

## Using Closed Loop (PI) Control on MM4

### What is Closed Loop control?

Closed loop control is widely used in industrial applications to control a wide variety of processes. Control engineering is a complex subject, but a simple closed loop control uses a feedback signal from the process (such as temperature, pressure, speed) a desired value or set point (often set manually) and a control system that compares the two and derives an error signal. The error signal is then processed and used to control the inverter and motor (in this case) to try to reduce the error.

The error signal processing can be very complex because of delays in the system. The error signal is usually processed using a Proportional and Integral (PI) controller whose parameters can be adjusted to optimise the performance and stability of the system. Once a system is set up and stable very efficient and accurate control can be achieved.

### Implementation on MM420

The MM420 has a built in PI controller that can be enabled by the user to allow closed loop control. Once the PI controller is enabled (using P2200) the PI controller internally generates the motor frequency necessary to minimise the error between the PI setpoint and the PI feedback. It does this by continuously comparing the feedback signal with the setpoint and uses the PI controller to determine the necessary motor frequency. The normal frequency setpoint (P1000 setting) and ramp times (P1120 & P1121) are automatically disabled but the minimum and maximum output frequency settings (P1080 and P1082) remain active.

### Setting up the PI controller

#### Accessing PI parameters

The PI parameters are in the range between P2200 and P2294. For most applications, the level 2 parameters are sufficient for setting up the PI controller. To access only the PI controller parameters, you can use the parameter filter as follows:

P0003 = 2

P0004 = 22

## Enabling PI control

PI control is enabled using parameter **P2200**. For constant enabling of the PI controller this should be set to 1. It is also possible to use a digital input (or other BiCo functions) to enable the Pi controller, e.g. the PI controller can be enabled using DIN 2 by setting P0702 = 99 and P2200 = 722.1. This allows the user to switch between frequency control and PI control when the inverter is not running.

## PI Feedback signal

PI control requires a feedback signal from the process to monitor how the system is behaving. For the majority of applications, this will be in the form of an analogue sensor.

The MM420 has one analogue input, terminal pins 3 & 4, and the feedback signal can be connected to this input. The source of the PI feedback signal must then be defined using **P2264 = 755** (*source of PI feedback = analogue input 1*). If required the analogue input can be scaled using parameters P0757 – P0760. If a different source of feedback signal is used (e.g. USS), P2264 must be set appropriately.

The value of the feedback signal can be viewed via parameter r2266.

The relation between the sensor signal and the manner in which the PI controller changes the motor frequency must also be defined at this point. This is done using **P2271** (*PI transducer type*). There are 2 possible settings for this parameter, 0 and 1. The difference between these settings is whether the PI controller increases or decreases output frequency as a response to a positive error signal (i.e. where the feedback signal is less than the setpoint). The parameter description for P2271 describes in detail how to determine which setting is correct for your application.

## PI setpoint

The PI controller controls the inverter frequency by comparing the actual system behaviour (via the feedback signal) with the desired system behaviour. The desired behaviour is defined using a *setpoint*. The user selects the source of the setpoint with parameter **P2253**. The MM420 only has one analogue input and this is most commonly used for the feedback signal, so an internal digital setpoint is usually used. There are two methods of doing this, either using the “fixed PI setpoint” or the “keypad (motorised potentiometer) setpoint”. It should be noted that the values are given in % rather than Hz, and the running frequency of the inverter is determined by the difference between the setpoint and feedback signals and the action of the PI controller.

- a. **P2253 = 2224** “fixed PI setpoint”. This method allows the user to define up to 7 setpoint values using parameters P2201 to P2207 and select between these using binary signals, usually via the digital inputs. The different selection methods are described in the parameter list under P2201.
- b. **P2253 = 2250** “keypad (motorised potentiometer) setpoint”. This method allows the user to set a fixed value in **P2240**. The setpoint can be increased or decreased either with the arrow keys on the BOP or more commonly via digital inputs (e.g. P0702 = 13 “increase” and P0703 = 14 “decrease”).

### PI Setpoint ramp times

When PI control is enabled using P2200, the normal frequency ramp up and ramp down times (P1120 and P1121) are bypassed. The PI setpoint has its own ramp times, **P2257** and **P2258**, which allow ramped PI setpoint changes. The ramp up time, P2257, is active when the PI setpoint is changed or when a RUN command is given. The ramp down time, P2258 is only effective on PI setpoint changes. The ramp down times used after OFF1 and OFF3 commands are set in P1121 and P1135 respectively.

