Subject	:	**PID control using MD500-PLUS drive**			
Document Category	:	General	**Product Category**	:	MD500-PLUS
Issued By	:	David Bedford	**Confidentiality**	:	Low / ~~High~~
Authorized By	:	David Bedford	**Circulation**	:	Distributors / ~~Internal~~

Revision History

Revision	Date	Revising Author	Description
1.0	04/03/2022	David Bedford	First issue

Summary of contents

This document describes how to set up PID control using MD500-PLUS drive to implement, for example, a pressure control with a pump, where the pump is moved by a motor controlled by a MD500-PLUS drive.

1. Introduction.

In MD500-PLUS drives we can get main frequency reference from PID control. This allows to implement an external process control, like pressure or flow.

2. Preparation.

Before setting up PID control in MD500-PLUS few items have to be checked. As an example, we will describe a set up for controlling pressure.

- Is the sensor capable of sensing the expected range?
  When we want to control the pressure in a system to 2 Bar, the sensor must be capable of measuring more. Preferably 1.5 times more, i.e. 3 Bar.
- Does it have an output signal that can be connected directly to the MD500-PLUS input?
  MD500-PLUS has inputs for 0-10 V and 4-20 (0-20) mA signals.

3. PID control Basics.

3.1 PID control introduction.

In PID control the drive obtains the main frequency reference coming from the PID controller, where:

- The desired process magnitude (pressure, flow) is the reference (*setpoint*) of this PID controller, and is set in the drive using analog input or preset (digital) value.
- The *feedback* signal for this controller comes from a sensor (pressure, flow) which measures the process magnitude, and is connected to an analog input of MD500-PLUS drive.

With this control architecture the main frequency is modified by the control action of the PID controller, so that the final frequency reference is the correct one for the process, to keep the magnitude (pressure, flow), to the desired setpoint.

3.2 PID basic concept of forward operation (normal use).

A PID regulator is a control structure that will try to control a certain magnitude (pressure, flow rate, temperature, ...) to a desired value, which is called *PID command* (or setpoint) value. To do so this structure needs information of the actual status of the system by means of the proper measurement device (pressure, flow or temperature sensor). This signal is called the *PID Feedback*. This control structure normally has three control actions: Proportional (P), Integral (I) and Derivative (D) that have to be tuned according to the real system by the corresponding gain/times:

- Proportional gain (Kp1): A large value tends to reduce present error, but too large setting will cause system oscillation.
- Integral time (Ti1): The shorter the integral time is, the faster the error will be predicted. But too short setting will cause overshoot or system oscillation.
- Derivative time (Td1): The longer the derivative time is, the faster the system will respond to the error. But too longer setting will cause vibration.

Figure 1 below depicts the PID control structure.

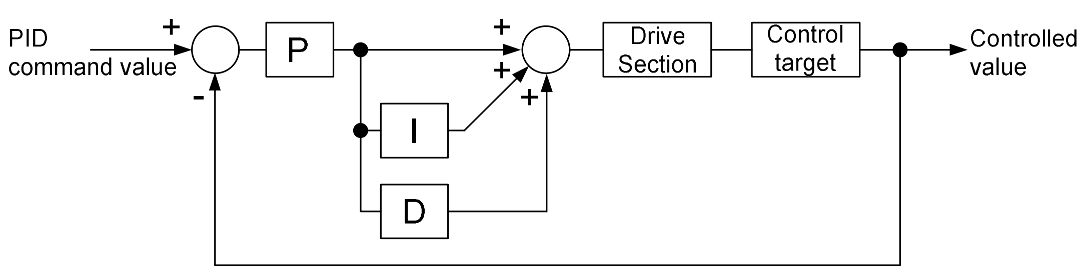

Figure 1. PID control structure diagram.

What happens in above picture?

In the picture you can see that the signals from the PID command and the PID Feedback are substracted resulting in an error signal. When the PID command and the PID feedback signal are the same no correction is needed, and the drive will run at the same frequency. When the PID command is larger than the PID feedback the error signal will be positive and the drive frequency will increase until the PID Feedback signal is the same. This is a continuous process. As soon as a difference in the feedback is detected the drive frequency will be adjusted accordingly.

- ***PID command*** = ***PID feedback*** => No output frequency change.
- ***PID command*** > ***PID feedback*** => Output frequency is **in**creased.
- ***PID command*** < ***PID feedback*** => Output frequency is **de**creased.

The example above is a simple representation of the process. In real world processes there usually is a time delay between changing the drive frequency and the response of the PID feedback signal.

