
USER MANUAL

DMC-41x3

Manual Rev. 1.0a



By Galil Motion Control, Inc.

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Using This Manual

This user manual provides information for proper operation of the DMC-41x3 controller. A separate supplemental manual, the Command Reference, contains a description of the commands available for use with this controller. It is recommended that the user download the latest version of the Command Reference and User Manual from the Galil Website.

<http://www.galilmc.com/support/manuals.php>

Your DMC-41x3 motion controller has been designed to work with both servo and stepper type motors. Installation and system setup will vary depending upon whether the controller will be used with stepper motors or servo motors. To make finding the appropriate instructions faster and easier, icons will be next to any information that applies exclusively to one type of system. Otherwise, assume that the instructions apply to all types of systems. The icon legend is shown below.



Attention: Pertains to servo motor use.



Attention: Pertains to stepper motor use.



Attention: Pertains to controllers with more than 4 axes.

Please note that many examples are written for the DMC-4143 four-axes controller or the DMC-4183 eight axes controller. Users of the DMC-4133 3-axis controller, DMC-4123 2-axes controller or DMC-4113 1-axis controller should note that the DMC-4133 uses the axes denoted as XYZ, the DMC-4123 uses the axes denoted as XY, and the DMC-4113 uses the X-axis only.

Examples for the DMC-4183 denote the axes as A,B,C,D,E,F,G,H. Users of the DMC-4153 5-axes controller, DMC-4163 6-axes controller or DMC-4173, 7-axes controller should note that the DMC-4153 denotes the axes as A,B,C,D,E, the DMC-4163 denotes the axes as A,B,C,D,E,F and the DMC-4173 denotes the axes as A,B,C,D,E,F,G. The axes A,B,C,D may be used interchangeably with A,B,C,D.

WARNING: Machinery in motion can be dangerous! It is the responsibility of the user to design effective error handling and safety protection as part of the machinery. Galil shall not be liable or responsible for any incidental or consequential damages.

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Chapter 1 Overview

Introduction

The DMC-41x3 Series are Galil's Econo motion controller that is a scaled-down version of the DMC-40x0 Acclerra series controller. The controller series offers many enhanced features compared to prior generation Econo series controllers including high speed communications, non-volatile program memory, faster encoder speeds, and improved cabling for EMI reduction.

Each DMC-41x3 provides two communication channels: a high speed 100BaseT Ethernet connection and a USB programming port. There is an auxiliary RS-232 port that can be used to communicate to external devices such as HMI's. The controllers allow for high-speed servo control up to 15 million encoder counts/sec and step motor control up to 3 million steps per second. Sample rates as low as 62 μ sec per axis are available.

A Flash EEPROM provides non-volatile memory for storing application programs, parameters, arrays and firmware. New firmware revisions are easily upgraded in the field.

The DMC-41x3 is available with up to eight axes in a single stand alone unit. The DMC-4113, 4123, 4133, 4143 are one thru four axes controllers and the DMC-4153, 4163, 4173, 4183 are five thru eight axes controllers. All eight axes have the ability to use Galil's integrated amplifiers or drivers and connections for integrating external devices.

Designed to solve complex motion problems, the DMC-41x3 can be used for applications involving jogging, point-to-point positioning, vector positioning, electronic gearing, multiple move sequences, contouring and a PVT Mode. The controller eliminates jerk by programmable acceleration and deceleration with profile smoothing. For smooth following of complex contours, the DMC-41x3 provides continuous vector feed of an infinite number of linear and arc segments. The controller also features electronic gearing with multiple master axes as well as gantry mode operation.

For synchronization with outside events, the DMC-41x3 provides uncommitted I/O, including 8 opto-isolated digital inputs (16 inputs for DMC-4153 thru DMC-4183), 8 optically isolated outputs (16 outputs for DMC-4153 thru DMC-4183), and 8 analog inputs for interface to joysticks, sensors, and pressure transducers. Further I/O is available if the auxiliary encoders are not being used (2 inputs / each axis). Dedicated opto-isolated inputs are provided for forward and reverse limits, abort, home, and definable input interrupts.

Commands are sent in ASCII. Additional software is available for automatic-tuning, trajectory viewing on a PC screen, and program development using many environments such as Visual Basic, C, C++ etc. Drivers for Windows XP, Vista and 7 (32 & 64 bit) as well as Linux are available.

Overview of Motor Types

The DMC-41x3 can provide the following types of motor control:

1. Standard servo motors with +/- 10 volt command signals
2. Step motors with step and direction signals
3. Other actuators such as hydraulics and ceramic motors - For more information, contact Galil.

The user can configure each axis for any combination of motor types, providing maximum flexibility.

Standard Servo Motor with +/- 10 Volt Command Signal

The DMC-41x3 achieves superior precision through use of a 16-Bit motor command output DAC and a sophisticated PID filter that features velocity and acceleration feed-forward, an extra pole filter and integration limits.

The controller is configured by the factory for standard servo motor operation. In this configuration, the controller provides an analog signal (+/- 10 volts) to connect to a servo amplifier. This connection is described in Chapter 2.

Stepper Motor with Step and Direction Signals



The DMC-41x3 can control stepper motors. In this mode, the controller provides two signals to connect to the stepper motor: Step and Direction. For stepper motor operation, the controller does not require an encoder and operates the stepper motor in an open loop fashion. Chapter 2 describes the proper connection and procedure for using stepper motors.

If encoders are available on the stepper motor, Galil's Stepper Position Maintenance Mode may be used for automatic monitoring and correction of the stepper position. See Stepper Position Maintenance Mode (SPM) in Chapter 6 for more information.

Overview of External Amplifiers

The amplifiers should be suitable for the motor and may be linear or pulse-width-modulated. An amplifier may have current feedback, voltage feedback or velocity feedback.

Amplifiers in Current Mode

Amplifiers in current mode should accept an analog command signal in the +/-10 volt range. The amplifier gain should be set such that a +10V command will generate the maximum required current. For example, if the motor peak current is 10A, the amplifier gain should be 1 A/V.

Amplifiers in Velocity Mode

For velocity mode amplifiers, a command signal of 10 volts should run the motor at the maximum required speed. The velocity gain should be set such that an input signal of 10V runs the motor at the maximum required speed.

Stepper Motor Amplifiers



For step motors, the amplifiers should accept step and direction signals.

Overview of Galil Amplifiers and Drivers

With the DMC-41x3 Galil offers a variety of Servo Amplifiers and Stepper Drivers that are integrated into the same enclosure as the controller. Using the Galil Amplifiers and Drivers provides a simple straightforward motion control solution in one box.

A1 – AMP-430x0 (-D3040, -D3020)

The AMP-43040 (four-axis) and AMP-43020 (two-axis) are multi-axis brush/brushless amplifiers that are capable of handling 500 watts of continuous power per axis. The AMP-43040/43020 Brushless drive modules are connected to a DMC-41x3. The standard amplifier accepts DC supply voltages from 18-80 VDC.

A2 – AMP-43140 (-D3140)

The AMP-43140 contains four linear drives for operating small brush-type servo motors. The AMP-43140 requires a \pm 12–30 DC Volt input. Output power is 20 W per amplifier or 60 W total. The gain of each transconductance linear amplifier is 0.1 A/V at 1 A maximum current. The typical current loop bandwidth is 4 kHz.

A3 – AMP-43240 (-D3240)

The AMP-43240 is a multi-axis brush/brushless amplifiers that is capable of handling 750 watts of continuous power per axis. The AMP-43240 Brushless drive module is connected to a DMC-40x0. The standard amplifier accepts DC supply voltages from 18-80 VDC.

A4 – AMP-43540 (-D3540)

The AMP-43540 contains four PWM drives for sinusoidally commutating brushless motors. It is capable of up to 8 Amps of continuous current and 15Amps of peak current and requires a single DC supply voltage in the range of 18-80 VDC.

A5 – AMP-43640 (-D3640)

The AMP-43640 contains four linear drives for sinusoidally commutating brushless motors. The AMP-43640 requires a single 18–30VDC input. Output power delivered is typically 20 W per amplifier or 80 W total.

A6 – SDM-44040 (-D4040)

The SDM-44040 is a stepper driver module capable of driving up to four bipolar two-phase stepper motors. The current is selectable with options of 0.5, 0.75, 1.0, and 1.4 Amps/Phase. The step resolution is selectable with options of full, half, 1/4 and 1/16.

A7 – SDM-44140 (-D4140)

The SDM-44140 microstepper module drives four bipolar two-phase stepper motors with 1/64 microstep resolution (the SDM-44140 drives two). The current is selectable with options of 0.5, 1.0, 2.0, & 3.0 Amps per axis.

DMC-41x3 Functional Elements

The DMC-41x3 circuitry can be divided into the following functional groups as shown in Figure 1.1 and discussed below.

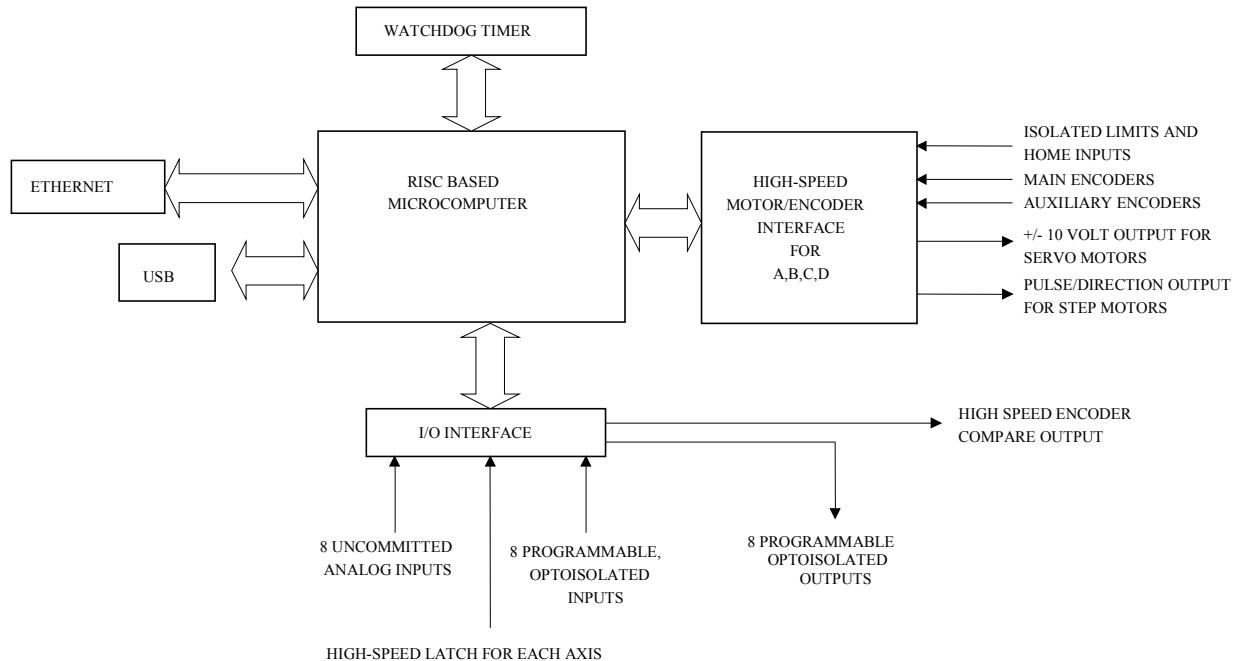


Figure 1.1: DMC-41x3 Functional Elements

Microcomputer Section

The main processing unit of the controller is a specialized Microcomputer with RAM and Flash EEPROM. The RAM provides memory for variables, array elements, and application programs. The flash EEPROM provides non-volatile storage of variables, programs, and arrays. The Flash also contains the firmware of the controller, which is field upgradeable.

Motor Interface

Galil's GL-1800 custom, sub-micron gate array performs quadrature decoding of each encoder at up to 15 MHz. For standard servo operation, the controller generates a +/-10 volt analog signal (16 Bit DAC). For stepper motor operation, the controller generates a step and direction signal.

Communication

The communication interface with the DMC-41x3 consists of high speed 100bT Ethernet and a USB programming port.

General I/O

The DMC-41x3 provides interface circuitry for 8 bi-directional, opto-isolated inputs, 8 opto-isolated outputs and 8 analog inputs with 12-Bit ADC (16-Bit optional). Unused auxiliary encoder inputs may also be used as additional inputs (2 inputs / each axis). The general inputs as well as the index pulse can also be used as high speed latches for each axis. A high speed encoder compare output is also provided.

4183

The DMC-4153 through DMC-4183 controller provides an additional 8 opto-isolated inputs and 8 opto-isolated outputs.

System Elements

As shown in Figure 1.2, the DMC-41x3 is part of a motion control system which includes amplifiers, motors and encoders. These elements are described below.

