

Small mine hoist type loads

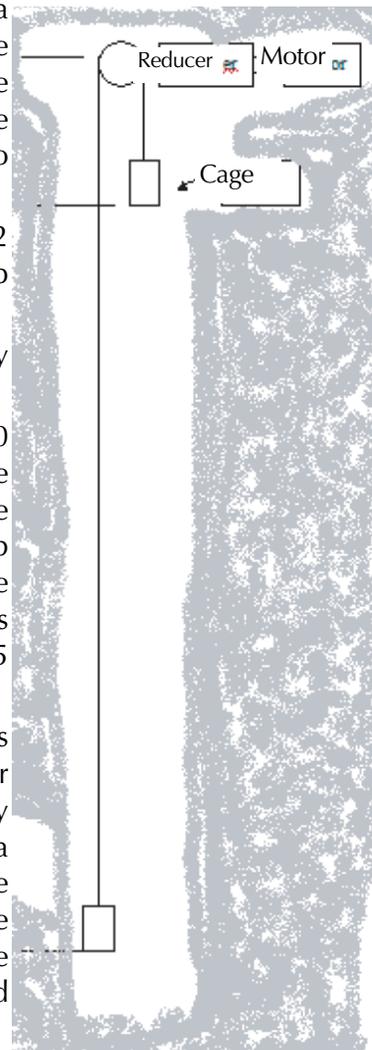
In this application note we will size and configure a DURApulse variable frequency drive for a small mine hoist. A mine hoist lifts mineral ore from one level to one up in underground mines. The transport capacities are variable, with motors ranging from hundreds of HP to some in the thousands.

In this case we have a vertical shaft small hoist with 2 cages or skips, in such a way that, when one loaded skip goes up the other, empty, goes down.

The loading and unloading happens simultaneously by mechanical means. See adjacent diagram.

The requirements are to have a daily lifting output of 1200 short tons in 15.5 hours for a distance of 350 feet. With the mechanical design, it has been determined that the unloaded cage weight is 2250 lb and the cable is 462 lb total. That results in a cycle of 86 liftings per hour and since the load/unload time is 10 second, the total travel time is 41.8 s. Acceleration and deceleration are equal to 3.5 second.

The calculations done by the mechanical engineering has issued a curve of torques versus time referred to the motor shaft operation from the point of view of the drive. Safety factors are already included. The control is done with a PLC, not shown in this example. The task in this example is to design the drive components and configure the parameters. We will make a list of the requirements of the application in order to decide which parameters need modifications.