3.3 Proportional (P) part.

The P part of a PID controller is the Proportional part. This means that the action of the P part only depends on the momentary difference (error) between the set value and the feedback. The drawback using P controller only is that the more the feedback signal approaches the set value, the smaller the action (correction) signal from P control becomes, slowing the settling of the process. In theory the set value (*PID command*) will never be reached.

3.4 Integral (I) part.

Adding the I (integral) part of the PID controller, the effect of the P controller only never reaching the set value can be solved. The I part integrates the difference between the set and feedback value. Even when this difference is small, after some time, the correction to the error signal will become larger, helping the process to reach the set value (*PID command*).

3.5 Derivative (D) part.

The D-part (derivative) part of the controller helps to overcome another drawback of the proportional controller. This is that the correction signal can never become larger than the difference between the setpoint and feedback signal (error). The D part of the controller can amplify the difference (error) a bit more so the correction signal to the process will become higher (for a short time) and the process will reach the set-point faster. It is recommended not to use this part unless a good response is not achieved with the P and I control.

4. Control signal wiring.

Following diagram describes a proposed wiring with MD500-PLUS.

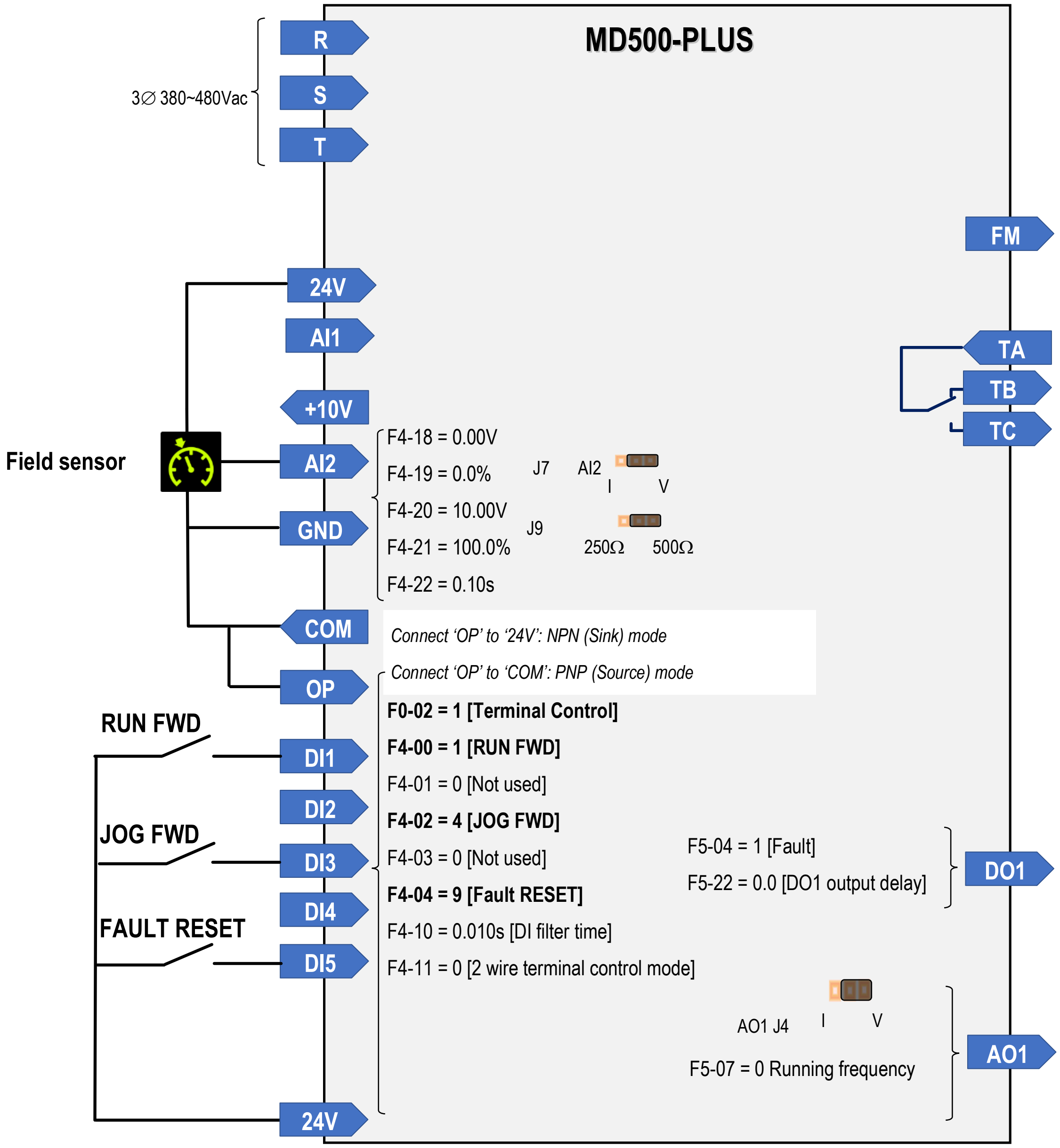

Figure 2. Proposed wiring with MD500-PLUS.