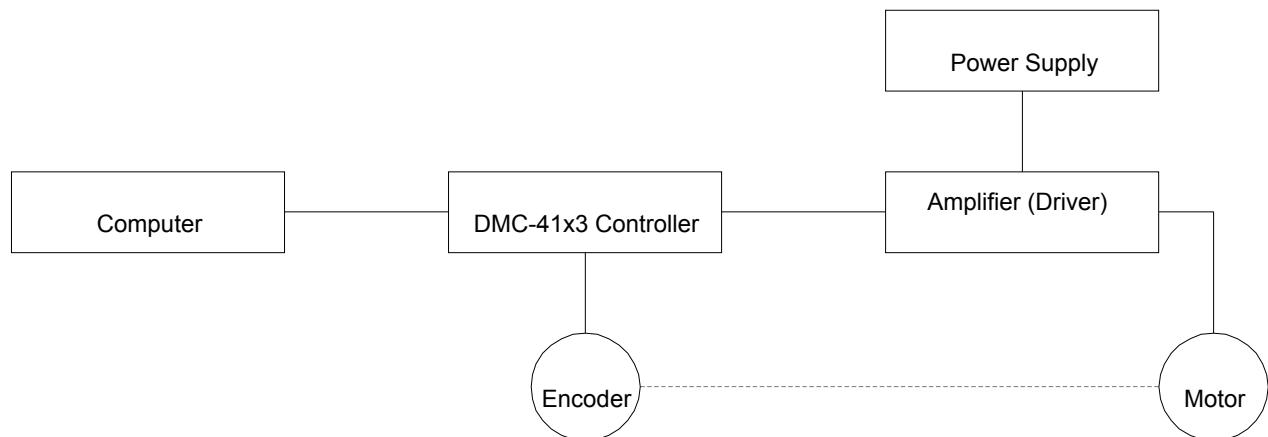


Figure 1.2: Elements of Servo Systems

Motor

A motor converts current into torque which produces motion. Each axis of motion requires a motor sized properly to move the load at the required speed and acceleration. (Galil's MotorSizer Web tool can help you with motor sizing: www.galilmc.com/support/motorsizer)

The motor may be a step or servo motor and can be brush-type or brushless, rotary or linear. For step motors, the controller can be configured to control full-step, half-step, or microstep drives. An encoder is not required when step motors are used.

Other motors and devices such as Ultrasonic Ceramic motors and voice coils can be controlled with the DMC-41x3.

Amplifier (Driver)

For each axis, the power amplifier converts a +/-10 volt signal from the controller into current to drive the motor. For stepper motors, the amplifier converts step and direction signals into current. The amplifier should be sized properly to meet the power requirements of the motor. For brushless motors, an amplifier that provides electronic commutation is required or the controller must be configured to provide sinusoidal commutation. The amplifiers may be either pulse-width-modulated (PWM) or linear. They may also be configured for operation with or without a tachometer. For current amplifiers, the amplifier gain should be set such that a 10 volt command generates the maximum required current. For example, if the motor peak current is 10A, the amplifier gain should be 1 A/V. For velocity mode amplifiers, 10 volts should run the motor at the maximum speed.

Galil offers amplifiers that are integrated into the same enclosure as the DMC-41x3. See the Integrated section in the Appendices or <http://galilmc.com/products/accelera/dmc41x3.html> for more information.

Encoder

An encoder translates motion into electrical pulses which are fed back into the controller. The DMC-41x3 accepts feedback from either a rotary or linear encoder. Typical encoders provide two channels in quadrature, known as MA and MB. This type of encoder is known as a quadrature encoder. Quadrature encoders may be either single-ended (MA and MB) or differential (MA+, MA- and MB+, MB-). The DMC-41x3 decodes either type into quadrature states or four times the number of cycles. Encoders may also have a third channel (or index) for synchronization.

The DMC-41x3 can be ordered with 120 Ohm termination resistors installed on the encoder inputs. See the Ordering Options for the DMC- in the Appendix for more information.

The DMC-41x3 can also interface to encoders with pulse and direction signals. Refer to the “CE” command in the command reference for details.

There is no limit on encoder line density; however, the input frequency to the controller must not exceed 3,750,000 full encoder cycles/second (15,000,000 quadrature counts/sec). For example, if the encoder line density is 10,000 cycles per inch, the maximum speed is 200 inches/second. If higher encoder frequency is required, please consult the factory.

The standard encoder voltage level is TTL (0-5v), however, voltage levels up to 12 Volts are acceptable. (If using differential signals, 12 Volts can be input directly to the DMC-41x3. Single-ended 12 Volt signals require a bias voltage input to the complementary inputs).

The DMC-41x3 can accept analog feedback (+/-10v) instead of an encoder for any axis. For more information see the command AF in the command reference.

To interface with other types of position sensors such as absolute encoders, Galil can customize the controller and command set. Please contact Galil to talk to one of our applications engineers about your particular system requirements.

Watch Dog Timer

The DMC-41x3 provides an internal watch dog timer which checks for proper microprocessor operation. The timer toggles the Amplifier Enable Output (AMPEN) which can be used to switch the amplifiers off in the event of a serious DMC-41x3 failure. The AMPEN output is normally high. During power-up and if the microprocessor ceases to function properly, the AMPEN output will go low. The error light will also turn on at this stage. A reset is required to restore the DMC-41x3 to normal operation. Consult the factory for a Return Materials Authorization (RMA) Number if your DMC-41x3 is damaged.

Chapter 2 Getting Started

DMC-4143-CARD Dimensions

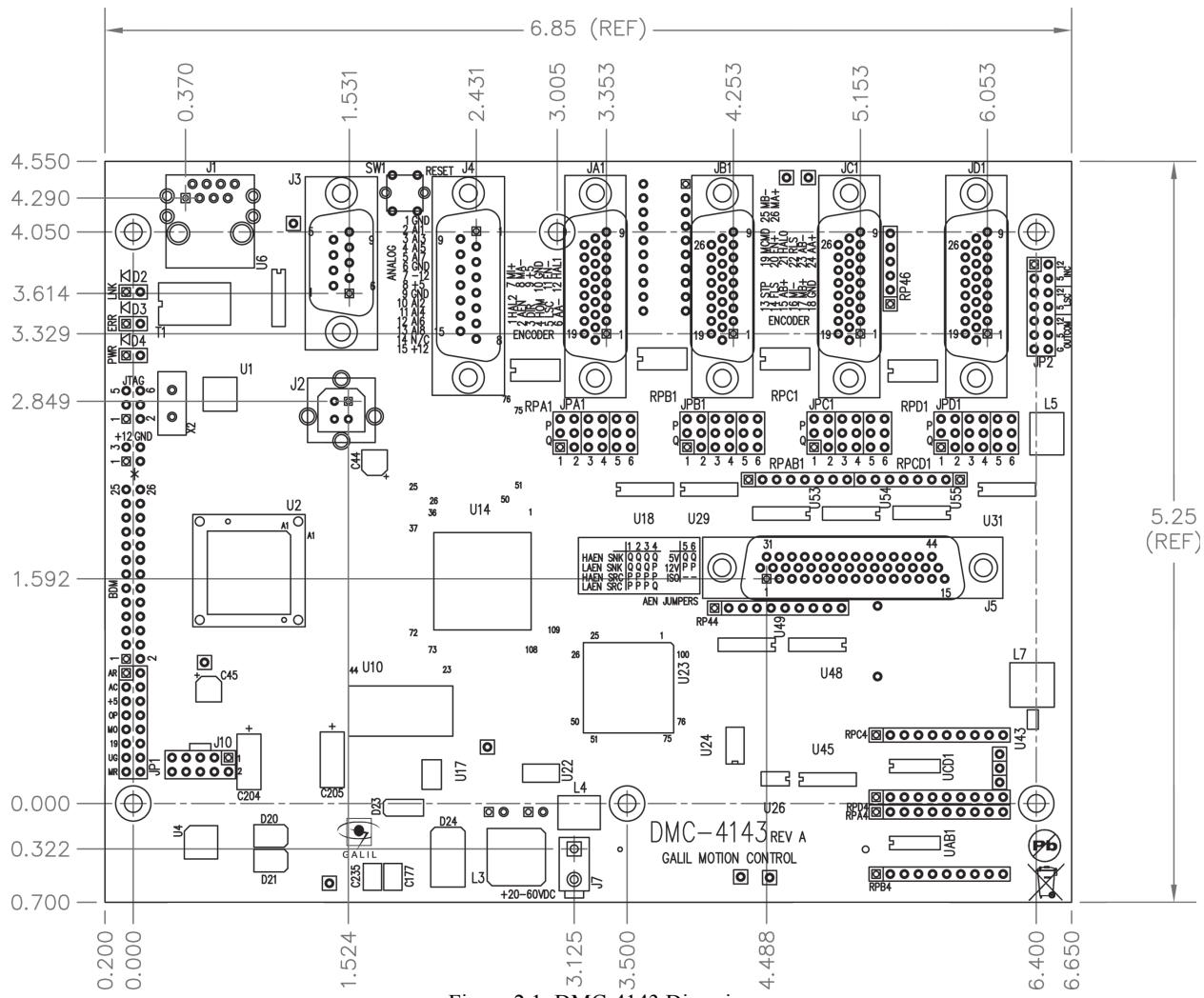


Figure 2.1: DMC-4143 Dimensions

The dimensions¹ for the DMC-4113, DMC-4123, DMC-4133 and DMC-4143 (all -CARD) are shown in Figure 2.1.

Dimensions are subject to change. Contact the Galil factory for current dimensions of all products.

DMC-4183-CARD Dimensions

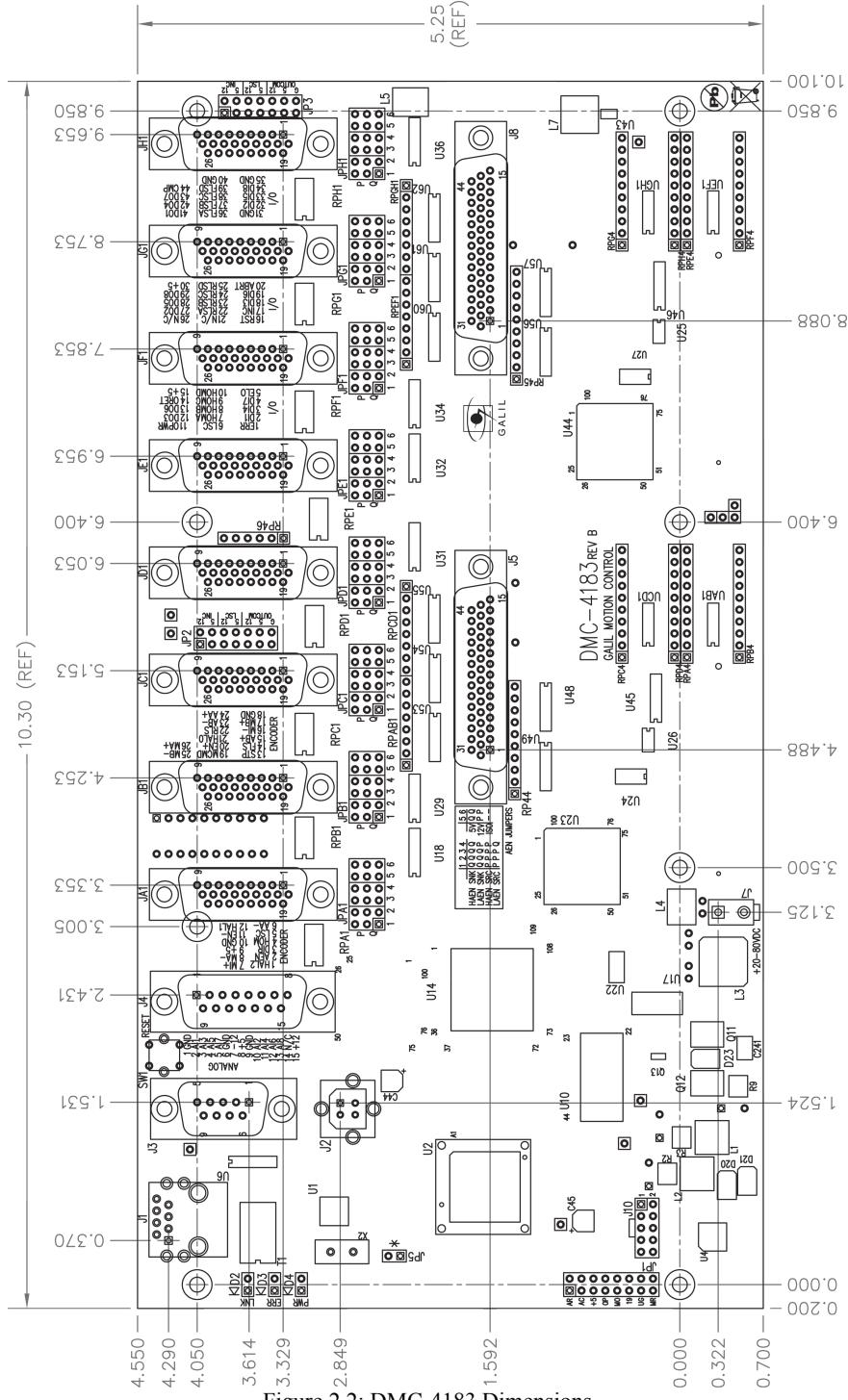


Figure 2.2: DMC-4183 Dimensions

The dimensions¹ for the DMC-4153, DMC-4163, DMC-4173 and DMC-4183 (all -CARD) are shown in Figure 2.2.

Dimensions are subject to change. Contact the Galil factory for current dimensions of all products.

