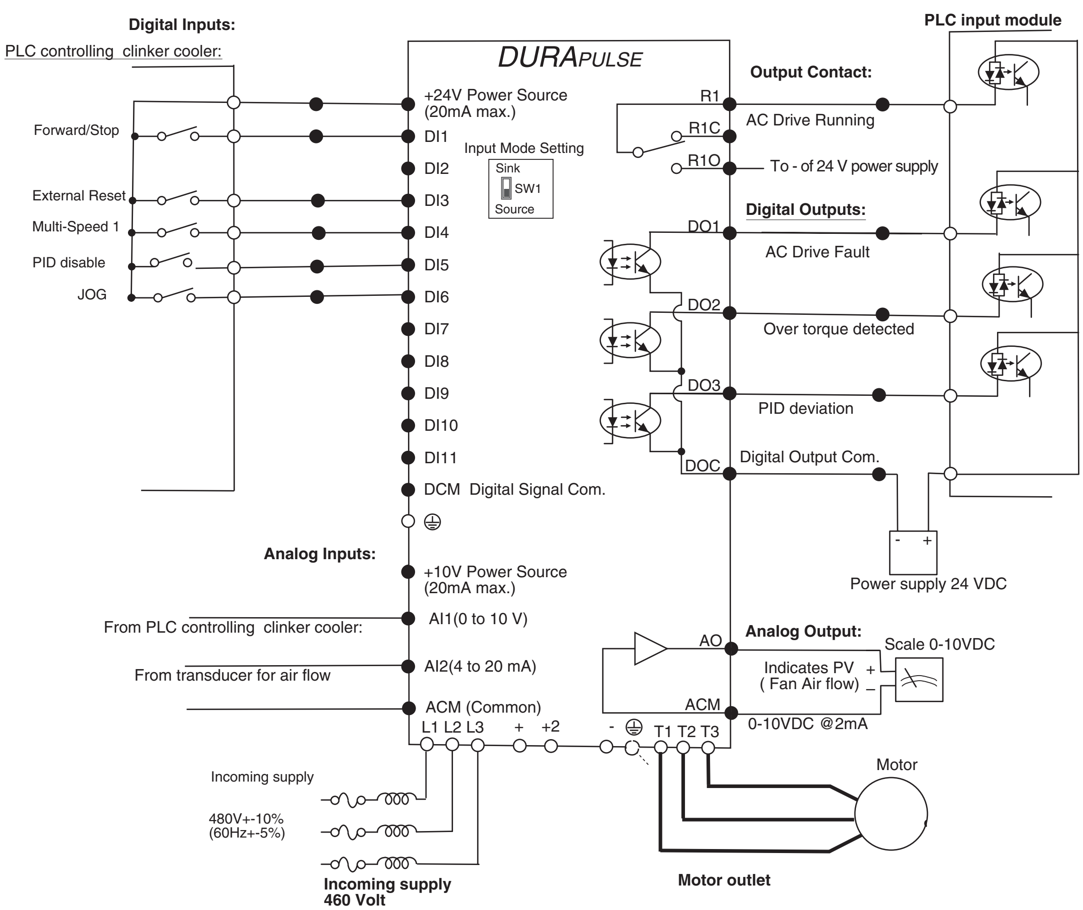
The drive will run to regulate the speed of fan to just deliver the right air flow.

On the next figure, we show the *Dura*pulse wiring diagram for this specific



application.

Note on the previous figure that the set point comes as a 0-10 Volt signal and the process



variable as 4-20 mA. Those values can come also as RS-485 values if the digital communication with MODBUS is selected, but not done in this case.

PID Auto-Tuning

The DURApulse drive should be configured initially as indicated on the next pages. In order to tune the PID control loop, set the proportional gain to 1.0, an arbitrary value that could be higher if the technician desires, the Integral Control value (P7.21) to 0 and Derivative Control value (P7.22) to zero (0). Set the setpoint to a fixed value such as 50%. Wait until the process variable PV stabilizes. If the PV and the control value begin to oscillate, reduce the proportional gain immediately.