5. Parameter settings for PID control in MD500-PLUS.

In order to set-up a PID-Control in MD500-PLUS please follow 3 steps.

Step 1. Basic set up of the drive.

In order to do this you have to set the following Parameters:

Basic Parameters:

F0-10. Maximum frequency.
This function sets the maximum output frequency for motor, in Hz.
Factory setting is 50 Hz.

F0-12. Frequency upper limit.
This function sets the upper limit for the setting frequency, in Hz.
Factory setting is 50 Hz.

F0-14. Frequency lower limit.
This function sets the lower limit for the setting frequency, in Hz.
Factory setting is 0 Hz.
Recommended value for PID control is zero or, at least, very low.
In case of controlling a pump this parameter is usually different from zero for several reasons. The action of the pump is effective over a minimum frequency (normally above 30 Hz) ant it doesn’t make sense to turn the motor at a speed lower than this. When the pump turns if it pumps fluid the pump self-cools but if the pump turns and it doesn’t pump fluid the pump is not self-cooled and it can be damaged. Normally when this boundary exist, the sleep function of the inverter (also described in this bulletin) must be used in combination with minimum frequency.

F0-17. Acceleration time 1.
This function sets the acceleration time for the output frequency from 0 to maximum frequency (F0-10, if F0-25=0), in seconds. Usually, for PID control the value of this function has to be small, otherwise the system could become unstable. If this parameter is increased the action of the PID will be softened and delayed (as a slew rate filter); it can be interesting for some applications although are not the most common.
Factory setting is 20.0 s.

F0-18. Deceleration time 1.
This function sets the deceleration time from maximum frequency (F0-10, if F0-25=0) to 0, in seconds. Usually, for PID control the value of this function has to be small, otherwise the system could become unstable. In the same manner that parameter F0-17, if this parameter is increased the action of the PID will be softened and delayed (as a slew rate filter); it can be interesting for some applications although are not the most common.
Factory setting is 20.0 s.

Motor parameters:

F1-00. Motor 1 type selection.
Allows to select the type of the motor 1, as follows:

0: Common asynchronous motor
1: Variable frequency asynchronous motor
2: Permanent magnet synchronous motor

Factory setting is 0 (common asynchronous motor).

F0-01. Motor 1 control mode.

Allows to select the control mode for motor 1, as follows:

0: Sensorless vector control (SVC)
1: Feedback vector control (FVC)
2: V/f control
5: VVC+ control (for synchronous motor only)

Factory setting is 0 (sensorless vector control)

F1-01. Motor 1 rated power.

This parameter should be set according to the motor 1 rated power, in kW.

Factory setting depends on the inverter size.

F1-02. Motor 1 rated voltage.

This parameter sets the rated voltage of the motor 1, in volts. Please note that the drive cannot output a voltage higher than the supply (input) voltage.

Factory setting depends on the inverter model.

F1-03. Motor 1 rated current.

This parameter sets the rated current of motor 1, in Amperes.

Factory setting depends on the inverter model.

F1-04. Motor 1 rated frequency.

This parameter sets the rated frequency of the motor 1, in Hz.

Factory setting depends on the inverter model.

F1-05. Motor 1 rated speed.

This parameter sets the rated speed of the motor 1, in rpm. This function allows to set the rated slip of the motor (case of induction motor) and calculate the number of poles of the motor.

Factory setting depends on the inverter model.

F3-01. Torque boost 1.

This parameter allows to set the voltage close to zero frequency for V/f control mode. Therefore it allows to set the motor torque at very low frequencies in V/f control mode.

Factory setting depends on the inverter model.

F1-37. Motor Auto-tuning.

This parameter allows to set the method of tuning used to measure the motor parameters.

Auto-tuning function is not necessary in V/f control mode, but it is highly recommended when using SVC mode, unless all the motor parameters can be copied from another drive.

The auto-tuning options that can be selected are shown in the following table.

Set value	Operation
0	Inactive
1	Static auto-tuning on partial parameters of the asynchronous motor
2	Dynamic auto-tuning on all parameters of the asynchronous motor
3	With-load static auto-tuning on all parameters of the asynchronous motor
11	Static auto-tuning on partial parameters of the PM synchronous motor (excluding back EMF)
12	No-load dynamic auto-tuning on all parameters of the PM synchronous motor
13	Static auto-tuning on all parameters of the PM synchronous motor (excluding the encoder installation angle)

Step 2. Set up the PID Controller.