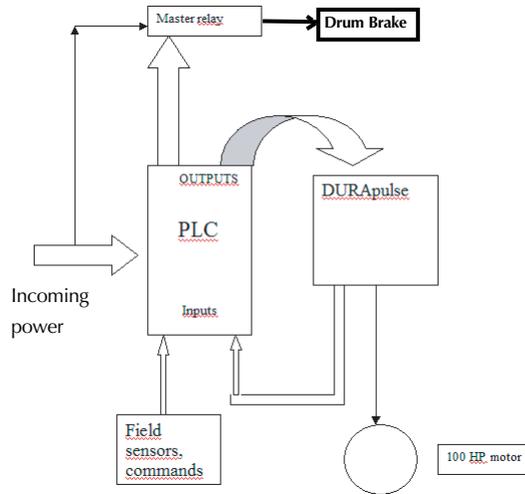


Application requirements

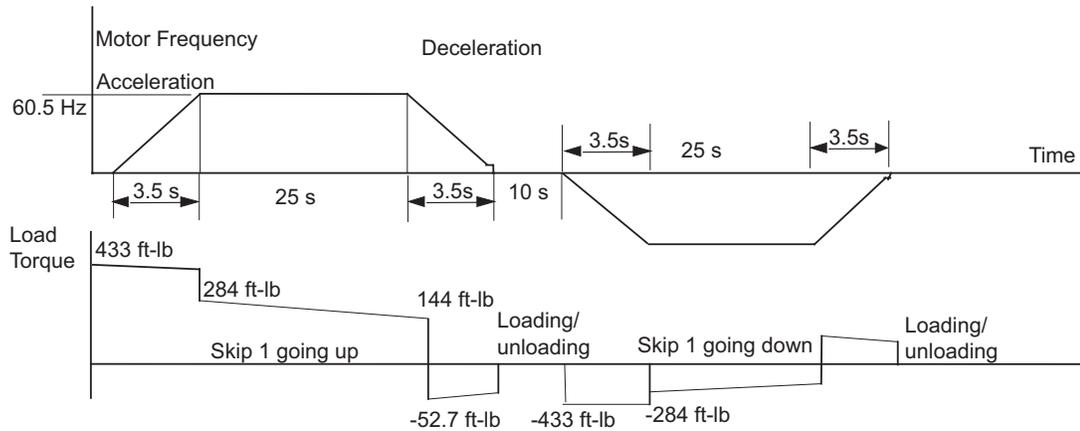
- See the concept of control in the diagram on the next page.
- The drive will control a 460 Volt motor, horsepower to be determined.
- The maximum speed of the motor is 1800 RPM, connected to a reducer.
- The motor must accelerate to the maximum speed in 3.5 seconds, preferably with an S-curve profile. The motor must stop with a deceleration of 3.5 seconds, when the mechanical brake will be applied.
- The operation of the system (start, stop, etc.) will be controlled by a controller, which could be a PLC.
- The frequency of the VFD will be preset by an external contact. The command to raise the hoist skip will be from one contact and the command to lower it will be from another contact.
- The analog signal output of the VFD will indicate the motor current when it is working.
- The mine hoist is stopped with drum brakes, not controlled by the VFD, but by a master relay, a safety control device.

- The system will incorporate dynamic braking.
- The system will utilize DC injection to hold the motor when the mechanical brake is released.
- The drive will change to the creep speed right before the stop point, to allow for exact application of the mechanical brake. That creep speed will be determined by the PLC based on position limit switches or proximity sensors.

The adjacent figure shows the concept of control. The shaft will have position limit switches and there is a central control room where it is commanded to start and stop.



Next we show the required torque at the input of the gearbox, through the cycle:



As the maximum torque required is 433 ft-lb and the *DURApulse* can supply up to 150% of the motor rated torque, we will use a motor with a rated torque of at least 289 ft-lb. The closest we have is a 100 HP, 1785 rpm, 295 ft-lb. We sell several different inverter duty type 100 HP motors. We select the Marathon inverter duty motor Y575-A774, Blue Max with 115A of rated current at 460 Volt, with an encoder of 1024 pulses per revolution, to assure stable speed, non dependent on the possibilities to change slip if the load is variable. This is a possibility because the density or even the load may not be exactly the same quantity during one load.

The motor has 3 normally closed contacts to determine overtemperature, that are wired to the PLC.

The corresponding drive is the GS3-4100, with up to 150A rated current. We will also select the braking resistor of the GS3-4100-BR type and a GS-4DBU braking unit.