DMC-4143-BOX4 Dimensions

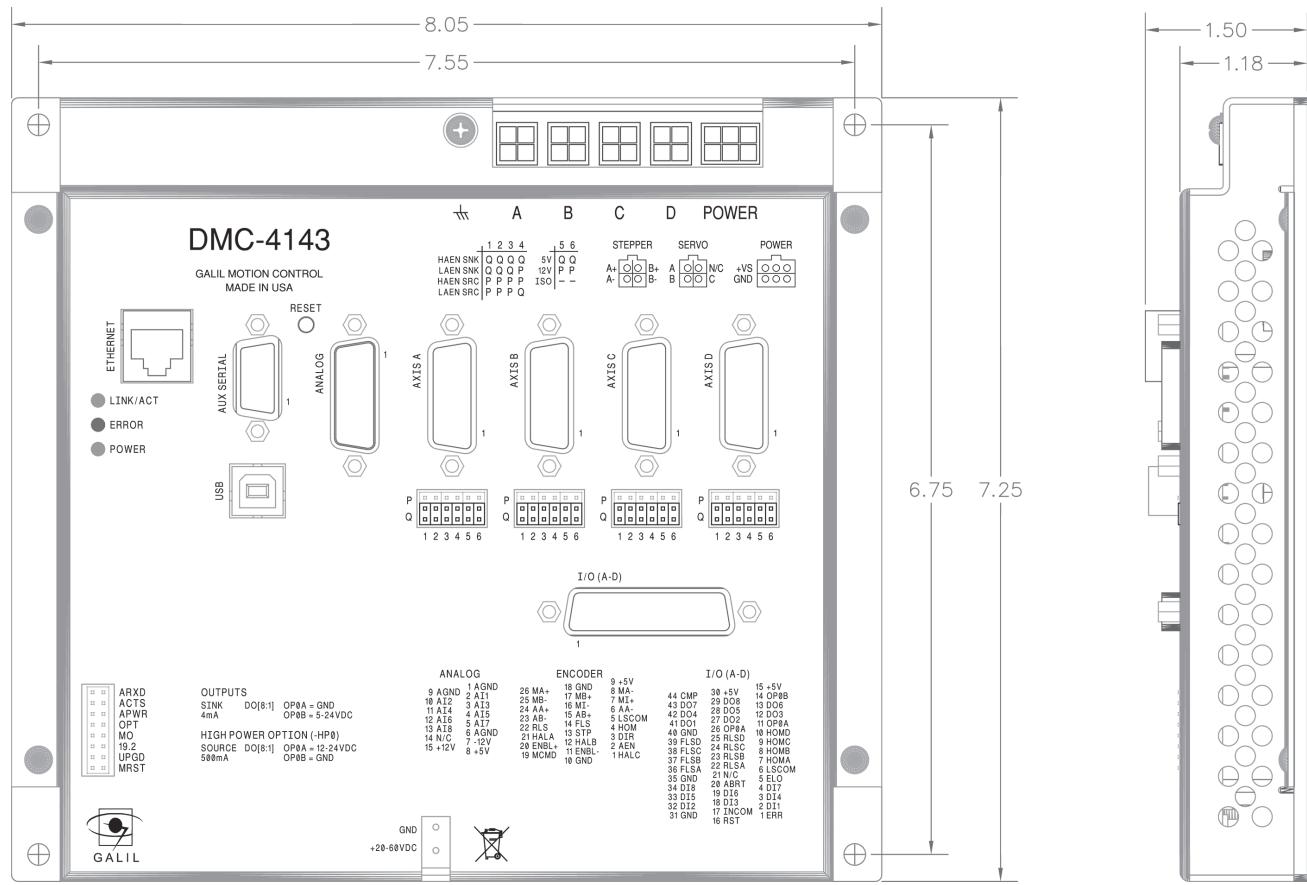


Figure 2.3: DMC-4143-BOX4 Dimensions

The dimensions¹ for the DMC-4113, DMC-4123, DMC-4133 and DMC-4143 with -BOX4 are shown in Figure 2.3.

1 Dimensions are subject to change. Contact the Galil factory for current dimensions of all products.

DMC-4183-BOX8 Dimensions

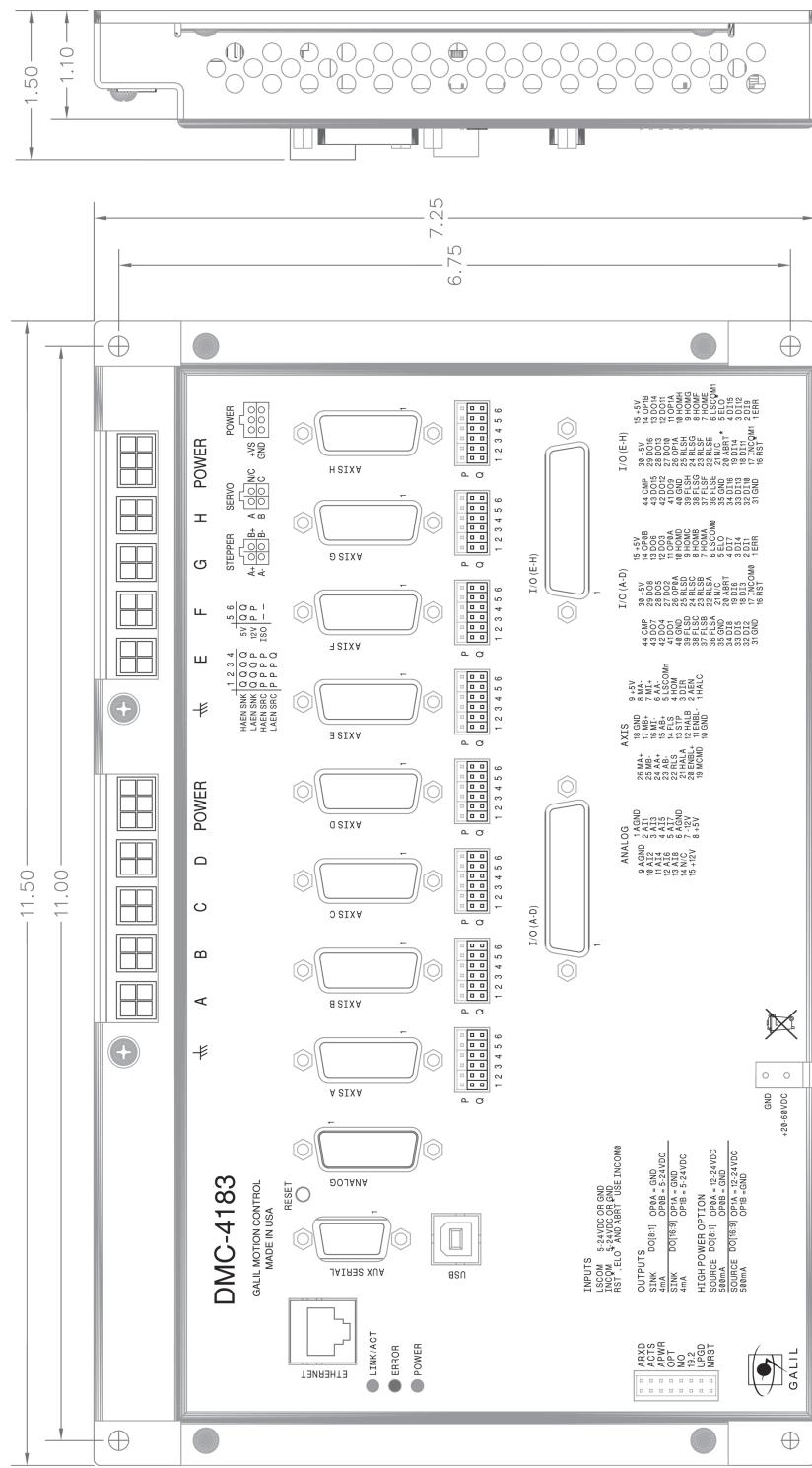


Figure 2.4: DMC-4183-BOX8 Dimensions

The dimensions¹ for the DMC-4153, DMC-4163, DMC-4173 and DMC-4183 with -BOX8 are shown in Figure 2.4.

Dimensions are subject to change. Contact the Galil factory for current dimensions of all products.

DMC-41x3 Power Connections

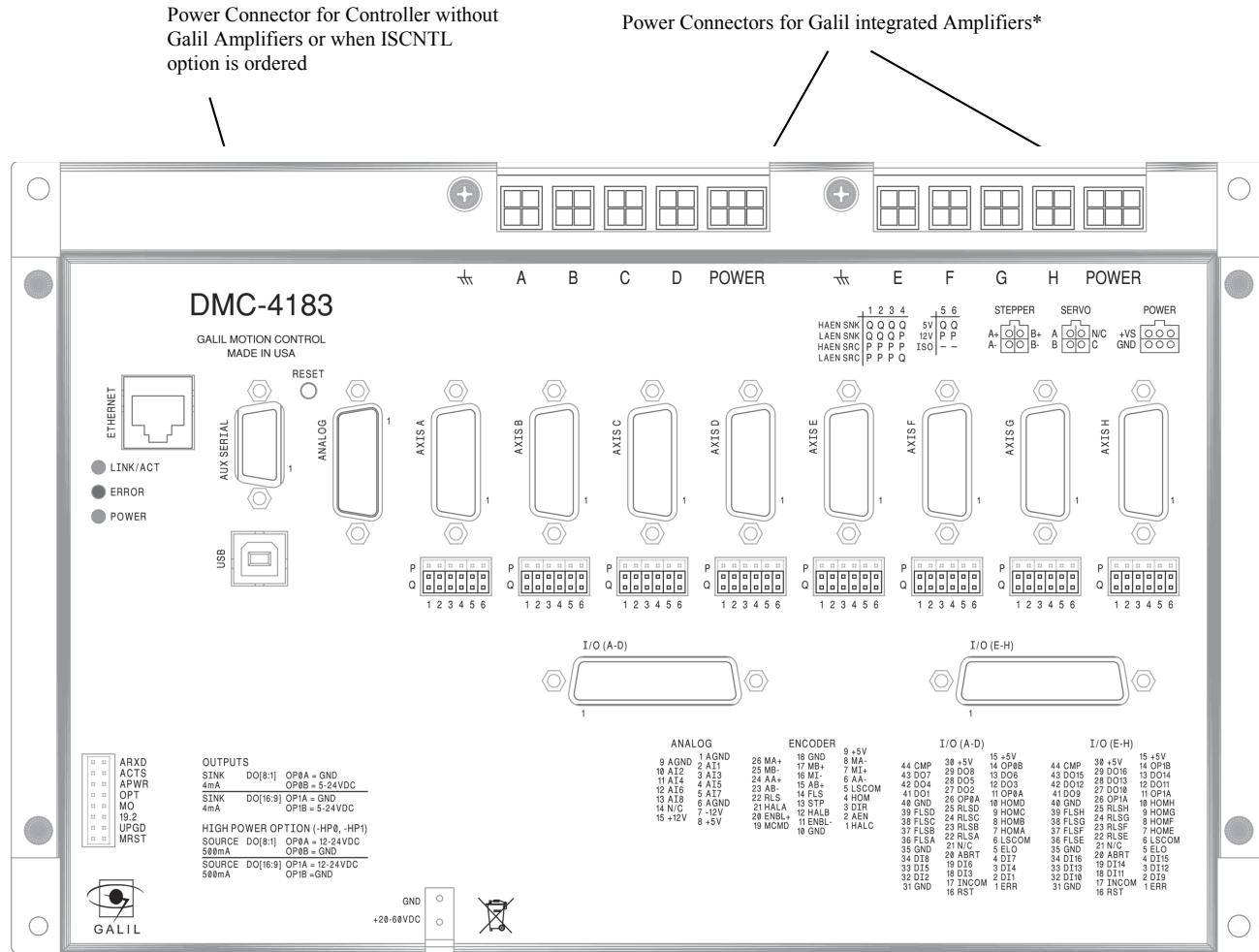


Figure 2.5: Power Connector locations for the DMC-41x3

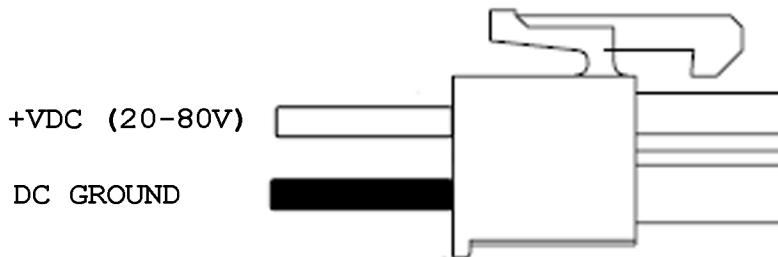


Figure 2.6: Power Connector used when controller is ordered without Galil Amplifiers

*See Power connector information for specific amplifiers in the Integrated section of the Appendices.

For more information on Connectors (mfg PN's and diagrams) see the Power Connector Section in the Appendix.

DMC-41x3 Mounting Instructions

-CARD

All standoff locations must be used when mounting the -CARD version of the DMC-41x3 controllers. There are 6 standoff locations for the DMC-4143 controller and 8 standoff locations for the DMC-4183 controller. See Figure 2.1 and Figure 2.2 for mounting hole sizing and locations.

The minimum standoff height that should be used for the DMC-41x3-CARD controllers is 0.656".

-BOX4 and -BOX8

All 4 mounting holes should be used to mount the controller to a secure base. See Figure 2.3 and Figure 2.4 for mounting hole locations and sizes.

If the controller is shipped with internal amplifiers the base of the DMC-41x3 is used as the heat sync for those amplifiers.

Elements You Need

For a complete system, Galil recommends the following elements:

1. DMC-4113, 4123, 4133, or DMC-4143 Motion Controller
 or
 DMC-4153, 4163, 4173 or DMC-4183
2. Motor Amplifiers (Integrated when using Galil amplifiers and drivers)
3. Power Supply for Amplifiers and controller
4. Brush or Brushless Servo motors with Optical Encoders or stepper motors.
 - a. Cables for connecting to the DMC-41x3.
5. PC (Personal Computer - USB or Ethernet for DMC-41x3)
6. GalilTools, or GalilTools-Lite Software package

GalilTools is highly recommended for first time users of the DMC-41x3. It provides step-by-step instructions for system connection, tuning and analysis.

Installing the DMC-41x3

Installation of a complete, operational DMC-41x3 system consists of 8 steps.

- Step 1.** Determine overall motor configuration.
- Step 2.** Install Jumpers on the DMC-41x3.
- Step 3.** Install the communications software.
- Step 4.** Connect DC power to controller.
- Step 5.** Establish communications with the Galil Communication Software.
- Step 6.** Make connections to amplifier and encoder.
- Step 7a.** Connect standard servo motors.
- Step 7b.** Connect step motors.
- Step 8.** Tune the servo system

Step 1. Determine Overall Motor Configuration

Before setting up the motion control system, the user must determine the desired motor configuration. The DMC-41x3 can control any combination of standard servo motors and stepper motors. Other types of actuators, such as hydraulics can also be controlled, please consult Galil.