In order to set up the PID controller the following parameters have to be set:

FA-03. PID action direction
This function is used to setup the PID action direction of the PID controller. The alternatives are:

FA-03=0: forward operation
FA-03=1: reverse operation

Factory setting is 0.

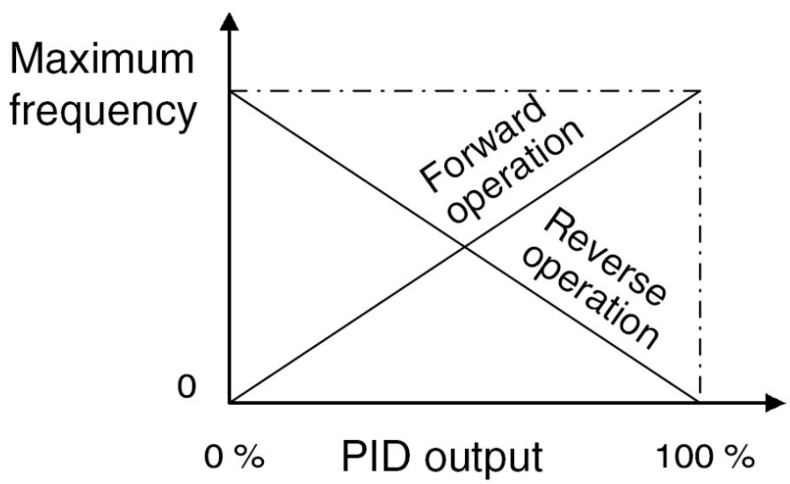

Figure 3. Forward and reverse operation.

FA-00. PID control reference source.
This parameter is used to set the source of the setpoint for the PID controller, as follows:

0: Digital setting of PID (FA-01)
1: AI1
2: AI2
3: AI3
4: Pulse reference (DI5)
5: Communication
6: Multi-reference

FA-01. PID control feedback source.
This parameter is used to set the source of the feedback for the PID controller, as follows:

0: AI1
1: AI2
2: AI3
3: AI1 – AI2
4: Pulse reference (DIO1)
5: Communication
6:AI1 + AI2
7: Max. (|AI1|, |AI2|)
8: Min. (|AI1|, |AI2|)
9: Reserved

FA-04. PID control reference and feedback range.
This parameter allows to show the PID setpoint and feedback in real process units.
The setting of this parameter affects the display of the monitoring parameters of the PID reference (U0-15) and feedback (U0-16), as follows:
U0-15: PID reference value = PID reference (percentage) x FA-04 (PID reference & feedback range)
U0-16: PID feedback value = PID feedback (percentage) x FA-04 (PID reference & feedback range)

FA-05. PID control proportional gain (Kp1).
This parameter is used to set the proportional gain (Kp1) of the PID controller, in times.
This parameter has to be tuned on site; the value depends on the application.
Factory setting is 20.0.

FA-06. PID control integral time (Ti1).
This parameter is used to set the integral time (Ti1) of the PID controller, in seconds.
This parameter has to be tuned on site; the value depends on the application.
Factory setting is 2.00 s.

FA-07. PID control derivative time (Td1).
This parameter is used to set the derivative time (Td1) of the PID controller, in seconds.
This parameter has to be tuned on site; the value depends on the application.
Factory setting is 0.000 s.

FA-12. PID controller feedback filter time.
This parameter is used to set the time constant of the filter for PID control feedback signal, in seconds.
This parameter has to be tuned on site; the value depends on the application.
Factory setting is 0.00 s.

FA-26: Detection level of PID feedback loss.
This parameter is used to set the level to determine that the PID feedback signal is lost.
If the feedback signal is lower that the value set in this parameter for a time longer than the time set in parameter FA-27 the drive trips with Error 31.
If the setting of this parameter is 0.0% then PID feedback loss is disabled.
Factory setting is 0.0 %.

FA-27: Detection level of PID feedback loss.
This parameter is used to set the time to determine that the PID feedback signal is lost.
If the feedback signal is lower that the value set in parameter FA-26 for a time longer than the time set in this parameter the drive trips with Error 31.
Factory setting is 0.0 s.

Analog input settings:
MD500-PLUS drive allows to set the relation between the analog input value and the corresponding set value, by setting the AI curves. The AI curves can be assigned to the analog inputs by parameter F4-33.