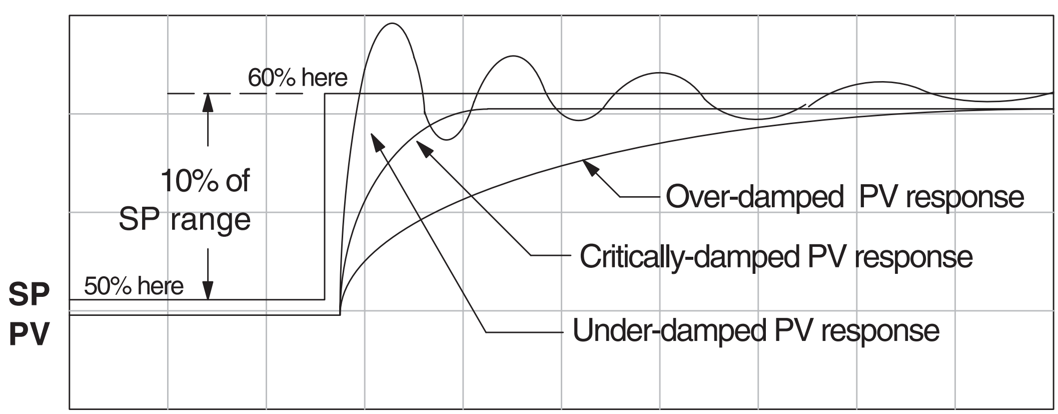
Observe the variables (Air flow setpoint and process variable) with either a trend recorder, an oscilloscope or the program GSOFT.

Begin tuning the process with a low Proportional Value (P7.20). Increase the setpoint to 60%. Soon the PV will move to the value of SP. The PV goes to **overdamped response** condition (see figure below). Increase the Proportional value (gain) and observe the behavior of the PV. Keep increasing the Gain P until the system begins to be unstable. When instability is reached, reduce the Proportional Value slightly until the system becomes stable (smaller values reduce system Gain). Stability can be tested by stepping between two wide-spread setpoint values like 60 to 80%. You should get the **overdamped response** condition with the shortest response time**. Observe that there is a difference between setpoint and process variable.**

The Integral Control P7.21 is used to generate additional corrective action. Continuing the tuning process, begin with a large Integral value and reduce the value until the system goes unstable (**underdamped response**). When instability is reached, increase the Integral value slightly until the system becomes stable and the desired setpoint value is reached, that is, you should aim for the **critically damped response**.

Ideal response shoud have a response time of approximatety 1 second or below if the step change is 10%.

Very seldom it is necessary to set the derivative control, parameter P7.22. You can try, if necessary.



Parameter configuration

In order to fulfill the requirements of this application, the parameters must be set as follows:

P 0.00 **Motor Nameplate Voltage** **Value: 460**

Range: 460Vclass: 380/400/415/440/460/480 Default 480

The value of this parameter is defined on the nameplate of the motor.

P 0.01 **Motor Nameplate Amps** **Value: 86**

Range: AC drive rated current x (0.1 to 1.0) Default I_{VFD} (A)

The value of this parameter is defined on the nameplate of the motor.

P 0.02 **Motor Base Frequency** **Value: 60**

Range: 50/60/400 Default 60

The value of this parameter is found in the nameplate of the motor.

.**P 0.03** **Motor Base RPM** **Value: 1785**

Range: 375 to 24,000 RPM Default 1750

The value of this parameter is defined in the nameplate of the motor.

P 0.04 **Motor maximum RPM** **Value: 1785**

Range: P 0.03 to 24,000 RPM Default P 0.03

The value of this parameter is determined by the requirements of the application.

P 1.00 **Stop Methods** **Value: 01**

Range: : 00 Ramp to stop Default 00

01 Coast to stop

This parameter causes the motor to coast to stop.