### PI controller Proportional and Integral terms

The user can tune the performance of the PI controller to suit his process demands by adjusting the **P** and **I** terms, **P2280** and **P2285**. The demands of the process will determine the optimal type of response, from a rapid recovery response with overshoot to a damped response. By adjusting the P and I parameters it is possible to achieve different types of response.

Example:

The following figures show how different responses to a 5% PI setpoint step change on a pressure control system. The traces show the PI feedback signal, with 1V = 10 %. The different responses are achieved by varying the settings of P2280 and P2285.

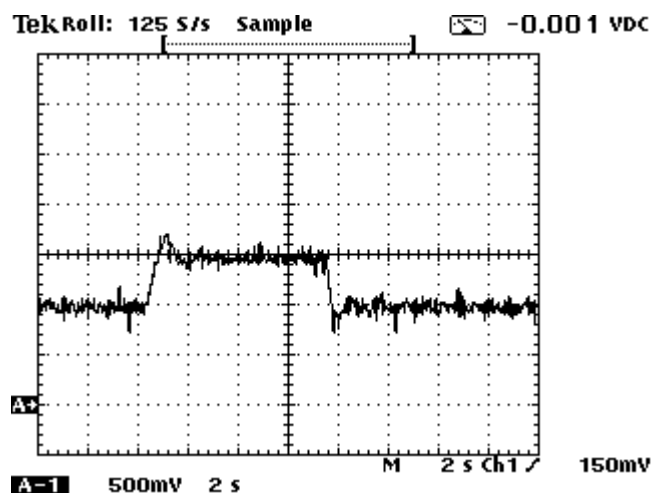


Fig.1: Quick response with overshoot: P2280 = 0.30; P2285 = 0.03 s

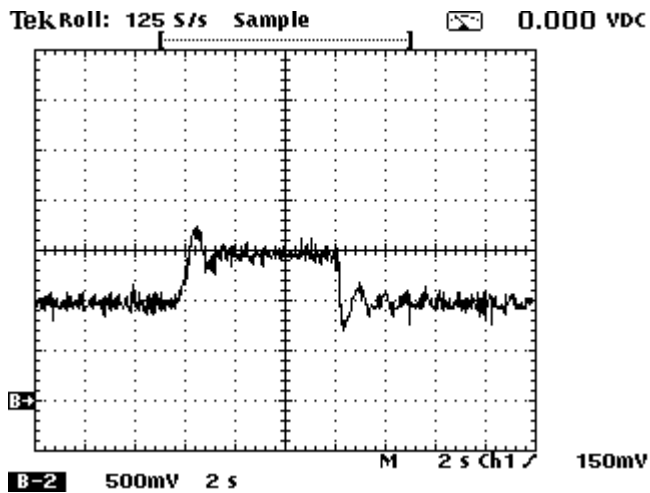


Fig.2: Quick response with overshoot, but instability: P2280 = 0.55; P2285 = 0.03 s

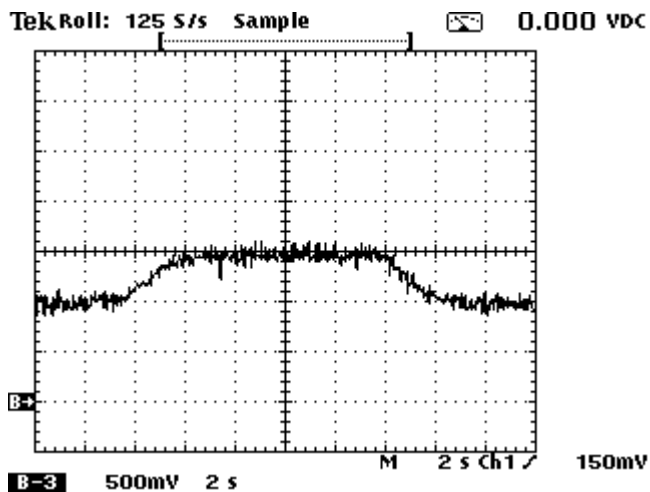


Fig.3: Damped response: P2280 = 0.20; P2285 = 0.15 s

The values of P2280 and P2285 will be determined by the relationship between motor frequency and the PI control quantity (e.g. pressure).

When optimising a control process we would recommend using an oscilloscope to monitor the feedback signal to see the system response. The analogue output can be used for this by setting P0771 = 2266. Most commonly small PI setpoint step changes (1- 10%) without the PI ramp times (P2257 = P2258 = 0.0s) are used to evaluate the system response. Once the desired response profile has been achieved, the operational ramp times are then set.