F4-13. AI curve 1 minimum input.
This parameter allows to set the minimum input value of the analog input in AI curve 1.
Setting range of this parameter is from –10.00 V to the value set in F4-15.
Factory setting is -10.00 V.

F4-14. Percentage corresponding to AI curve 1 minimum input.
This parameter allows to set the percentage value corresponding to the minimum input value of the analog input in AI curve 1.
Setting range of this parameter is from -100.0 % to +100.0 %.
Factory setting is -100.0 %.

F4-15. AI curve 1 maximum input.
This parameter allows to set the maximum input value of the analog input in AI curve 1.
Setting range of this parameter is from the value set in F4-12 to +10.00 V.
Factory setting is +10.00 V.

F4-16. Percentage corresponding to AI curve 1 maximum input.
This parameter allows to set the percentage value corresponding to the maximum input value of the analog input in AI curve 1.
Setting range of this parameter is from -100.0 % to +100.0 %.
Factory setting is +100.0 %.

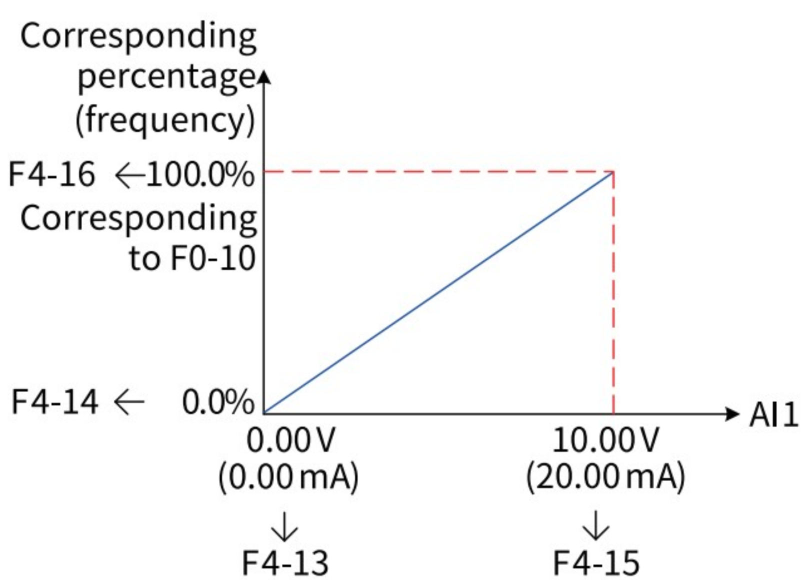

Figure 4. AI curve 1 settings.

F4-18. AI curve 2 minimum input.
This parameter allows to set the minimum input value of the analog input in AI curve 2.
Setting range of this parameter is from –10.00 V to the value set in F4-20.
Factory setting is -10.00 V.

F4-19. Percentage corresponding to AI curve 2 minimum input.
This parameter allows to set the percentage value corresponding to the minimum input value of the analog input in AI curve 2.
Setting range of this parameter is from -100.0 % to +100.0 %.
Factory setting is -100.0 %.

F4-20. AI curve 2 maximum input.
This parameter allows to set the maximum input value of the analog input in AI curve 2.
Setting range of this parameter is from the value set in F4-18 to +10.00 V.
Factory setting is +10.00 V.

F4-21. Percentage corresponding to AI curve 2 maximum input.
This parameter allows to set the percentage value corresponding to the maximum input value of the analog input in AI curve 2.
Setting range of this parameter is from -100.0 % to +100.0 %.
Factory setting is +100.0 %.

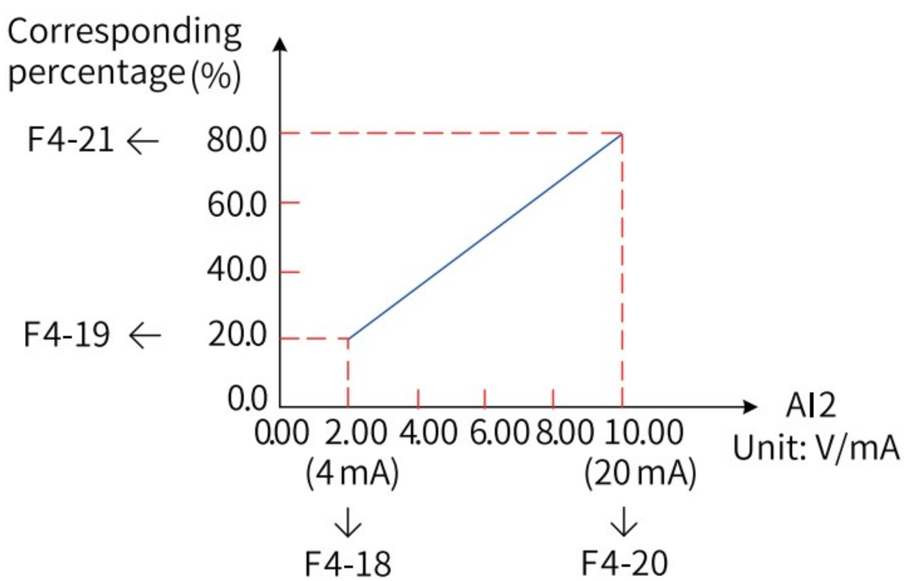

Figure 5. AI curve 2 settings.