P 1.01 **Acceleration time 1** **Value: 10.0**

Range: 0.1 to 600 sec Default 10 sec

The motor must accelerate from 0 RPM to the maximum speed of the motor (P 0.04) in 10 seconds. It can happen that the motor is running backwards at about 50% of rated speed by the reverse flow of air caused by other fans already started.

P2.00 Volt/Hz settings — Value: 02

Range: 00 to 03 Default 00

Since it is a fan with standard inertia (WK^2), we will use the variable torque mode.

P 2.10 Control mode — Value: 00

Range: 00: V/Hz open loop control Default 00
01: V/Hz closed loop control
02: Sensorless vector
03: Sensorless vector with external feedback

This parameter determines the method of control of the drive. We selected mode 00 (Volt/ Hertz mode).

P 3.00 Source of operation command — Value: 02

Operation determined by the PLC. Default 00
STOP key on the keypad is disabled

- This parameter defines the source of the operation command for the variable frequency drive. In this case the main controller contacts (PLC) will define the commands.

P 3.01 Multi-function input terminals (DI-DI2) — Value: 02

Settingss DI1 - FWD/STOP Default 00
DI2 - REV/STOP

This parameter defines the input source for the operation commands of the variable frequency drive. We want the fan to begin movement when the control system closes a contact on the PLC. It will stop when this contact opens.

P 3.02 Multi-function input terminal (DI3) — Value: 02

Default 00

This is a button in the drive enclosure that will reset the drive in case of a failure.The PLC should check that every safety is in compliance before resetting the drive

P 3.03 Multi-function input terminal (DI4) — Value: 03

Default 00

This parameter will define multi-speed 1. This speed will be defined as the normal speed of the fan and corresponds to 1780 rpm. The value is to be set with P5.01.

P 3.04 **Multi-function input terminal (DI5) Value: 17**

Default 00

This parameter will cause PID control disable, for special operations.

P 3.04 **Multi-function input terminal (DI6) Value: 09**

Default 00

This parameter will define the jog command. This speed will be defined to correspond to 178 rpm. The value is to be set with P5.00. This speed is designed for maintenance operations.

P 3.06 **Multi-function Input terminal(DI7) Value: 99**

Default 00

This terminal does not have any input. Input disabled.

P 3.07 **Multi-function Input terminal(DI8) Value: 99**

Default 00

This terminal does not have any input. Input disabled.

P 3.08 **Multi-function Input terminal(DI9) Value: 99**

Default 00

This terminal does not have any input. Input disabled

P 3.09 **Multi-function Input terminal(DI10) Value: 99**

Default 00

This terminal does not have any input. Input disabled

P 3.10 **Multi-function Input terminal(DI11) Value: 99**

Default 00

This terminal does not have any input. Input disabled

P 3.11 **Multi-function Output Terminal 1 (Relay Output)Value:00**

Default 00

This output terminal is programmed as **AC drive running** and will go to the PLC.

P 3.12 **Multi-function Output Terminal 2 (DO1) Value: 01**

Default 01

This output terminal is programmed as **AC drive Fault** and will go to the PLC.

P 3.13 Multi-function Output Terminal 3 (DO2) Value: 07

Default 02

This output terminal is programmed as **Overtorque detected** and will go to the PLC.

P 3.14 Multi-function Output Terminal 4 (DO3) Value: 10

Default 03

This output terminal is programmed as **PID Deviation alarm** and will go to the PLC.

P 3.18 ◆ PID deviation level Value: 5

Range: 1.0 to 50.0%. Default 10.0

Selected 5 % because the precision is not too important.

P 3.19 ◆ PID deviation time Value: 10.1

Range: 0.1 to 300.0 s. Default: 5.0

The time of 10.1 second is selected because we do not need to have this alarm during acceleration. It might need to be adjusted after tune up.

P 4.00 Source of Frequency Command Value: 02

Default: 01

Settings: 02 Frequency determined by 0 to +10V input on AI1 terminal.