The following configuration information is necessary to determine the proper motor configuration:

Standard Servo Motor Operation:

Unless ordered with stepper motor drivers or in a non-standard configuration, the DMC-41x3 has been setup by the factory for standard servo motor operation providing an analog command signal of +/- 10V. No hardware or software configuration is required for standard servo motor operation.

Stepper Motor Operation

To configure the DMC-41x3 for stepper motor operation, the controller requires that the command, MT, must be given. Further instruction for stepper motor connections are discussed in Step 7b.

Step 2. Install Jumpers on the DMC-41x3

Master Reset and Upgrade Jumpers

JP1 on the main board contains two jumpers, MRST and UPGD. The MRST jumper is the Master Reset jumper. When MRST is connected, the controller will perform a master reset upon PC power up or upon the reset input going low. Whenever the controller has a master reset, all programs, arrays, variables, and motion control parameters stored in EEPROM will be ERASED.

The UPGD jumper enables the user to unconditionally update the controller's firmware. This jumper is not necessary for firmware updates when the controller is operating normally, but may be necessary in cases of corrupted EEPROM. EEPROM corruption should never occur, however, it is possible if there is a power fault during a firmware update. If EEPROM corruption occurs, your controller may not operate properly. In this case, install the UPGD Jumper and use the update firmware function on the Galil Terminal to re-load the system firmware.

Motor Off Jumper

The state of the motor upon power up may be selected with the placement of a hardware jumper on the controller. With a jumper installed at the MO location, the controller will be powered up in the “motor off” state. The SH command will need to be issued in order for the motor to be enabled. With no jumper installed, the controller will immediately enable the motor upon power up. The MO command will need to be issued to turn the motor off, unless an error occurs that will turn the motors off. The MO jumper is located on JP1, the same block as the Master Reset (MRST) and Upgrade (UPGD) jumpers.

Communications Jumpers for DMC-41x3

The baud rate for USB communication can be set with jumpers found on JP1 of the communication board (same set of jumpers where MO, MRST and UPGD can be found). There are two options for baud rate, 19200, and 115200. 19200 should only be used when an external device such as an HMI requires the slower communication speed. To set the baud rate to the desired value, see Table 2.1 below.

19.2	BAUD RATE
ON	19200
OFF	115200

Table 2.1: Baud Rate settings for USB communication

Amplifier Enable Jumper Configuration

When using external amplifiers, then amplifier enable must be configured to provide the correct polarity and voltage to enable and disable the drive. Information on configuring the Amplifier Enable signal can be found in Chapter three in Configuring the Amplifier Enable Circuit section.

If the Galil internal amplifiers are being utilized for all axes then no configuration of the Amplifier Enable signals is required.

Step 3. Install the Communications Software

After applying power to the computer, you should install the Galil software that enables communication between the controller and PC.

Using Windows XP, Vista and 7 (32 & 64 bit):

Install the Galil Software Products CD-ROM into your CD drive. A Galil .htm page should automatically appear with links to the software products. Select the correct version of GalilTools software for your particular operating system (32 or 64 bit) and click “Install...” Follow the installation procedure as outlined.

The most recent copy of the GalilTools software can be downloaded from the Galil website:

<http://www.galilmc.com/products/software/galiltools.html>

All other Galil software is also available for download at the Galil software downloads page:

[33http://www.galilmc.com/support/download.html](http://www.galilmc.com/support/download.html)

Using Linux (32 & 64 bit):

The GalilTools software package is fully compatible with a number of Linux distributions. See the GalilTools webpage and user manual for downloads and installation instructions.

<http://www.galilmc.com/products/software/galiltools.html>

Step 4. Connect 20-80 VDC Power to the Controller

If the controller was ordered with Galil Amplifiers or Drivers, then power to the controller will be supplied through those power connectors. Otherwise the power will come through the connector on the side of the controller. See DMC-41x3 Power Connections.

The DMC-41x3 power should never be plugged in HOT. Always power down the power supply before installing or removing the power connector to the controller.

NOTE: Any E-Stop or Disconnect switches should be installed on the AC input to the DC power supply. Relays and/or other switches should not be installed on the DC line between the Galil and the Power supply. This is shown in Figure 2.7 with a DMC-4183 and 2 AMP-43040's.

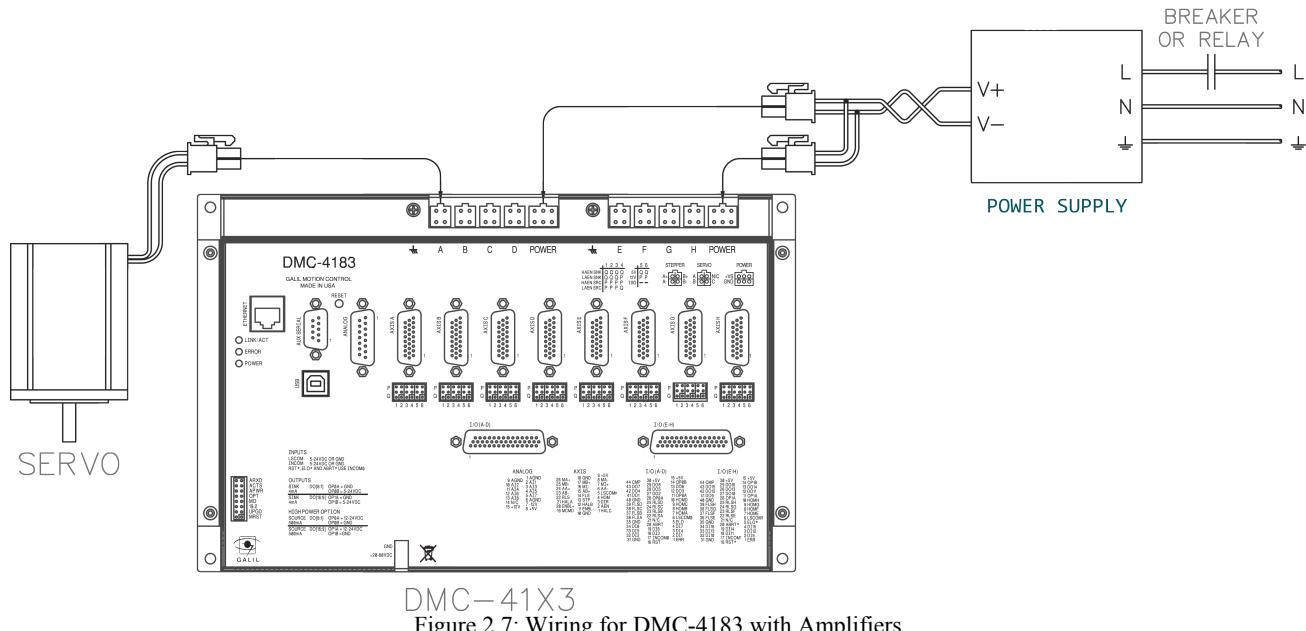


Figure 2.7: Wiring for DMC-4183 with Amplifiers

WARNING: Dangerous voltages, current, temperatures and energy levels exist in this product and the associated amplifiers and servo motor(s). Extreme caution should be exercised in the application of this equipment. Only qualified individuals should attempt to install, set up and operate this equipment. Never open the controller box when DC power is applied to it.

The green power (POWER) led indicator should go on when proper power is applied.

Step 5. Establish Communications with Galil Software

Communicating through an Ethernet connection

The DMC-41x3 motion controller is equipped with DHCP. If the controller is connected to a DHCP enabled network, an IP address will automatically be assigned to the controller. See Ethernet Configuration in Chapter 4 for more information.

Using GalilTools Software for Windows

Registering controllers in the Windows registry is no longer required when using the GalilTools software package. A simple connection dialog box appears when the software is opened that shows all available controllers.

Any available controllers with assigned IP addresses can be found under the ‘Available’ tab in the Connections Dialog Box. If the controller is not connected to a DHCP enabled network or the DH command is set to 0, and the controller has not been assigned an IP address, the controller can be found under the ‘No IP Address’ tab.

For more information on establishing communication to the controller via the GalilTools software, see the GalilTools user manual.

<http://www.galilmc.com/support/manuals/galitools/index.html>

Communicating through the USB Programming Port

Connect the DMC-41x3 USB port to your computer via a Male Type A – Male Type B USB cable. The port will be identified as a new Serial port. The USB port is designed for basic communication to the controller. Higher speed communication such as scope captures and continuous polling of data should be done through the Ethernet port.

Using GalilTools Software for Windows

Registering controllers in the Windows registry is no longer required when using the GalilTools software package. A simple connection dialog box appears when the software is opened that shows all available controllers.

The serial ports are listed as COMn ‘communication speed’. (ex COM3 115200). The default USB communication speed on the DMC-41x3 is 115200Bps.

For more information on establishing communication to the controller via the GalilTools software, see the GalilTools user manual.

<http://www.galilmc.com/support/manuals/galitools/index.html>

Sending Test Commands to the Terminal:

After you connect your terminal, press <return> or the <enter> key on your keyboard. In response to carriage return <return>, the controller responds with a colon, : :

Now type:

TPA <RETURN>

This command directs the controller to return the current position of the A axis. The controller should respond with a number such as

:0

Step 6. Make Connections to Amplifier and Encoder.

If the system is run solely by Galil’s integrated amplifiers or drivers, skip this section, the amplifier is already connected to the controller.

Once you have established communications between the software and the DMC-41x3, you are ready to connect the rest of the motion control system. The motion control system typically consists of the controller with interconnect module, an amplifier for each axis of motion, and a motor to transform the current from the amplifier into torque for motion.

System connection procedures will depend on system components and motor types. Any combination of motor types can be used with the DMC-41x3. There can also be a combination of axes running from Galil integrated amplifiers and drivers and external amplifiers or drivers.

Connecting to External Amplifiers

Here are the first steps for connecting a motion control system:

Step A. Connect the motor to the amplifier *with no connection to the controller*. Consult the amplifier documentation for instructions regarding proper connections. Connect and turn-on the amplifier power supply. If the amplifiers are operating properly, the motor should stand still even when the amplifiers are powered up.

Step B. Connect the amplifier enable signal.

Before making any connections from the amplifier to the controller, you need to verify that the ground level of the amplifier is either floating or at the same potential as earth.

WARNING: When the amplifier ground is not isolated from the power line or when it has a different potential than that of the computer ground, serious damage may result to the computer, controller and amplifier.

If you are not sure about the potential of the ground levels, connect the two ground signals (amplifier ground and earth) by a 10 kΩ resistor and measure the voltage across the resistor. Only if the voltage is zero, connect the two ground signals directly.

The amplifier enable signal is used by the controller to disable the motor. Use the command, MO, to disable the motor amplifiers - check to insure that the motor amplifiers have been disabled (often this is indicated by an LED on the amplifier).

This signal changes under the following conditions: the watchdog timer activates, the motor-off command, MO, is given, or the OE3 command (Enable Off-On-Error) is given and the position error exceeds the error limit. AEN can be used to disable the amplifier for these conditions.

The AEN signal from the DMC-41x3 is shipped as a default of 5V active high or high amp enable. In other words, the AEN signal will be high when the controller expects the amplifier to be enabled. If your amplifier requires a different configuration, see the Configuring the Amplifier Enable Circuit section in Chapter 3. The DMC-41x3 can be configured from the factory with the required amplifier enable signals for a particular system, contact Galil directly for more information.

Step C. Connect the encoders

For stepper motor operation, an encoder is optional.

For servo motor operation, if you have a preferred definition of the forward and reverse directions, make sure that the encoder wiring is consistent with that definition.

The DMC-41x3 accepts single-ended or differential encoder feedback with or without an index pulse. The encoder signals are wired to that axis associated 26pin DSub connector found on top of the controller. The signal leads are labeled MA+ (channel A), MB+ (channel B), and MI+. For differential encoders, the complement signals are labeled MA-, MB-, and MI-. For complete pin-out information see in the Appendices.

NOTE: When using pulse and direction encoders, the pulse signal is connected to MA+ and the direction signal is connected to MB+. The controller must be configured for pulse and direction with the command CE. See the command summary for further information on the command CE.

Step D. Verify proper encoder operation.

Start with the A encoder first. Once it is connected, turn the motor shaft and interrogate the position with the instruction TPA <return>. The controller response will vary as the motor is turned.

At this point, if TPA does not vary with encoder rotation, there are three possibilities:

1. The encoder connections are incorrect - check the wiring as necessary.
2. The encoder has failed - using an oscilloscope, observe the encoder signals. Verify that both channels A and B have a peak magnitude between 5 and 12 volts. Note that if only one encoder channel fails, the position reporting varies by one count only. If the encoder failed, replace the encoder. If you cannot observe the encoder signals, try a different encoder.
3. There is a hardware failure in the controller - connect the same encoder to a different axis. If the problem disappears, you may have a hardware failure. Consult the factory for help.

Step 7a. Connect Standard Servo Motors

The following discussion applies to connecting the DMC-41x3 controller to standard servo motors:

The motor and the amplifier may be configured in the torque or the velocity mode. In the torque mode, the amplifier gain should be such that a 10 volt signal generates the maximum required current. In the velocity mode, a command

signal of 10 volts should run the motor at the maximum required speed. For Galil amplifiers, see Integrated Components.

Step A. Check the Polarity of the Feedback Loop

It is assumed that the motor and amplifier are connected together and that the encoder is operating correctly (Step 6. Make Connections to Amplifier and Encoder.). Before connecting the motor amplifiers to the controller, read the following discussion on setting Error Limits and Torque Limits. Note that this discussion only uses the A axis as an example.

Step B. Set the Error Limit as a Safety Precaution

Usually, there is uncertainty about the correct polarity of the feedback. The wrong polarity causes the motor to run away from the starting position. Using a terminal program, such as Galil Tools, the following parameters can be given to avoid system damage:

Input the commands:

ER 2000	Sets error limit on the A axis to be 2000 encoder counts
OE 1	Disables A axis amplifier when excess position error exists

If the motor runs away and creates a position error of 2000 counts, the motor amplifier will be disabled.