If you are optimising without an oscilloscope we suggest starting with a small P term (e.g. P2280 = 0.20) and adjusting the I term until stable operation constant achieved. A small PI setpoint change should then be given and depending on the system response the parameters adjusted according to the tendencies shown in the figures above.

In general, the most stable control is achieved by using both proportional and integral terms, and if the system is liable to experience sudden disturbances we would not recommend setting the P term (P2280) greater than 0.50.

### Ziegler-Nichols method of Optimisation

The Ziegler-Nichols method is a means of calculating the **P**roportional gain and **I**ntegral time by measuring the system response to a step change in open loop. This is done by putting the inverter in frequency control and monitoring the feedback signal. From the feedback response, the time before the system starts to respond, **L**, and the dominant time constant, **T**, which is measured by estimating when the system response would have reached its stationary value if the maximum slope was maintained (typically measure to where the system response has reached 85% of its final value). From L, T and the ratio between the frequency step  $\Delta f$  (as % of Fmax) to the feedback value change  $\Delta x$  (%), it is possible to calculate the P and I terms for a PI control process as follows:

$$\mathbf{P\ gain = (0.9)(T)(\Delta f) / (L)(\Delta x)}$$

$$\mathbf{I\ time = 3L}$$

Example:

With the inverter in frequency control, a frequency step of 5 Hz is given and the feedback signal monitored. To allow this the following parameters are set:

$$P2200 = 0$$

$$P1120 = 0.0\ s$$

$$P1121 = 0.0\ s$$

$$P1080 = 50.0\ Hz$$

Fig. 1: *Response to 5 Hz step: L = 100 ms*

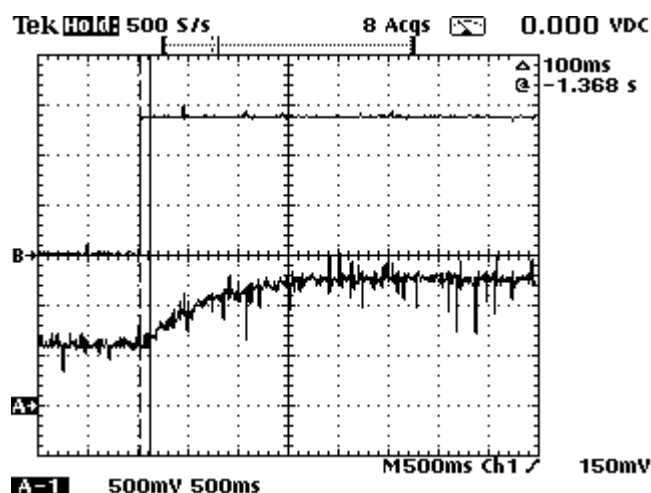
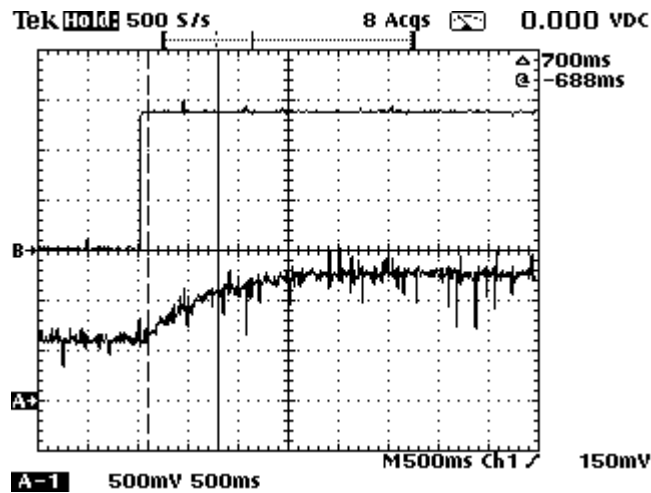


Fig. 2: Response to 5 Hz step: T = 700 ms



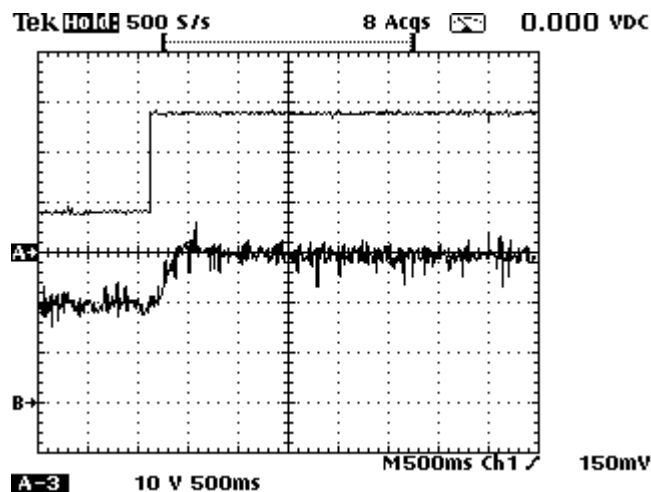
The frequency step  $\Delta f = 5 \text{ Hz} / 50 \text{ Hz} = 10\%$   
 The feedback step  $\Delta x = 0.64 \text{ V} / 10 \text{ V} = 6.4\%$