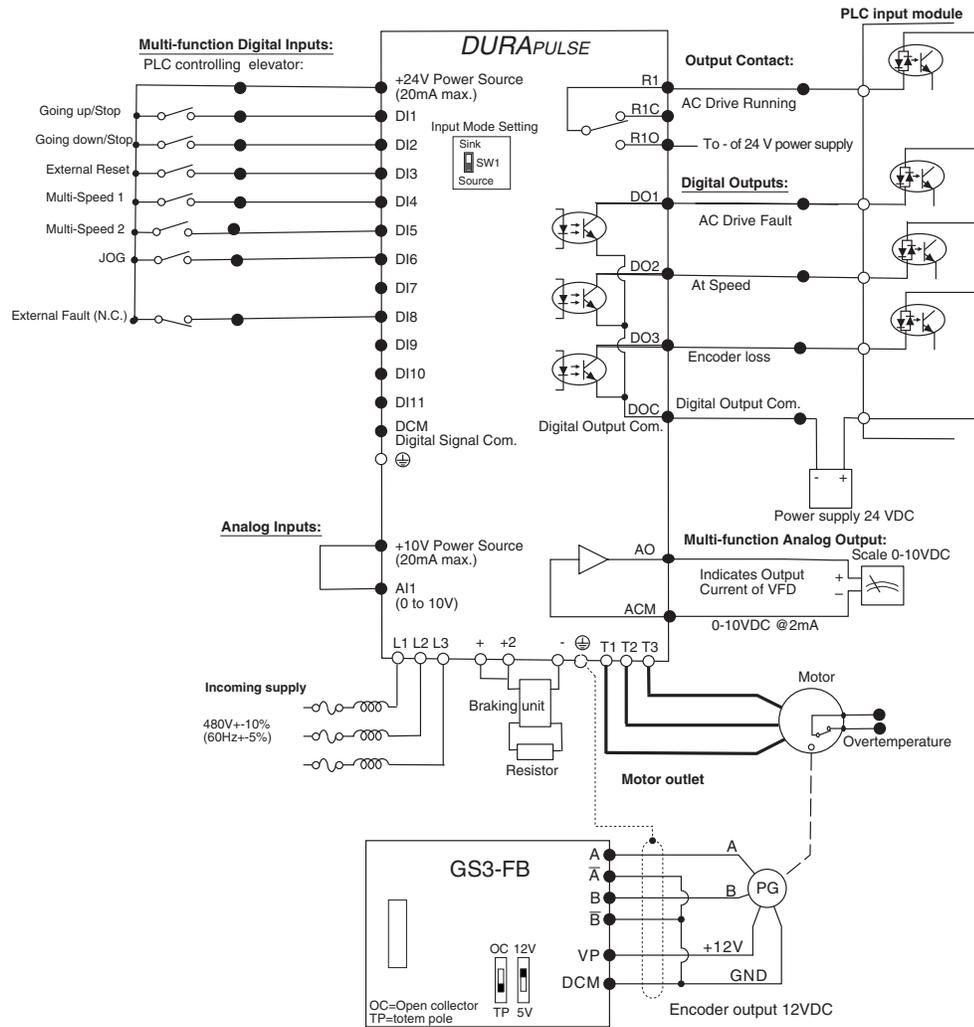
The braking resistor allows the drive to brake up to 125% of the motor torque, which is enough since we need only 52.7 ft-lb. This corresponds to about 19 % of the motor rated torque.

We will select the sensorless vector method with feedback, to have a better torque behavior, which is needed to perform the cycle consistently every time.

The motor heating calculation should be verified with the method of RMS power during a complete cycle, or other method, shown later in this note.

The line reactor to be used is the GS-4100-LR, for 460 Volt, and the fuse kit including the fuses is the GS-4100-FKIT. Please note that the fuse is sized for 600A, 600 Volt and is fast blow, to protect the drive and not the wire feeding the drive; In general the branch circuit fusing is of a lower rating than that sized to protect the AC drive.

Next we show the *Durapulse* wiring diagram for this specific application.



Note that it is necessary to determine the motor parameters for use with sensorless vector control. This is done with the auto-tuning procedure.

The auto-tuning procedure should be done during the start up procedure. This is not described here. Refer to the auto-tune procedure in Chapter 3 of the *DURApulse* user manual.

Motor heating calculation:

There are several methods to check that the motor does not get too hot. Here is one method:

The motor has a rated efficiency at full load of 94.5% respecting class F insulation. This means that the losses at rated current (115A) are 4.34 kW. These continuous operation losses will maintain the temperature below the limit of class F (155 C in the hottest point). Since there is no continuous current, we will have to estimate the heating effect during a cycle:

The motor losses are comprised of friction, cooling losses caused by the fan, iron losses and the losses I^2R on the copper. The I^2R losses can be estimated because we have the values R_1 and R_2 from the tables published on the AutomationDirect Web site. $R_1=0.034$ Ohm and $R_2=0.0219$ Ohm; the value for the copper losses I^2R are about 3345 Watt; the rest should be the constant losses (995 Watt). The iron losses and friction can be considered constant.

The energy during the cycle is about 42 seconds. That is, if constant the motor will loose 4340 Watt x42 s=182280 Joule.