NOTE: This function requires the AMPEN signal to be connected from the controller to the amplifier.

Step C. Set Torque Limit as a Safety Precaution

To limit the maximum voltage signal to your amplifier, the DMC-41x3 controller has a torque limit command, TL. This command sets the maximum voltage output of the controller and can be used to avoid excessive torque or speed when initially setting up a servo system.

When operating an amplifier in torque mode, the voltage output of the controller will be directly related to the torque output of the motor. The user is responsible for determining this relationship using the documentation of the motor and amplifier. The torque limit can be set to a value that will limit the motors output torque.

When operating an amplifier in velocity or voltage mode, the voltage output of the controller will be directly related to the velocity of the motor. The user is responsible for determining this relationship using the documentation of the motor and amplifier. The torque limit can be set to a value that will limit the speed of the motor.

For example, the following command will limit the output of the controller to 1 volt on the X axis:

TL 1

NOTE: Once the correct polarity of the feedback loop has been determined, the torque limit should, in general, be increased to the default value of 9.99. The servo will not operate properly if the torque limit is below the normal operating range. See description of TL in the command reference.

Step D. Connect the Motor

Once the parameters have been set, connect the analog motor command signal (MCM n where n is A-H) to the amplifier input.

To test the polarity of the feedback, command a move with the instruction:

PR 1000	Position relative 1000 counts
BGA	Begin motion on A axis

When the polarity of the feedback is wrong, the motor will attempt to run away. The controller should disable the motor when the position error exceeds 2000 counts. If the motor runs away, the polarity of the loop must be inverted.

Inverting the Loop Polarity

When the polarity of the feedback is incorrect, the user must invert the loop polarity and this may be accomplished by several methods. If you are driving a brush-type DC motor, the simplest way is to invert the two motor wires (typically red and black). For example, switch the M1 and M2 connections going from your amplifier to the motor.

When driving a brushless motor, the polarity reversal may be done with the encoder. If you are using a single-ended encoder, interchange the signal MA+ and MB+. If, on the other hand, you are using a differential encoder, interchange only MA+ and MA-. The loop polarity and encoder polarity can also be affected through software with the MT, and CE commands. For more details on the MT command or the CE command, see the Command Reference section.

To Invert Polarity using Hall-Commutated brushless motors, invert motor phases B & C, exchange Hall A with Hall B, and invert encoder polarity as described above.

Sometimes the feedback polarity is correct (the motor does not attempt to run away) but the direction of motion is reversed with respect to the commanded motion. If this is the case, reverse the motor leads AND the encoder signals.

If the motor moves in the required direction but stops short of the target, it is most likely due to insufficient torque output from the motor command signal MCM_n. This can be alleviated by reducing system friction on the motors. The instruction:

TTA Tell torque on A

reports the level of the output signal. It will show a non-zero value that is below the friction level.

Once you have established that you have closed the loop with the correct polarity, you can move on to the compensation phase (servo system tuning) to adjust the PID filter parameters, KP, KD and KI. It is necessary to accurately tune your servo system to ensure fidelity of position and minimize motion oscillation as described in the next section.



Step 7b. Connect Step Motors

In Stepper Motor operation, the pulse output signal has a 50% duty cycle. Step motors operate open loop and do not require encoder feedback. When a stepper is used, the auxiliary encoder for the corresponding axis is unavailable for an external connection. If an encoder is used for position feedback, connect the encoder to the main encoder input corresponding to that axis. The commanded position of the stepper can be interrogated with RP or TD. The encoder position can be interrogated with TP.

If encoders are available on the stepper motor, Galil's Stepper Position Maintenance Mode may be used for automatic monitoring and correction of the stepper position. See Stepper Position Maintenance Mode (SPM) in Chapter 6 Programming Motion for more information.

The frequency of the step motor pulses can be smoothed with the filter parameter, KS. The KS parameter has a range between 0.25 and 64, where 64 implies the largest amount of smoothing. *See Command Reference regarding KS.*

The DMC-41x3 profiler commands the step motor amplifier. All DMC-41x3 motion commands apply such as PR, PA, VP, CR and JG. The acceleration, deceleration, slew speed and smoothing are also used. Since step motors run open-loop, the PID filter does not function.

To connect step motors with the DMC-41x3 you must follow this procedure – If you have a Galil integrated stepper driver skip Step A, the step and direction lines are already connected to the driver:

Step A. Connect step and direction signals from controller to motor amplifier

From the controller to respective signals on your step motor amplifier. (These signals are labeled STPA and DIRA for the A-axis on the EXTERNAL DRIVER (A-D) D-Sub connector top of the controller).

Consult the documentation for connecting these signals to your step motor amplifier.

Step B. Configure DMC-41x3 for motor type using MT command.

You can configure the DMC-41x3 for active high or active low pulses. Use the command MT 2 or 2.5 for active low step motor pulses and MT -2 or -2.5 for active high step motor pulses. *See description of the MT command in the Command Reference.*

Step 8. Tune the Servo System

Adjusting the tuning parameters is required when using servo motors (standard or sinusoidal commutation). The system compensation provides fast and accurate response and the following section suggests a simple and easy way for compensation. More advanced design methods are available with software design tools from Galil, such as the GalilTools.

The filter has three parameters: the damping, KD; the proportional gain, KP; and the integrator, KI. The parameters should be selected in this order.

To start, set the integrator to zero with the instruction

```
KI 0 Integrator gain
```

and set the proportional gain to a low value, such as

```
KP 1 Proportional gain  
KD 100 Derivative gain
```

For more damping, you can increase KD (maximum is 4095.875). Increase gradually and stop after the motor vibrates. A vibration is noticed by audible sound or by interrogation. If you send the command

```
TE A Tell error
```

a few times, and get varying responses, especially with reversing polarity, it indicates system vibration. When this happens, simply reduce KD by about 20%.

Next you need to increase the value of KP gradually (maximum allowed is 1023.875). You can monitor the improvement in the response with the Tell Error instruction

```
KP 10 Proportion gain  
TE A Tell error
```

As the proportional gain is increased, the error decreases.

Again, the system may vibrate if the gain is too high. In this case, reduce KP by about 20%. Typically, KP should not be greater than KD/4 (only when the amplifier is configured in the current mode).

Finally, to select KI, start with zero value and increase it gradually. The integrator eliminates the position error, resulting in improved accuracy. Therefore, the response to the instruction

```
TE A
```

becomes zero. As KI is increased, its effect is amplified and it may lead to vibrations. If this occurs, simply reduce KI. Repeat tuning for the B, C and D axes.

NOTE: For a more detailed description of the operation of the PID filter and/or servo system theory, see Chapter 10 Theory of Operation and our Manual Tuning Application Note, #3413:
<http://www.galilmc.com/support/appnotes/optima/note3413.pdf>

Design Examples

Here are a few examples for tuning and using your controller. These examples have remarks next to each command - these remarks must not be included in the actual program.

Example 1 - System Set-up

This example assigns the system filter parameters, error limits and enables the automatic error shut-off.

Instruction	Interpretation
KP 10,10,10,10	Set gains for a,b,c,d (or A,B,C,D axes)
KP*=10	Alternate method for setting gain on all axes
KPA=10	Method for setting only A (or X) axis gain
KPX=10	Method for setting only X (or A) axis gain

KP ,20	Set B axis gain only
Instruction	Interpretation
OE 1,1,1,1,1,1,1,1	Enable automatic Off on Error function for all axes
ER*=1000	Set error limit for all axes to 1000 counts
KP 10,10,10,10,10,10,10,10	Set gains for a,b,c,d,e,f,g, and h axes
KP*=10	Alternate method for setting gain on all axes
KPA=10	Alternate method for setting A axis gain
KP ,,10	Set C axis gain only
KPD=10	Alternate method for setting D axis gain
KPH=10	Alternate method for setting H axis gain

Example 2 - Profiled Move

Rotate the A axis a distance of 10,000 counts at a slew speed of 20,000 counts/sec and an acceleration and deceleration rates of 100,000 counts/s². In this example, the motor turns and stops:

Instruction	Interpretation
PR 1000	Distance
SP 20000	Speed
DC 100000	Deceleration
AC 100000	Acceleration
BGA	Start Motion

Example 3 - Multiple Axes

Objective: Move the four axes independently.

Instruction	Interpretation
PR 500,1000,600,-400	Distances of A,B,C,D
SP 10000,12000,20000,10000	Slew speeds of A,B,C,D
AC 10000,10000,10000,10000	Accelerations of A,B,C,D
DC 80000,40000,30000,50000	Decelerations of A,B,C,D
BGAC	Start A and C motion
BGBD	Start B and D motion

Example 4 - Independent Moves

The motion parameters may be specified independently as illustrated below.

Instruction	Interpretation
PR ,300,-600	Distances of B and C
SP ,2000	Slew speed of B
DC ,80000	Deceleration of B
AC ,100000	Acceleration of B
AC ,,100000	Acceleration of C
DC ,,150000	Deceleration of C
BGC	Start C motion
BGB	Start B motion

Example 5 - Position Interrogation

The position of the four axes may be interrogated with the instruction, TP.

Instruction	Interpretation
--------------------	-----------------------

TP	Tell position all four axes
TPA	Tell position - A axis only
TPB	Tell position - B axis only
TPC	Tell position - C axis only
TPD	Tell position - D axis only

The position error, which is the difference between the commanded position and the actual position can be interrogated with the instruction TE.

Instruction	Interpretation
TE	Tell error - all axes
TEA	Tell error - A axis only
TEB	Tell error - B axis only
TEC	Tell error - C axis only
TED	Tell error - D axis only

Example 6 - Absolute Position

Objective: Command motion by specifying the absolute position.

Instruction	Interpretation
DP 0,2000	Define the current positions of A,B as 0 and 2000
PA 7000,4000	Sets the desired absolute positions
BGA	Start A motion
BGB	Start B motion

After both motions are complete, the A and B axes can be command back to zero:

PA 0,0	Move to 0,0
BGAB	Start both motions

Example 7 - Velocity Control

Objective: Drive the A and B motors at specified speeds.

Instruction	Interpretation
JG 10000,-20000	Set Jog Speeds and Directions
AC 100000, 40000	Set accelerations
DC 50000,50000	Set decelerations
BGAB	Start motion

after a few seconds, command:

JG -40000	New A speed and Direction
TVA	Returns A speed

and then

JG ,20000	New B speed
TVB	Returns B speed

These cause velocity changes including direction reversal. The motion can be stopped with the instruction

ST	Stop
----	------

Example 8 - Operation Under Torque Limit

The magnitude of the motor command may be limited independently by the instruction TL.

Instruction	Interpretation
TL 0.2	Set output limit of A axis to 0.2 volts
JG 10000	Set A speed
BGA	Start A motion

In this example, the A motor will probably not move since the output signal will not be sufficient to overcome the friction. If the motion starts, it can be stopped easily by a touch of a finger.

Increase the torque level gradually by instructions such as

Instruction	Interpretation
TL 1.0	Increase torque limit to 1 volt.
TL 9.998	Increase torque limit to maximum, 9.998 volts.

The maximum level of 9.998 volts provides the full output torque.

Example 9 - Interrogation

The values of the parameters may be interrogated. Some examples ...

Instruction	Interpretation
KP ?	Return gain of A axis
KP , , ?	Return gain of C axis.
KP ?, ?, ?, ?	Return gains of all axes.

Many other parameters such as KI, KD, FA, can also be interrogated. The command reference denotes all commands which can be interrogated.

Example 10 - Operation in the Buffer Mode

The instructions may be buffered before execution as shown below.

Instruction	Interpretation
PR 600000	Distance
SP 10000	Speed
WT 10000	Wait 10000 milliseconds before reading the next instruction
BGA	Start the motion

Example 11 - Using the On-Board Editor

Motion programs may be edited and stored in the controller's on-board memory. When the command, ED is given from the a terminal such as telnet or hyperterminal, the controllers editor will be started. It is recommended to use the GalilTools software to download programs to the controller rather than using the ED command.

The instruction

ED	Edit mode
----	-----------

moves the operation to the editor mode where the program may be written and edited. The editor provides the line number. For example, in response to the first ED command, the first line is zero.

Line #	Instruction	Interpretation
000	#A	Define label
001	PR 700	Distance
002	SP 2000	Speed
003	BGA	Start A motion

```
004      EN          End program
```

To exit the editor mode, input <cntrl>Q. The program may be executed with the command.

```
XQ #A          Start the program running
```

Example 12 - Motion Programs with Loops

Motion programs may include conditional jumps as shown below.

Instruction	Interpretation
#A	Label
DP 0	Define current position as zero
v1=1000	Set initial value of v1
#LOOP	Label for loop
PA v1	Move A motor v1 counts
BGA	Start A motion
AMA	After A motion is complete
WT 500	Wait 500 ms
TPA	Tell position A
v1=v1+1000	Increase the value of v1
JP #LOOP,v1<10001	Repeat if v1<10001
EN	End

After the above program is entered, quit the Editor Mode, <cntrl>Q. To start the motion, command:

```
XQ #A          Execute Program #A
```

Example 13 - Motion Programs with Trippoints

The motion programs may include trippoints as shown below.

Instruction	Interpretation
#B	Label
DP 0,0	Define initial positions
PR 30000,60000	Set targets
SP 5000,5000	Set speeds
BGA	Start A motion
AD 4000	Wait until A moved 4000
BGB	Start B motion
AP 6000	Wait until position A=6000
SP 2000,50000	Change speeds
AP ,50000	Wait until position B=50000
SP ,10000	Change speed of B
EN	End program

To start the program, command:

```
XQ #B          Execute Program #B
```

Example 14 - Control Variables

Objective: To show how control variables may be utilized.