03 Frequency determined by 4 to +20 mA input on AI2 terminal.

We will set the analog setpoint for air flow with mode 02, to allow the control room to set the speed.

P 4.05 Loss of AI2 Signal (4-20mA) Value: 02

Range: 00 - Decelerate a 0Hz Default: 00

01 - Stop immediately y display “EF”.
02 - Continue operation by the last frequency command

This parameter determines the operation of the drive when the PV is lost. It is selected the mode 02 because the priority is to cool the clinker. The operator wil stop the cooler when the clinker bed flow is decreased at a convenient time during the process.

P 4.11 ◆ Analog Output Signal Value 02

Range: 00 - Frequency Hz Default 00

01 - Current A

02 - PV Process variable value

This parameter selects **PV** (air flow) at the the analog output A0 (0 to 10V). This will allow the operator to know the process variable remotely.

P5.00 ◆ Jog — Value: 6.0

Range: 0.0 to 400.0 Hz — Default 6.0

The Jog Command is selected by a Multi-Function Input Terminal (P 3.04) set to the Jog Function (09) and this frequency corresponds to 178 RPM.

P 5.01 ◆ Multi-Speed 1 — Value: 60.0

Default 00

The multi-speed 1 value is defined as 60 Hz, that corresponds to 1780 rpm and will be used at the maximum speed of the fan and when the PID control is disabled.

P 6.00 Electronic Thermal Overload Relay — Value: 01

Range: 00 - Constant Torque — Default 00
01 - Variable Torque
02 - Inactive

This function is used to limit the output power of the AC drive when powering the motor at low speed. We use variable torque.

P 6.02 Momentary Power Loss — Value: 01

Settings:
00 Stop operation after momentary power loss — Default 00
01 Continue operation after momentary power loss, speed search from Speed Reference.
02 Continue operation after momentary power loss, speed search from Minimum speed.

Selected to reach the necessary speed as soon as possible.

P 6.03 Reverse Operation Inhibit — Value: 01

Default : 00

Settings:00 Enable Reverse Operation
01 Disable Reverse Operation

This parameter determines whether the AC Drive can operate in the reverse direction. In this case we clearly will disable reverse operation.

P6.07 Over Torque Detection Mode — Value: 02

Settings:00 Disabled — Default 00

01 Enabled during constant speed operation

02 Enabled during acceleration

P 6.08 Over Torque Detection level Value 142

Range: 30 to 200% Default 150

- A setting of 100% is proportional to the Rated Output Current of the drive. Since the drive has a rating of 91 A and we want to detect overtorque arbitrarily at 150% of the motor rated current, the factor is 142%
- This parameter sets the Over Torque Detection level in 1% increments.

P 6.09 Over Torque Detection time Value 10.0

Range: 0.1 to 10.0 Default 0.1

This parameter sets the Over Torque Detection Time in units of 0.1seconds

P 6.10 Overcurrent Stall Prevention during Acceleration Value 140.0

Range: 20 to 200% Default 150

A setting of 100% is equal to the Rated Output Current of the drive.

Under the condition of backward fan running, when starting, the drive current output may increase abruptly and exceed the value specified by P 6.10. This is caused by excessive load on the motor. When this function is enabled, the drive will stop accelerating and maintain a constant output frequency; the drive will only resume acceleration when the current drops below 140% (120 A). The intention is that the motor will apply a forward motor torque to reduce the reverse speed until the FWD direction is reached.

P 6.12 Maximum allowable Power Loss Time Value: 5.0

Range: 0.3 to 5.0 s . Default 2.0

During a power loss, if the power loss time is less than the time defined by this parameter, the drive will resume operation. If the Maximum Allowable Power Loss Time is exceeded, the output is turned off.