In the case of this hoist, we can say with certain approximation that the current will change in the same way as the torque changes. On the following table we study the torque on every segment of the torque curve, we determine the % of torque related to the motor rated torque and then estimate the same increase on the current; since The I^2R losses are proportional to the square of the current, we have to find the factor to multiply the basic losses at full load, shown on line A. Having that, we can determine the watts; the energy in Joules corresponds to the watts by seconds that the motor keeps running; since they are not constant on time, we do the average value of the end values on each segment, for example, for the segment 3.5 + and 28.5-, the average value of the losses are $(797 + 107 \text{ Watt})/2$ and this is multiplied by the time. This is an approximation, but it is close enough as we will see from the result.

The result shows that the energy in the cycle is considerably less than if the motor runs continuously. If the calculation has errors, the error can be as high as 107000 Joule. This proves that the motor will not get too hot.

Item	Time	Torque	Torque	Current	Squared	Factor	Losses	Losses	Joules
	second	lb-ft	per cent	A	A*A		in Watt	in Joules	{sum}
A	Rated	295	100%	115	13225	1 in p/u	3345	n/a	
B	0+	433	146.8	168.8	28492	2.154	7205		
C	3.5-	432	146.4	168.4	28361	2.144	7172	25160	
D	3.5+	283.9	96.2	110.7	12247	0.926	3097		
E	28.5-	144	48.8	56.1	3153	0.238	796	48662	
F	28.5+	52.7	17.9	38 (No load)	1444	0.109	365		
G	32-	52.0	17.6	38 (No load)	1444	0.109	365	1278	
H	32+	0	0	0			0	0	
I	42	0	0	0			0	0	75100

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: 200V class: 200/208/220/230/240 Default 240
460V class: 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: 115**

Range: AC drive rated current \times (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 on 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 on the nameplate of the motor.

P 0.04 Motor maximum RPM **Value: 1800**

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: 00**

Default 00

Range: : 00 Ramp to stop
01 Coast to stop

This parameter causes the motor to stop in a fixed time.

P 1.01 Acceleration time 1 **Value: 5.0**

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 5 seconds.

P 1.02 ◆ Deceleration time 1 **Value: 5.0**

Range: 0.1 to 600 s.

Default 30 sec

This parameter is used to define in 5 seconds as the deceleration time that the frequency drive is going to impose. The speed change is linear unless the S-curve is activated. This is a typical value for low speed elevators.

P 1.03 Acceleration with S-curve **Value: 03**

Range: 00 to 07

Default 00

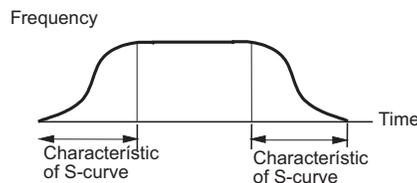
This parameter is used whenever the motor and the load need a smoother acceleration. The acceleration with S-curve is set in 03. This is necessary to avoid abrupt accelerations of the skip and the cable.

P 1.04 Deceleration with S-curve **Value: 3**

Range 00 to 07

Default 00

This parameter is used whenever the motor and the load need a smoother deceleration. The deceleration with the S-curve is set in 03 and will be activated when the contact to stop is deactivated. This contact opens when the limit switch of the stop level is activated, before reaching that level. The PLC will make the corresponding logic.

**P 1.18** DC Current injection **Value: 10**

Range: 00 to 100%

Default 00

This parameter determines the DC current of motor braking applied during starting and stopping. When setting DC Current Braking, please notice that 100% is equal to the rated current of the drive. It is recommended to start with low DC Current Braking Level and then increase until proper holding torque has been attained.

P 1.20 DC Injection time during starting **Value: 0.5**

Range: 0.0 to 5.0 s.

Default 0.0

This parameter determines the period in which the DC injection is applied to the motor during starting of the frequency drive. The DC braking will be applied for the time set in this parameter until the minimum frequency is reached. This is done to avoid the elevator cage dropping when the mechanical brake is released.

P 1.21 DC Injection during stop **Value: 0.5**

Range: 0.0 to 25.0 s.