Instruction	Interpretation
-------------	----------------

```

#A;DPO          Label; Define current position as zero
PR 4000         Initial position
SP 2000         Set speed
BGA             Move A
AMA             Wait until move is complete
WT 500          Wait 500 ms
#B
v1 = _TPA       Determine distance to zero
PR -v1/2        Command A move 1/2 the distance
BGA             Start A motion
AMA             After A moved
WT 500          Wait 500 ms
MG v1           Report the value of v1
JP #C, v1=0    Exit if position=0
JP #B           Repeat otherwise
#C
EN              Label #C
EN              End of Program

```

To start the program, command

XQ #A Execute Program #A

This program moves A to an initial position of 1000 and returns it to zero on increments of half the distance. Note, _TPA is an internal variable which returns the value of the A position.

Example 15 - Linear Interpolation

Objective: Move A,B,C motors distance of 7000,3000,6000, respectively, along linear trajectory. Namely, motors start and stop together.

Instruction	Interpretation
LMABC	Specify linear interpolation axes
LI 7000,3000,6000	Relative distances for linear interpolation
LE	Linear End
VS 6000	Vector speed
VA 20000	Vector acceleration
VD 20000	Vector deceleration
BGS	Start motion

Example 16 - Circular Interpolation

Objective: Move the AB axes in circular mode to form the path shown on Figure 2.8. Note that the vector motion starts at a local position (0,0) which is defined at the beginning of any vector motion sequence. See application programming for further information.

Instruction	Interpretation
VMAB	Select AB axes for circular interpolation
VP -4000,0	Linear segment
CR 2000,270,-180	Circular segment
VP 0,4000	Linear segment
CR 2000,90,-180	Circular segment
VS 1000	Vector speed
VA 50000	Vector acceleration
VD 50000	Vector deceleration

VE
BGS

End vector sequence
Start motion

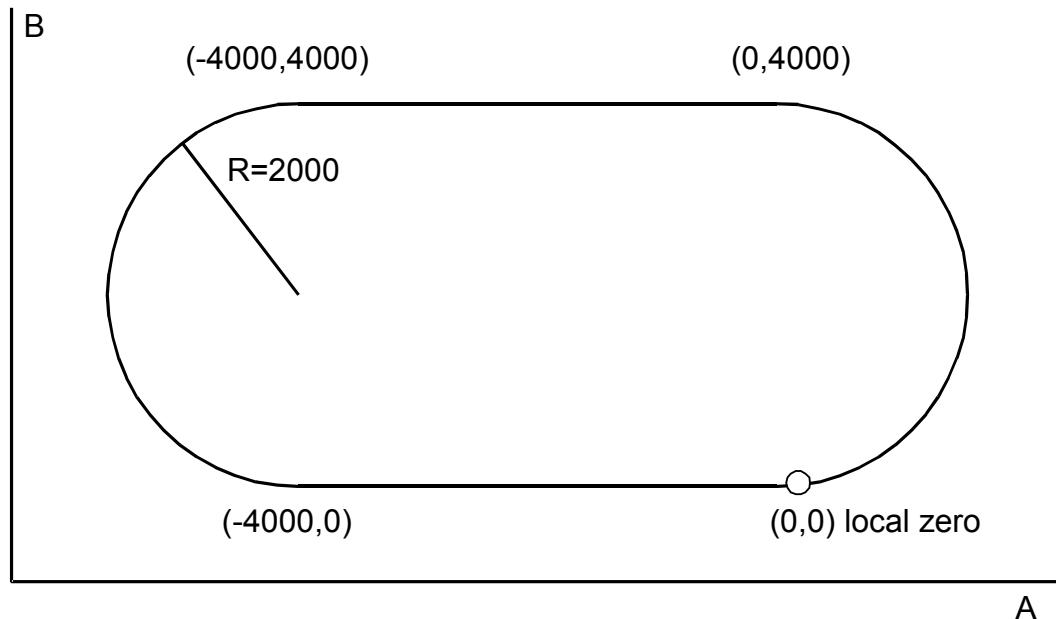


Figure 2.8: Motion Path for Circular Interpolation Example

Chapter 3 Connecting Hardware

Overview

The DMC-41x3 provides opto-isolated digital inputs for **forward limit**, **reverse limit**, **home**, and **abort** signals. The controller also has **8 opto-isolated, uncommitted inputs** (for general use) as well as **8 opto-isolated outputs** and **8 analog inputs** configured for voltages between +/- 10 volts.

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Controllers with 5 or more axes have an additional 8 opto-isolated inputs and an additional 8 opto-isolated outputs.

This chapter describes the inputs and outputs and their proper connection.

Overview of Opto-Isolated Inputs

Limit Switch Input

The forward limit switch (FLSx) inhibits motion in the forward direction immediately upon activation of the switch. The reverse limit switch (RLSx) inhibits motion in the reverse direction immediately upon activation of the switch. If a limit switch is activated during motion, the controller will make a decelerated stop using the deceleration rate previously set with the SD command. The motor will remain on (in a servo state) after the limit switch has been activated and will hold motor position. The controller can be configured to disable the axis upon the activation of a limit switch, see the OE command in the command reference for further detail.

When a forward or reverse limit switch is activated, the current application program that is running in thread zero will be interrupted and the controller will automatically jump to the #LIMSWI subroutine if one exists. This is a subroutine which the user can include in any motion control program and is useful for executing specific instructions upon activation of a limit switch. Automatic Subroutines for Monitoring Conditions are discussed in Chapter 7 Application Programming.

After a limit switch has been activated, further motion in the direction of the limit switch will not be possible until the logic state of the switch returns back to an inactive state. Any attempt at further motion before the logic state has been reset will result in the following error: “22 - Begin not possible due to limit switch” error.

The operands, _LFx and _LRx, contain the state of the forward and reverse limit switches, respectively (x represents the axis, X, Y, Z, W etc.). The value of the operand is either a ‘0’ or ‘1’ corresponding to the logic state of the limit switch. Using a terminal program, the state of a limit switch can be printed to the screen with the command, MG_LFx or MG_LRx. This prints the value of the limit switch operands for the ‘x’ axis. The logic state of the limit switches can also be interrogated with the TS command. For more details on TS see the Command Reference.

Home Switch Input

Homing inputs are designed to provide mechanical reference points for a motion control application. A transition in the state of a Home input alerts the controller that a particular reference point has been reached by a moving part in the motion control system. A reference point can be a point in space or an encoder index pulse.

The Home input detects any transition in the state of the switch and toggles between logic states 0 and 1 at every transition. A transition in the logic state of the Home input will cause the controller to execute a homing routine specified by the user.

There are three homing routines supported by the DMC-41x3: Find Edge (FE), Find Index (FI), and Standard Home (HM).

The Find Edge routine is initiated by the command sequence: FEX, BGX. The Find Edge routine will cause the motor to accelerate, and then slew at constant speed until a transition is detected in the logic state of the Home input. The direction of the FE motion is dependent on the state of the home switch. High level causes forward motion. The motor will then decelerate to a stop. The acceleration rate, deceleration rate and slew speed are specified by the user, prior to the movement, using the commands AC, DC, and SP. *When using the FE command, it is recommended that a high deceleration value be used so the motor will decelerate rapidly after sensing the Home switch.*

The Find Index routine is initiated by the command sequence: FIX, BGX. Find Index will cause the motor to accelerate to the user-defined slew speed (SP) at a rate specified by the user with the AC command and slew until the controller senses a change in the index pulse signal from low to high. The motor then decelerates to a stop at the rate previously specified by the user with the DC command and then moves back to the index pulse and speed HV. Although Find Index is an option for homing, it is not dependent upon a transition in the logic state of the Home input, but instead is dependent upon a transition in the level of the index pulse signal.

The Standard Homing routine is initiated by the sequence of commands HMX, BGX. Standard Homing is a combination of Find Edge and Find Index homing. Initiating the standard homing routine will cause the motor to slew until a transition is detected in the logic state of the Home input. The motor will accelerate at the rate specified by the command, AC, up to the slew speed. After detecting the transition in the logic state on the Home Input, the motor will decelerate to a stop at the rate specified by the command, DC. After the motor has decelerated to a stop, it switches direction and approaches the transition point at the speed of HV counts/sec. When the logic state changes again, the motor moves forward (in the direction of increasing encoder count) at the same speed, until the controller senses the index pulse. After detection, it decelerates to a stop, moves back to the index, and defines this position as 0. The logic state of the Home input can be interrogated with the command MG_HMX. This command returns a 0 or 1 if the logic state is low or high, respectively. The state of the Home input can also be interrogated indirectly with the TS command.

For examples and further information about Homing, see command HM, FI, FE of the Command Reference and the section entitled Homing in the Programming Motion Section of this manual.

Abort Input

The function of the Abort input is to immediately stop the controller upon transition of the logic state.

NOTE: The response of the abort input is significantly different from the response of an activated limit switch. When the abort input is activated, the controller stops generating motion commands immediately, whereas the limit switch response causes the controller to make a decelerated stop.

NOTE: The effect of an Abort input is dependent on the state of the off-on-error function (OE Command) for each axis. If the Off-On-Error function is enabled for any given axis, the motor for that axis will be turned off when the abort signal is generated. This could cause the motor to ‘coast’ to a stop since it is no longer under servo control. If the Off-On-Error function is disabled, the motor will decelerate to a stop as fast as mechanically possible and the motor will remain in a servo state.

All motion programs that are currently running are terminated when a transition in the Abort input is detected. This can be configured with the CN command. For information see the Command Reference, OE and CN.

ELO (Electronic Lock-Out) Input

Used in conjunction with Galil amplifiers, this input allows the user to shutdown the amplifier at a hardware level. For more detailed information on how specific Galil amplifiers behave when the ELO is triggered, see Integrated in the Appendices.

Reset Input/Reset Button

When the Reset line is triggered the controller will be reset. The reset line and reset button will not master reset the controller unless the MRST jumper is installed during a controller reset.

Uncommitted Digital Inputs

The DMC-41x3 has 8 opto-isolated inputs. These inputs can be read individually using the function @ IN[x] where x specifies the input number (1 thru 8). These inputs are uncommitted and can allow the user to create conditional statements related to events external to the controller. For example, the user may wish to have the x-axis motor move 1000 counts in the positive direction when the logic state of DI1 goes high.

The Digital inputs can be used as high speed position latch inputs, see High Speed Position Capture (The Latch Function) for more information.

This can be accomplished by connecting a voltage in the range of +5V to +28V into INCOM0 of the input circuitry from a separate power supply.

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Controllers with more than 4 axes have an additional 8 general opto-isolated inputs (inputs 9-16). INCOM1 is used for these inputs and is found on the I/O (E-H) D-Sub connector. The grouping is shown in Table 3.1.

NOTE: INCOM1 and LSCOM1 for Inputs 9-16 and Limit and Home Switches for axes 5-8 are found on the connectors for the E-H axes. **These are NOT the same INCOM0 and LSCOM0 for axes 1-4.**

Opto-Isolated Input Electrical Information

Electrical Specifications

Input Common (INCOM) and Digital Input Max Voltage	28 VDC
Input Common (INCOM) and Digital Input Min Voltage	0 VDC
Limit Common (LSCOM) and Limit/Home Input Max Voltage	28 VDC
Input Command (INCOM) and Limit/Home Input Max Min Voltage	0 VDC
Minimum current to turn on Inputs	1.2 mA
Minimum current to turn off Inputs once activated (hysteresis)	0.5 mA
Internal Resistance of Inputs (xxCOM to Inputs)	2.2 kΩ

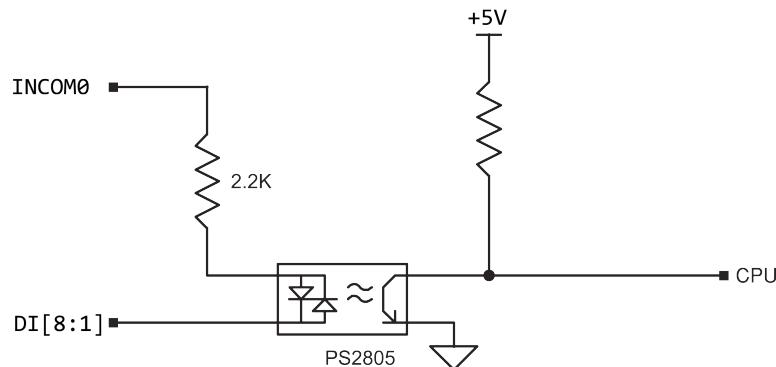


Figure 3.1: Digital Inputs 1-8 (DI[8:1])

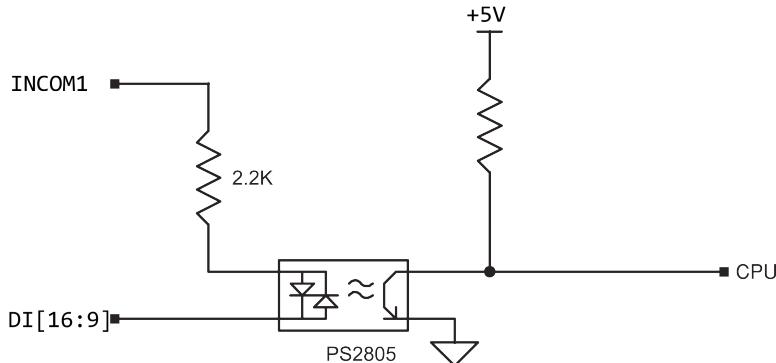


Figure 3.2: Digital Inputs 9-16 (DI[16:9])