F4-33. AI curve selection.
This parameter allows to assign an AI curve to an analog input.
The units dígit setting determines the assignment for AI1, the tens dígit the assignment for AI2 and the hundreds dígit the assignment for AI3.
Factory setting is F4-33 = 321, which assigns AI curve 1 to AI1, AI curve 2 to AI2, and AI curve 3 to AI3.

F4-17. Analog input 1 (AI1) filter time.
This parameter allows to set the analog input 1 filter time.
When using analog input AI1 as PID feedback, this parameter is alternative to parameter FA-12. Therefore, if parameter FA-12 is set, it is recommended to set this parameter to 0.00 s.

The setting range of this parameter is 0.00 s to 10.00 s.
Factory setting is 0.10 s.

F4-22. Analog input 2 (AI2) filter time.
This parameter allows to set the analog input 2 filter time.
When using analog input AI2 as PID feedback, this parameter is alternative to parameter FA-12. Therefore, if parameter FA-12 is set, it is recommended to set this parameter to 0.00 s.
The setting range of this parameter is 0.00 s to 10.00 s.
Factory setting is 0.10 s.

Sleep and wake up functions
The following parameters are especially designed for pump applications.

These parameters specify the data for low flow-rate stop in pump control, a feature that allows to stop the drive when there is no water consumption.

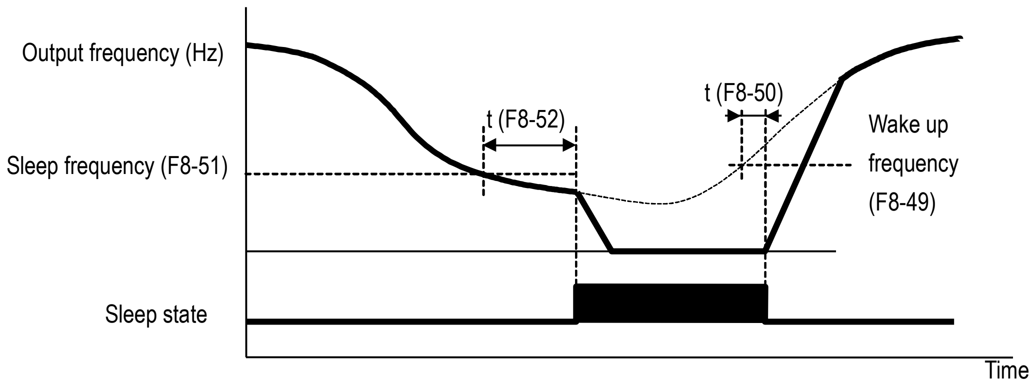

Figure 6. Sleep and wake up functions.

When the discharge pressure has increased, decreasing the reference frequency (output of the PID processor) below the sleep frequency level (F8-51) for a time longer than the sleep delay time (F8-52), the inverter decelerates to stop, while PID control itself continues to operate. When the discharge pressure decreases, increasing the reference frequency (output of the PID processor) above the wake up frequency (F8-49), for a time longer than the wake up delay time (F8-50), the inverter resumes operation.
To use the sleep and wake up functions, set the wake up frequency, wake up delay time, sleep frequency and sleep delay time. Generally, set the wake up frequency (F8-49) equal to or greater than the sleep frequency (F8-5). If the wake up frequency and the sleep frequency are both 0.00 Hz, the sleep and wake up functions are disabled.

F8-51. Sleep frequency.
Specifies the sleep frequency level.
If the setpoint frequency is below the level set in this parameter during a time longer than the setting in parameter F8-52 (sleep delay time), the drive will trigger sleep mode.
This frequency must be equal or lower than the value set in parameter F8-49 (wake up frequency).
Factory setting is 0 Hz.

F8-52. Sleep delay time.
Specifies the delay time to enter in
If the setpoint frequency is below the level set in parameter F8-51 during a time longer than the setting in this parameter, the

drive will trigger sleep mode.
Factory setting is 0.0 s.