Default 0.0

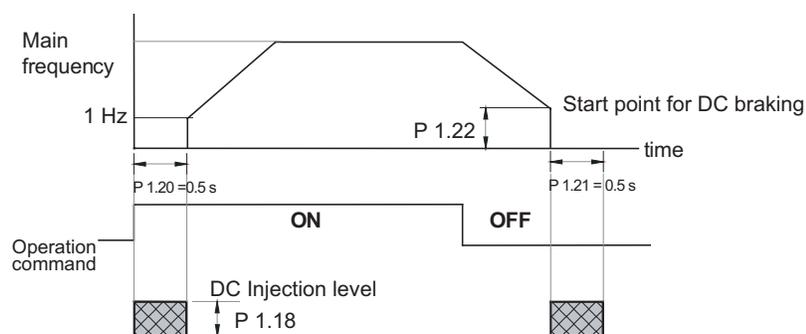
This parameter determines the duration for which the injection voltage will be applied to the motor during stopping. If it is planned to stop with DC braking, then P1.00 must be set as Ramp to stop (00).

P 1.22 Start point for DC injection **Value: 1.5**

Range: 0.0 to 60.0 Hz

Default 0.0

This parameter determines the frequency where the DC injection braking during the deceleration. We want to apply DC so that when the mechanical brake get released there is already a resistive torque in the motor.

**P 2.10** Control mode **Value: 03**

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 03 to have better torque control compared to Volt/ Hertz mode.

P 3.00 Source of operation command **Value: 02**

Default 00

- Settings
- 00 Operation determined by Digital Keypad
 - 01 Operation determined by external control terminals. Keypad STOP is enabled.
 - 02 Operation determined by external control terminals. Keypad STOP is disabled.
 - 03 Operation determined by communication interface. Keypad STOP is enabled.
 - 04 Operation determined by communication interface.

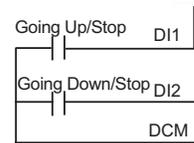
Keypad STOP is disabled.

- This parameter defines the source of the operation command for the variable frequency drive. In this case the PLC, and possibly some sensors, will define the commands.

P 3.01 Multi-function input terminals (DI-DI2) Value: 00

Settings DI1 - FWD/STOP Default 0.0
DI2 - REV/STOP

This parameter defines the input source for the operation commands of the variable frequency drive. We want the skip to begin movement when the operator presses the button that will close a contact on the PLC and we want to stop when near the other level. The operation can also be automatic. The stop function will be reached with 2 preset speeds; one at 60.5 Hz and the other at 3 Hz. The low speed is the creep speed to allow the skip to stop just in front of the level.



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

Default 00

This is a button in the machine room that will reset the drive in case of a failure. The PLC should check that every safety element 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 cage and corresponds to 1800 rpm. The value is to be set with P5.01.

P 3.04 Multi-function input terminal (DI5) Value: 04

Default 00

This parameter will define multi-speed 2. This speed will be defined as the creep speed of the skip and corresponds to 89 rpm. The value is to be set with P5.02. This speed is applied for the last few feet close to the level to allow for an exact positioning of the cage.

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 92 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: 01**

Default 00

This terminal has a contact from a master relay that will open in case of voltage shutdown as well as any other emergency situation. This master relay shall also remove energy from the drum brake to cause an immediate stop of the skip.

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: 02**

Default 02

This output terminal is programmed as AC drive **At Speed** and will go to the master relay.

P 3.14 **Multi-function Output Terminal 4 (DO3)** **Value: 15**

Default 03

This output terminal is programmed as **Encoder loss** and will go to the PLC. This signal will tell the PLC that the skip will wait for repair on one of the end travel positions.

P 4.00 **Source of Frequency Command** **Value: 02**

Default: 01

Settings: 01 Frequency determined by digital keypad up/down

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

We will set the analog setpoint for frequency with mode 02.

P 4.11 **◆ Analog Output Signal** **Value 01**

Range: 00 - Frequency Hz

Default 00

01 - Current A

02 - PV

This parameter selects current to be the output on the 0 to 10V A0 output.

P5.00 **◆ Jog** **Value: 3.1**

Range: 0.0 to 400.0 Hz

Default 6.0

The Jog Command is selected by to Multi-Function Input Terminal (P 3.04)

set to the Jog Function (09) that corresponds to 92 RPM.

P 5.01 **◆ Multi-Speed 1** **Value: 60.5**

Default 00

The multi-speed 1 value is defined as 60.5 Hz, that corresponds to 1800 rpm and will be used at the normal speed of the skip.