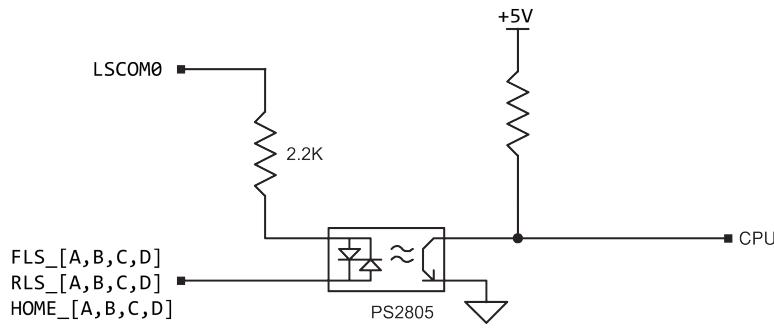


Figure 3.3: Limit Switch Inputs for Axes A-D

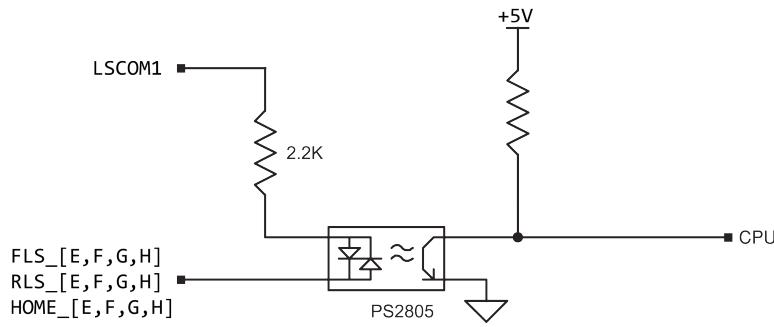


Figure 3.4: Limit Switch Inputs for Axes E-H

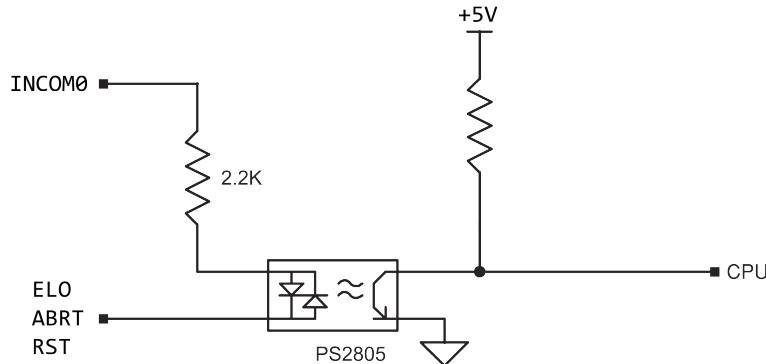


Figure 3.5: ELO, Abort and Reset Inputs

Wiring the Opto-Isolated Digital Inputs

All inputs can be used as active high or low - If you are using an isolated power supply you can connect the positive voltage of the supply (+Vs) to INCOM or supply the isolated ground to INCOM. Connecting +Vs to INCOM will configure the inputs for active low. Connecting the isolated ground to INCOM will configure the inputs for active high. If there is not an isolated supply available, the Galil 5V or 12V and GND may be used. It is recommended to use an isolated supply for the opto-isolated inputs.

To take full advantage of opto-isolation, an isolated power supply should be used to provide the voltage at the input common connection. When using an isolated power supply, do not connect the ground of the isolated power to the ground of the controller. A power supply in the voltage range between 5 to 28 Volts may be applied directly (see Figure 3.6).

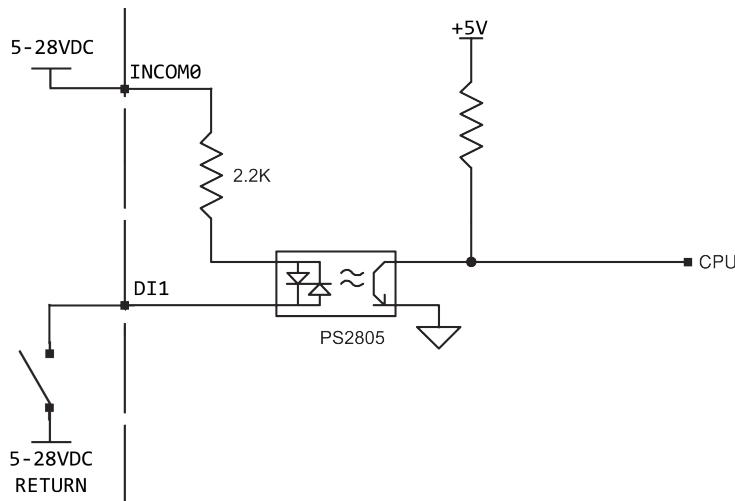


Figure 3.6: Digital Input Wiring for +Vs to INCOM0

The opto-isolated inputs are configured into groups. For example, the general inputs, DI[8:1] (inputs 1-8), the ABRT (abort) input and RST (reset) and ELO (electronic lock-out) inputs are one group. The INCOM and LSCOM signals are a common connection for all of the inputs in each group.

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The ELO, ABRT and RST pins are found on the I/O (A-D) D-Sub and are duplicated on the I/O (E-H) D-Sub. I.e. There is only one ELO, ABRT and RST input for an 8 axis controller. The common is the INCOM0 found on the I/O (A-D) D-Sub connector.

The opto-isolated inputs are connected in the following groups:

Group (Controllers with 1- 4 Axes)	Common Signal
DI1-DI8, ABRT, RST, ELO	INCOM0 (I/O (A-D) D-Sub Connectors)
FLSA,RLSA,HOMA FLSB,RLSB,HOMB FLSC,RLSC,HOMC FLSD,RLSD,HOMD	LSCOM0 (I/O (A-D) D-Sub Connectors)
Group (Controllers with 5-8 Axes)	
DI1-DI8, ABRT, RST, ELO	INCOM0 (I/O (A-D) D-Sub Connectors)
FLSA,RLSA,HOMA FLSB,RLSB,HOMB FLSC,RLSC,HOMC FLSD,RLSD,HOMD	LSCOM0 (I/O (A-D) D-Sub Connectors)
DI9-DI16	INCOM1 (I/O (E-H) D-Sub Connectors)
FLSE,RLSE,HOME FLSF,RLSF,HOMF FLSG,RLSG,HOMG FLSH,RLSH,HOMH	LSCOM1 (I/O (E-H) D-Sub Connectors)

Table 3.1: INCOM and LSCOM information

Using Voltages > 28 VDC

For voltages greater than 28 Volts, a resistor, R, is needed in series with the input such that:

$$1 \text{ mA} < V_s / (R + 2.2\text{K}\Omega) < 11 \text{ mA}$$

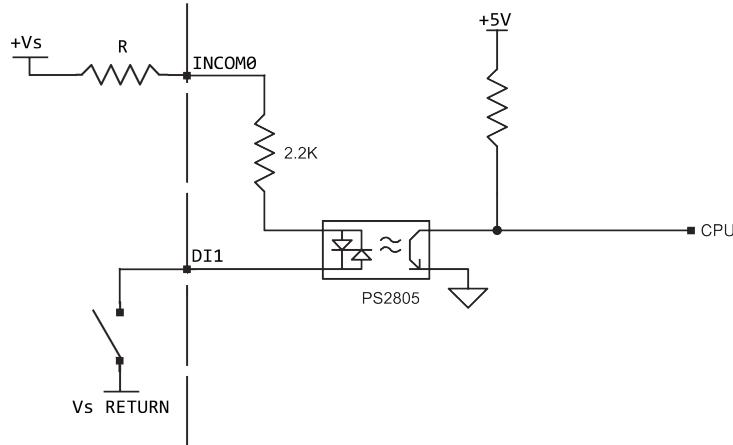


Figure 3.7: Wiring inputs for > 28VDC

Bypassing the Opto-Isolation

If no isolation is needed, the internal 5 Volt supply may be used to power the switches. This can be done by connecting LSCOM or INCOM to 5V.

To close the circuit, wire the desired input to any ground (GND) pin on the controller.

Opto-Isolated Outputs

The DMC-41x3 has different options for the uncommitted digital outputs. The standard outputs are 4mA sinking outputs, these are ideal for interfacing to TTL level devices. There are options for 25mA sinking or sourcing and 500mA sourcing outputs.

Standard 4mA Sinking Opto-Isolated Outputs

Description

The default outputs of the DMC-41x3 are shown in Figure 3.8 and Figure 3.9 and are capable of 4mA and are configured as sinking outputs. The voltage range for the outputs is 5-24 VDC. These outputs should not be used to drive inductive loads directly.

Electrical Specifications

Output Common (OP0B, OP1B)	Max Voltage	24 VDC
	Min Voltage	5 VDC
ON Voltage (No Load, 5V OPxB)		0.1 VDC
Max Drive Current per Output		4mA – Sinking

Wiring the Standard 4mA outputs

The standard outputs are sinking outputs. With this configuration the load will be connected from the digital output to the 5-24VDC source and/or OPxB as shown in Figure 3.8 and Figure 3.9. The supply voltage must be connected to OPxB, and the supply return must be connected to OPxA.

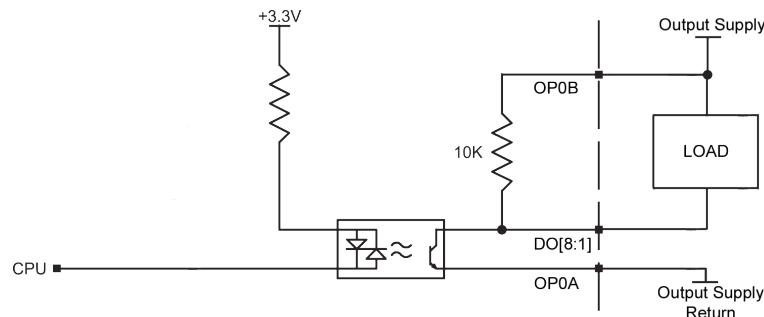


Figure 3.8: 4mA sinking outputs DO[8:1]

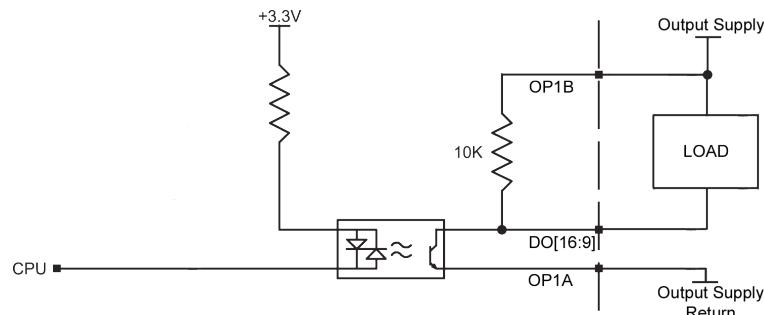


Figure 3.9: 4mA sinking outputs DO[16:9]

25mA Sinking Opto-Isolated Outputs (LSNK)

Description

With the (LSNK) option on the DMC-41x3 the digital outputs are modified to be capable of sinking up to 25mA per output. The ABCD(LSNK) option configures digital outputs 1-8 for 25mA sinking outputs, this is shown in Figure 3.10. The EFGH(LSNK) option (only valid for 5-8 axis controllers) configures digital outputs 9-16 for 25mA sinking outputs, this is shown in Figure 3.11. These outputs should not be used to drive inductive loads directly.

Electrical Specifications

Output Common (OP0B, OP1B)	Max Voltage	24 VDC
	Min Voltage	5 VDC
Max Drive Current per Output		25mA – Sinking

Wiring the 25mA Sinking Outputs

With the 25mA sinking outputs the load is wired in the same fashion as the 4mA sinking outputs. The load will be connected from the digital output to the 5-24VDC source and/or OPxB as shown in Figure 3.10 and Figure 3.11. The supply voltage must be connected to OPxB, and the supply return must be connected to OPxA.

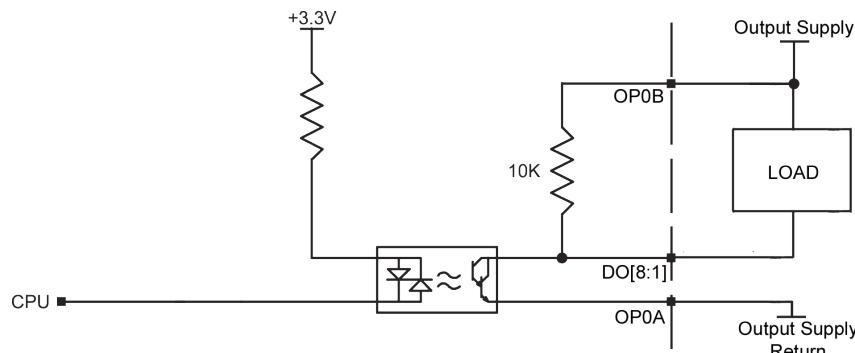


Figure 3.10: 25mA sinking outputs for ABCD(LSNK) option (DO[8:1])

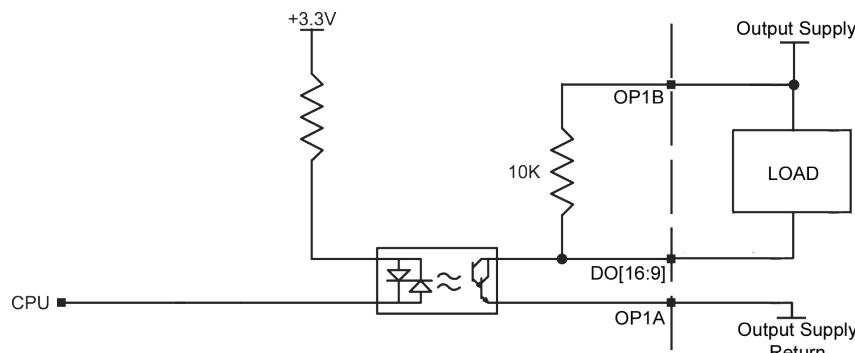


Figure 3.11: 25mA sinking outputs for EFGH(LSNK) option (DO[16:9])

25mA Sourcing Opto-Isolated Outputs (LSRC)

Description

With the (LSRC) option on the DMC-41x3 the digital outputs are modified to be capable of sourcing up to 25mA per output. The ABCD(LSRC) option configures digital outputs 1-8 for 25mA sourcing outputs, this is shown in Figure 3.12. The EFGH(LSRC) option (only valid for 5-8 axis controllers) configures digital outputs 9-16 for 25mA sourcing outputs, this is shown in Figure 3.13. These outputs should not be used to drive inductive loads directly.