$$P \text{ gain} = (0.9)(T)(\Delta f) / (L)(\Delta x) = 9.84 = \mathbf{P2280}$$

$$I \text{ time} = 3L = 0.30 \text{ s} = \mathbf{P2285}$$

The PI controller should now be enabled (P2200 = 1)

Fig. 3: Step Response in PI control with P2280 = 9.84 and P2285 = 0.30



### PI output limits

The PI controller generates the frequency at which the inverter runs. This is generated as a % which is normalised into Hz via P2000. The user can limit the output range of the controller using parameters **P2291** and **P2292**. While the inverter will only operate within the frequency range defined by Fmin

(P1080) and Fmax (P1082), the PI output limits can be used to further limit the output frequency. Once one of the limits has been reached, a bit is set 53.A or 53.B which can be connected to the digital output via P0731, or used for internal control purposes using BiCo.

It should be noted that if Fmax (P1082) is greater than the value in P2000, then either P2000 or P2291 should be adjusted to allow Fmax to be reached.

Setting P2292 to a negative value allows bipolar operation of the Pi controller.

### Further features

Further features, such as a PI setpoint trim can be accessed in user access level 3 (P0003 = 3). These features are described in the Parameter List.

## Implementation on MM440

The same parameters and principles of operation are used on the MM440 so that completely compatible parameterisation and operation is possible between MM420 and MM440.

The MM440 does have a number of additional features and enhancements, which may be useful for many applications.

### 2 Analogue inputs

This allows the setpoint and sensor signals to be given as analogue values. The analogue inputs can be connected using the values **755.0** and **755.1** for inputs 1 and 2 respectively (refer to earlier explanation for PI setpoint and feedback connection). Each of the analogue inputs can be fully calibrated using parameters P0757 to P0761, indices 0 and 1.

### PID Autotuning (Automatic Optimisation)

An automatic optimisation of the PID control loop can be simply carried out on MM440. The procedure for carrying this out is as follows:

1. Select PID setpoint and feedback sources using **P2253** and **P2264**.
2. Optimise the range of the feedback signal. What this means is ensuring that the range of the feedback signal is comparable with the frequency range. For example if a sensor signal gives 0 V at minimum frequency and 1 V at maximum frequency, it is necessary to change P0757 to P0760 to give a range that will allow better resolution for automatic optimisation (e.g. setting P0759 and P0760 giving, say, a 60 % feedback value for a 1 V signal).
3. Ensure **P2271**, the transducer type, is correctly set.
4. Set **P2200 = 1** to enable PID control.
5. Set **P2350** according to the type of optimised behaviour required (see Parameter List for details). If necessary set P2335 to value greater than the 5.00% default value if the system time constant is very large (i.e. if the system responds very slowly to frequency changes).
6. Apply the RUN command. The system will be autotuned. Once this has taken place, the inverter will regulate to the PI setpoint. A second RUN command is not required. P2350 will be automatically reset to 0. If autotuning is unsuccessful, the inverter continues to attempt autotuning after a RUN command for the time defined in P2354.

### Differential (D) term

The differential (D) term is set in **P2274**. The D term is particularly useful for applications where the PI setpoint is constant and the error must be reacted to very quickly (e.g. a dancer arm controlling tension).



### 3 Drive Data Sets (DDS)

This allows the user to select between different parameter sets (typically using a digital input). This can be particularly useful if the user requires different P, I and D terms for different materials or processes.

#### Using the PID output as a frequency setpoint trim

If **P2200 = 0**, the inverter will run in frequency control, but the output of the PID controller can be used as a frequency setpoint trim by setting **P1075 = 2294**. This can then be scaled using P1076 and enabled / disabled via P1074. The Motorpoti setpoint (P2253 = 2250) cannot be used in this case. The PID output could also be connected to the analogue output. While this is also possible on the MM420, the limitations on the setpoint and PI feedback selection due to the availability of only one analogue input makes it more difficult to use in practice.