F8-49. Wake up frequency.
Specifies the wake up frequency.
If the setpoint frequency is above the level set in this parameter during a time longer than the setting in parameter F8-50 (wake up delay time), the drive will resume operation.
This frequency must be higher or equal than the sleep frequency (F8-51) and lower or equal than the maximum frequency (F0-10).
Factory setting is 0 Hz.

F8-50. Wake up delay time.
Specifies the delay time to resume the drive operation (after entering sleep mode).
If the setpoint frequency is above the level set in parameter F8-49 during a time longer than the setting in this parameter, the drive will resume operation.
Factory setting is 0.0 s.

Step 3. Tuning of the System.

- Set acceleration (function F0-17) and deceleration times (function F0-18) of the MD500-PLUS drive as small as possible. Use 1.00 second as starting point.
- Check that the frequency upper limit and lower limit settings (parameters F0-12 and F0-14 respectively) do not obstruct the operation of the PID controller or the system.
- Check if the sensor levels and response are suitable for the application. When controlling a process up to 8 Bar do not use an 8 Bar sensor; use for example a 12 Bar sensor.
- Try to keep the set-point of the PID to a lower value of its operating range. This means for example when using 0-10V input, choose a source that has an output value of 8 Volt at the set value.
- When setting up a control system make sure the motor has sufficient capacity. A good control cannot be achieved when the set value of a compressor is set to 4 Bar and the maximum achievable pressure of the system is 4 Bar.
- Measure or estimate the time lag between the process control and the feedback signal of the process. It is important to anticipate on the time lag of the process or instability can easily occur. It is important to know this time. One can determine this time in many ways. One way can be to change the set-point of the controller and monitor the feedback value for a change. The time it takes is the time lag of the control loop.

When setting up the PID controller, we start disabling the I (by setting FA-25=1 and activating a digital input configured with function 38) and D actions (by setting FA-07=0). Then we set P gain to 1.000 and we operate the inverter. If the process oscillates we lower the gain of P. If the process does not reach the set-point but only goes half way of the set-point we can slowly increase the P gain until 80-90% is achieved. We have to test the response of the system by adding different loads. When the process starts to oscillate we have to lower the P gain again until a stable control is achieved. It may be possible that the feedback does not reach the set-point. This will be solved with the I action of the PID controller. At this moment it is only important that no oscillation occurs when the load of the process is changed.

When we are sure that the system does not oscillate with the P gain setting, we can start to optimise the control loop by adding some I action (enable by FA-25=0). We could start by entering the value of the time lag of the process as the value of I parameter. After this, we have to test if the system is stable when applying different loads. Remember that decrease the value of I term (FA-06) means increase the Integral action and the other way round. Low values of FA-06 mean strong Integral action (PID response is fast). High values of FA-06 mean soft Integral action (PID response is slow).

The D action is seldom needed for drives and processes that take seconds to settle. When using D we have to take care that the system does not oscillate. Same as Integral action low values of FA-07 means strong action of the D term and viceversa.

After adjusting the PID control gains, please remember that other parameters can be adjusted, such as minimum frequency, sleep and wake up frequencies,…

The table below summarizes the MD500-PLUS parameter settings for PID control.

Function Code	Parameter Name	Parameter Setting	Remarks
F0-02	Command source selection	1: Terminal I/O control	
F0-03	Main frequency reference setting channel selection	8: PID reference	
F4-00	DI1 function selection	1: Forward RUN (FWD)	
F4-04	DI5 function selection	9: Fault reset (RESET)	
FA-00	PID reference (set point) setting channel	0: Set by FA-01	It can be set from 0- 6 as per requirement
FA-01	PID digital setting	Depends on the process	0.0% to 100.0%
FA-02	PID feedback setting channel	1: AI2	It can be set from 0- 8 as per requirement
FA-03	PID operation direction	0: Forward	0
FA-05	Proportional gain Kp1	0.0 – 1000.0 Depends on the process	PID setting can be done by adjusting these parameters for achieving the desired performance
FA-06	Integral time Ti1	0.01 - 100.00 s Depends on the process	
FA-07	Derivative time Td1	0.000 - 10.000 s Depends on the process	
FA-12	PID feedback filter time	0.00–60.00 s Depends on the process	Set only when the feedback signal is disturbed
FA-25	PID integral property	0	Set 1 to disable integral action (and activate a DI set to function 38)

6. Tips and Tricks.

PID control can be held (frozen) temporarily from a digital input, by setting function 22 in this input (PID pause). For example, if we want to use input DI5 to activate/deactivate PID control we shall program F4-04= 22.

It is recommended to start the set up of the inverter from a known configuration. Therefore it is recommended to set all functions to factory setting by means of function FP-01 (setting to 1), prior to change the functions described in this document.