P 6.13 Base-Block Time for Speed Search Value: 0.3

Range: 0.3 to 5.0 s. Default 0.5

- When a momentary power loss is detected, the drive turns off for a specified time interval determined by P 6.13 before resuming operation. This time interval is called Base-Block. This parameter should be set to a value where the residual output voltage due a regeneration is nearly zero, before the drive resumes operation.
- This parameter also determines the searching time when performing external Base-Block y Fault Reset (P 6.01)

P 6.30 | **Line Start Lockout** | **Value 00**

Range: 00 Line lockout start lockout enable — Default 00

01 Line lockout start lockout disable

When enabled, the AC drive will not start when powered up when the command RUN is ON. The drive must see the transition of the RUN signal from OFF to ON after power OFF. When disabled, the drive will start on power up with Run Signal ON.

P 7.00 | **Input Terminal for PID Feedback** | **Value: 02**

Settings: 00 Inhibit PID operation. — Default 00

01 Forward-acting (heating loop) PID feedback, PV from AI1 (0 a +10V)

02 Forward-acting (heating loop) PID feedback, PV from AI2 (4 a 20mA)

03 Reverse-acting (cooling loop) PID feedback, PV from AI1 (0 a +10V)

04 Reverse-acting (cooling loop) PID feedback, PV from AI2 (4 a 20mA)

P 7.01 | **PV 100% Value** | **Value: 100**

Range: 0.0 to 999 — Default 100

This parameter should be set to the value corresponding to the 100% value of the process variable (PV), that is, 20 mA. The setting for P 7.01 cannot be less than any setting for P7.10 to P 7.17.

P 7.02 | **PID Reference Source** | **Value: 03**

Range: 00: Keypad — Default 02

01: Serial Communications

02: AI1 (0 a 10V)

03: AI2 (4 a 20mA)

.**P 7.03** | **◆PID Feedback Gain** | **Value: 100**

Range: 00 to 300.0% — Default 100

P 7.04 | **◆PID Setpint offset Polarity** | **Value: 00**

Range: 00 No Offset — Default 00

01 Positive Offset

02 Negative Offset

P 7.05 | **◆PID Reference offset** | **Value: 0.0**

Range: 0.0 to100.0% — Default 00

P 7.06 | **◆PID Reference Gain** | **Value: 100**

Range: 0.0 to 300.0% — Default 100

P 7.20 | **◆ Proportional Control (P)** | **Value: 1.0**

Rango: 0.0 a 10.0 — Default 1.0

The first parameter of PID control is Proportional Control (P). For a given process, if the Proportional Value is set too low, the control action will be too sluggish. If the Proportional value is set too high, the control action will be unstable (erratic).

P 7.21 ◆ Integral Control (I) Value: 0.0

Range: 0.00 to 100.0 sec (0.00 disable) Default 1.0

Using only the Proportional Control, the corrective action may not increase fast enough or the setpoint may never be reached because of system losses.

The Integral Control is used to generate additional corrective action.

P 7.22 ◆ Derivative Control (D) Value: 0.0

Range: 0.00 to 1.00 sec Default 00

If the control output is too sluggish after the Proportional Control (P) and Integral Control (I) values are set, Derivative Control (D) may be required. Begin with a high Derivative value and reduce the value to the point of system instability. Then increase the Derivative value until the control output regains stability. Stability can be tested by moving between two wide-spread setpoint values.

P 7.27 PID Feedback Loss Operation Value: 01

Range: 00 - Warn and AC Drive Stop
01 - Warn and Continue Operation

This parameter sets the operation of the drive when there is a loss of the PID feedback signal. The main function here is to cool the clinker.

.P 8.00 User Defined Display Function Value: 01

Default 00

Settings:	00	Output Frequency (Hz)
	01	Motor Speed (RPM)
	02	Scaled Frequency
	03	Output Current (A)
	04	Motor Load (%)
	05	Output Voltage(V)
	06	DC Bus Voltage (V)
	07	PID Reference
	08	PID Feedback (PV)
	09	Frequency Reference

This value is the mode to indicate the motor RPM.

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