P 5.02 **◆ Multi-Speed 2** **Value: 3.0**

Default 00

The multi-speed 2 value is defined as 3.0 Hz, that corresponds to 89 rpm and will be used at the creep speed of the skip.

P 6.00 **Thermal Overload type selection** **Value: 00**

Modes: 00 - Use with inverter duty motor

Default 00

01 - Use with standard fan cooled motor

02 - Inactive

The mode 00 uses the normal inverse time thermal overload protection over the full speed range, tripping at 100% of motor current with tripping @ 150% in one minute. The mode 01 is used to derate the thermal protection at lower speeds in such a way that there is a linear derating from rated speed to speed zero. The current to trip at 0 Hz is 40%. We use constant torque in this case.

P 6.03 **Reverse Operation Inhibit** **Value: 00**

Default Setting: 00

Settings: 00 Enable Reverse Operation
 01 Disable Reverse Operation

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

P 8.00 User Defined Display Function **Value: 00**

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 Default to indicate the Output Frequency

P 10.00 Encoder Pulse Per Revolution **Value: 1024**

Range: 01 to 20000 Default 1024

An encoder is used as a transducer to feed back the motor speed, and this parameter defines the number of pulses for each cycle of the PI control.

P 10.01 Encoder Type Input **Value: 02**

Range: 00: Disable Default 00

01: Single Phase
 02: Quadrature, FWD - CCW
 03: Quadrature, FWD - CW

This parameter is used to specify encoder signal type. Settings 02 and 03 are used to distinguish motor rotation in relation to the quadrature type encoder signal. Error message "ENC SIGNAL ERROR" will come up if motor rotation does not match quadrature settings.

P 10.02 ◆Proportional Control **Value: 1.00**

Range: 0.0 to 10.0 Default 1.00

This parameter specifies Proportional control and associated gain (I), used for vector control with encoder feedback. Leave as default.



Note: The diagram on the following page shows the output control relationship of P 10.02, P 10.03 and P 10.04.

P 10.03 ◆ Integral Control **Value: 1.00**

Range: 0.0 to 100.0 sec Default 1.00

This parameter specifies integral control and associated gain (I). Leave as default.

P 10.04 Speed Control Output Speed Limit **Value: 7.5**

Range: 0.0 to 20.0% Default 7.5

This parameter limits the amount of correction by the PI control on the output frequency when controlling speed. It can limit the maximum output frequency.

P 10.05 Encoder Loss Detection **Value: 00**

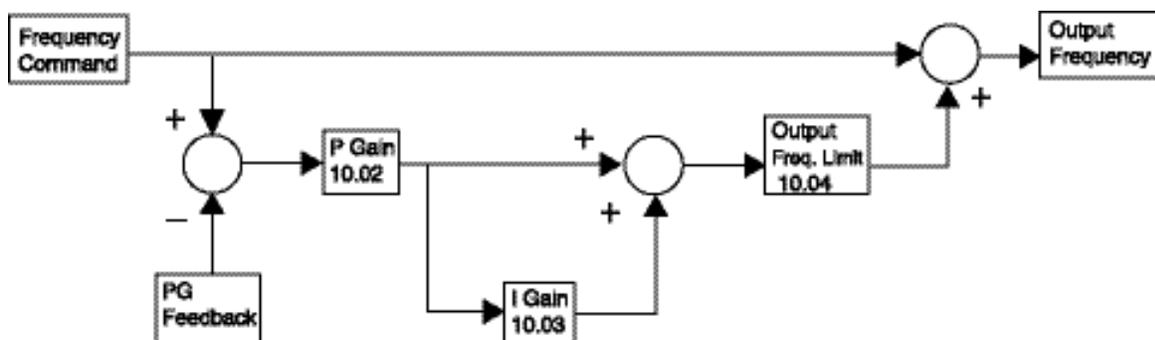
Range: 00: Warn and continue operation Default 00

01: Warn and RAMP to stop

02: Warn and COAST to stop

This parameter governs the response of the drive to the feedback signals, such as the analog or encoder pulse signals, when they are performing abnormally.

Closed Loop Tuning Diagram



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