To adjust the gain and offset for the analog input AI1, refer to the parameters A6-16 and A6-17 respectively, and for the analog input AI2, refer to the parameters A6-18 and A6-19 respectively.

If the feedback signal is disturbed we can filter by setting parameter FA-12 (PID feedback filter time). This however will slow down the response of the PID controller. Feedback can become unstable when for example the pressure sensor is too close to the pump.

7. Application examples.

7.1 Application example 1.

In this application we describe the settings of MD500-PLUS PID controller. The set-point is set by digital preset, and feedback is coming from a transducer (4-20 mA pressure transmitter) connected to analog input AI2 (set in current mode); PID controller operates in forward operation.

Connect the signal output of the pressure transmitter to AI2 input for the feedback signal (as shown in figure 7).

F0-02=1 (FWD/REV from digital inputs)
F0-17=1.0 s (Acceleration time 1)
F0-18=1.0 s (Deceleration time 1)

PID parameters:

F0-03=8 (Frequency command from PID)
FA-03=0 (PID forward operation)
FA-00=0 (PID setpoint value from preset value FA-01)
FA-02=1 (PID feedback value from analog input AI2)

FA-05 (PID control P-gain)
FA-06 (PID control I-gain)
FA-07 (PID control D-gain)
FA-12 (PID control Feedback filter)

FA-05, FA-06, FA-07 and FA-12 may be set as described in this document.

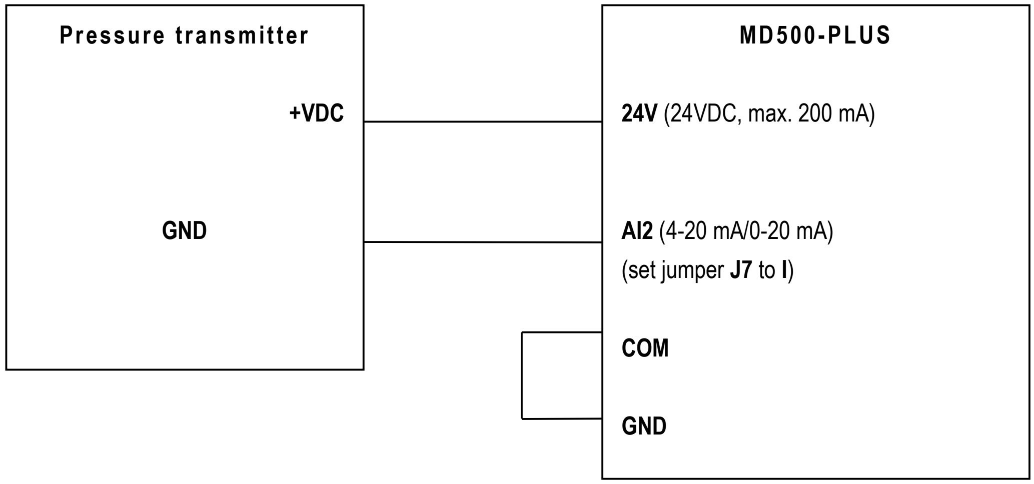

Figure 7. Pressure transmitter connected to analog input AI2.

7.2 Application example 2.

In this application we describe the settings of MD500-PLUS PID controller, using a potentiometer (0-10 V) for the PID setpoint, connected to analog input 1 (AI1), and feedback is coming from a transducer (4-20 mA pressure transmitter) connected to analog input AI2 (set in current mode); PID controller operates in forward operation.

Connect the potentiometer to terminals +10V, AI1 and GND.

Connect the signal output of the pressure transmitter to AI2 input for the feedback signal (as shown in figure 7).

The following parameters have to be programmed:

F0-02=1 (FWD/REV from digital inputs)
F0-17=1.0 s (Acceleration time 1)
F0-18=1.0 s (Deceleration time 1)

PID parameters:

F0-03=8 (Frequency command from PID)
FA-03=0 (PID forward operation)
FA-00=1 (PID setpoint value from analog input AI1)
FA-02=1 (PID feedback value from analog input AI2)

FA-05 (PID control P-gain)
FA-06 (PID control I-gain)
FA-07 (PID control D-gain)
FA-12 (PID control Feedback filter)

FA-05, FA-06, FA-07 and FA-12 may be set as described in this document.

In this configuration the potentiometer determines the PID set-point value.

8. Summary.

MD500-PLUS drive can be used to control an external process (pressure or flow) by using the PID control function on the drive.
For more detailed information about the MD500-PLUS drive functions please refer to the *MD500-PLUS Software Guide*.