Electrical Specifications

Output Common (OP0A, OP1A)	Max Voltage	24 VDC
	Min Voltage	5 VDC
Max Drive Current per Output		25mA – Sourcing

Wiring the 25mA Sourcing Outputs

The load will be connected from the digital output to the 5-24VDC supply return and/or OPxB as shown in Figure 3.12 and Figure 3.13. The supply voltage must be connected to OPxA, and the supply return must be connected to OPxB.

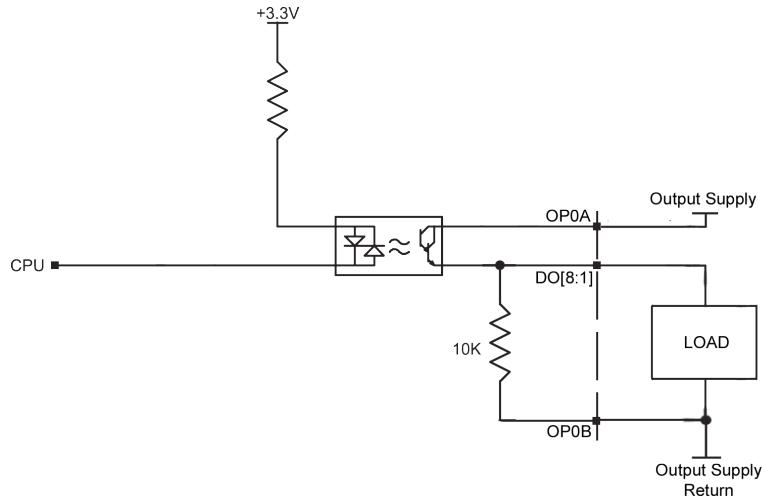


Figure 3.12: 25mA sourcing outputs for ABCD(LSRC) option (DO[8:1])

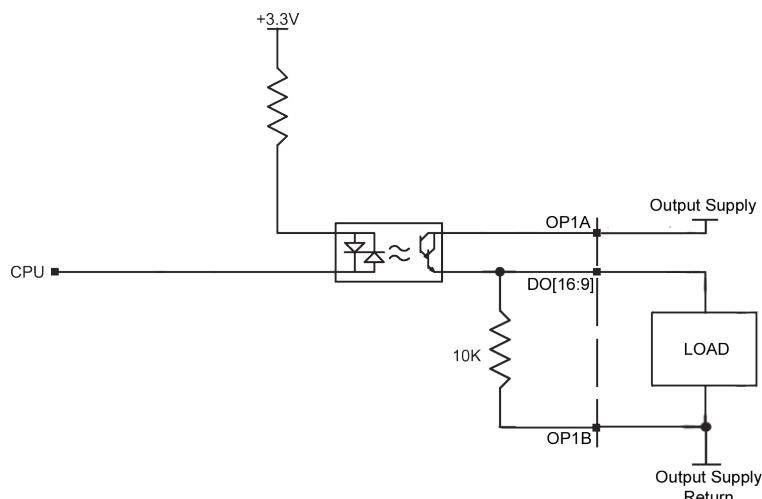


Figure 3.13: 25mA sourcing outputs for EFGH(LSRC) option (DO[16:9])

500mA Sourcing Opto-Isolated Outputs (HSRC)

Description

With the (HRSC) option on the DMC-41x3 the digital outputs are modified to be capable of sourcing up to 0.5 A per pin with a 4 A limit for the group of 8 outputs. These outputs are capable of driving inductive loads such as solenoids or relays. The outputs are configured for hi-side drive only. The supply voltage must be connected to OPxA, and the supply return must be connected to OPxB.

The ABCD(HRSC) option configures digital outputs 1-8 for 500mA sourcing, this is shown in Figure 3.14. The EFGH(HRSC) option (only valid for 5-8 axis controllers) configures digital outputs 9-16 for 500mA sourcing, this is shown in Figure 3.15.

Electrical Specifications

Output Common (OP0A, OP1A)	Max Voltage	24 VDC
	Min Voltage	12 VDC
Max Drive Current per Output	0.5 A (not to exceed 4A for all 8 outputs)	

Wiring the 500mA Sourcing Opto-Isolated Outputs

The outputs will be the voltage that is supplied to the OPxA pin. Up to 24 VDC may be supplied to OPxA. The outputs are configured for hi-side drive only. The supply voltage must be connected to OPxA, and the supply return must be connected to OPxB. The load will be connected from the digital output to the Return of the 12-24VDC source and OPxB as shown in Figure 3.14 and Figure 3.15.

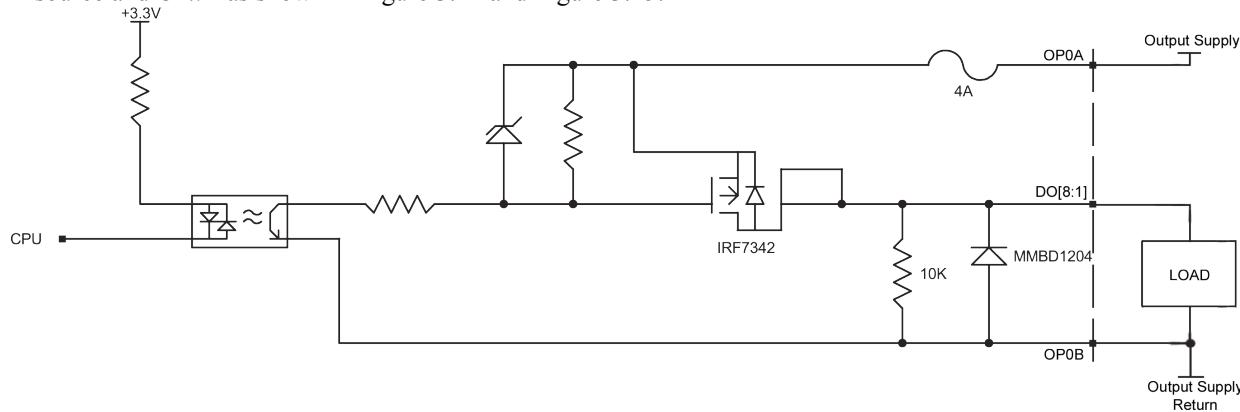


Figure 3.14: 500mA sourcing outputs for ABCD(HRSC) option (DO[8:1])

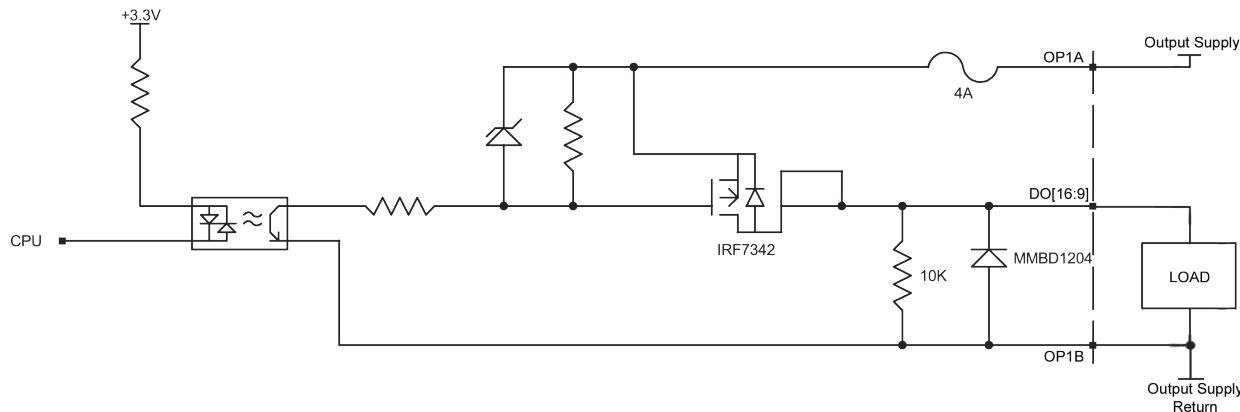


Figure 3.15: 500mA sourcing outputs for EFGH(HRSC) option (DO[16:9])

TTL Inputs and Outputs

Main Encoder Inputs

The main encoder inputs can be configured for quadrature (default) or pulse and direction inputs. This configuration is set through the CE command. The encoder connections are found on the 26 pin HD D-sub Encoder connectors and are labeled MA+, MA-, MB+, MB-. The '-' (negative) inputs are the differential inputs to the encoder inputs; if the encoder is a single ended 5V encoder, then the negative input should be left floating. If the encoder is a single ended and outputs a 0-12V signal then the negative input should be tied to the 5V line on the DMC-41x3.

When the encoders are setup as step and direction inputs the MA channel will be the step or pulse input, and the MB channel will be the direction input.

The encoder inputs can be ordered with 120Ohm termination resistors installed. See TRES – Encoder Termination Resistors in the Appendix for more information.

Electrical Specifications

Maximum Voltage	12 VDC
Minimum Voltage	-12 VDC
Maximum Frequency (Quadrature)	15 MHz
'+' inputs are internally pulled-up to 5V through a 4.7 kΩ resistor	
'-' inputs are internally biased to ~1.3V	
	pulled up to 5V through a 7.1 kΩ resistor
	pulled down to GND through a 2.5 kΩ resistor

The Auxiliary Encoder Inputs

The auxiliary encoder inputs can be used for general use. For each axis, the controller has one auxiliary encoder and each auxiliary encoder consists of two inputs, channel A and channel B. The auxiliary encoder inputs are mapped to the inputs 81-96. The Aux encoder inputs are not available for any axis that is configured for step and direction outputs (stepper).

Each input from the auxiliary encoder is a differential line receiver and can accept voltage levels between +/- 12 volts. The inputs have been configured to accept TTL level signals. To connect TTL signals, simply connect the signal to the + input and leave the - input disconnected. For other signal levels, the '-' input should be connected to a voltage that is $\sim\frac{1}{2}$ of the full voltage range (for example, connect the '-' input to the 5 volts on the Galil if the signal is 0 - 12V logic).

Example:

A DMC-4113 has one auxiliary encoder. This encoder has two inputs (channel A and channel B). Channel A input is mapped to input 81 and Channel B input is mapped to input 82. To use this input for 2 TTL signals, the first signal will be connected to AA+ and the second to AB+. AA- and AB- will be left unconnected. To access this input, use the function @IN[81] and @IN[82].

NOTE: The auxiliary encoder inputs are not available for any axis that is configured for stepper motor.

Electrical Specifications

Maximum Voltage	12 VDC
Minimum Voltage	-12 VDC
'+' inputs are internally pulled-up to 5V through a 4.7kΩ resistor	
'-' inputs are internally biased to ~1.3V	
pulled up to 5V through a 7.1kΩ resistor	
pulled down to GND through a 2.5kΩ resistor	

Step,Direction Outputs (PWM/SIGN)

The controller provides step and direction (STPn, DIRn) outputs for every axis available on the controller. These outputs are typically used for interfacing to external stepper drivers, but they can be configured for a PWM output. See the MT command for more details.

Electrical Specifications

Output Voltage	0 – 5 VDC
Current Output	20 mA Sink/Source

Output Compare

The output compare signal is TTL and is available on the I/O (A-D) D-Sub connector as CMP. Output compare is controlled by the position of any of the main encoder inputs on the controller. The output can be programmed to produce an active low pulse (510 nsec) based on an incremental encoder value or to activate once when an axis position has been passed. When setup for a one shot, the output will stay low until the OC command is called again. For further information, see the command OC in the Command Reference.

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For controllers with 5-8 axes, a second output compare signal is available on the I/O (E-H) D-Sub connector.

Electrical Specifications

Output Voltage	0 – 5 VDC
Current Output	20 mA Sink/Source

Error Output

The controller provides a TTL signal, ERR, to indicate a controller error condition. When an error condition occurs, the ERR signal will go low and the controller LED will go on. An error occurs because of one of the following conditions:

1. At least one axis has a position error greater than the error limit. The error limit is set by using the command ER.
2. The reset line on the controller is held low or is being affected by noise.
3. There is a failure on the controller and the processor is resetting itself.
4. There is a failure with the output IC which drives the error signal.

The ERR signal is found on the I/O (A-D) D-Sub connector.

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For controllers with 5-8 axes, the ERR signal is duplicated on the I/O (E-H) D-Sub connector.

For additional information see Error Light (Red LED) in Chapter 9 Troubleshooting.

Electrical Specifications

Output Voltage	0 – 5 VDC
Current Output	20 mA Sink/Source

Analog Inputs

The DMC-41x3 has eight analog inputs configured for the range between -10V and 10V. The inputs are decoded by a 12-bit A/D decoder giving a voltage resolution of approximately .005V. A 16-bit ADC is available as an option (Ex. *DMC-4123-CARD(-16bit)*). The analog inputs are specified as AN[x] where x is a number 1 thru 8.

AQ settings

The analog inputs can be set to a range of +/-10V, +/-5V, 0-5V or 0-10V, this allows for increased resolution when the full +/-10V is not required. The inputs can also be set into a differential mode where analog inputs 2,4,6 and 8 can be set to the negative differential inputs for analog inputs 1,3,5 and 7 respectively. See the AQ command in the command reference for more information.

Electrical Specifications

Input Impedance (12 and 16 bit) –	
Single Ended (Unipolar)	42kΩ
Differential (Bipolar)	31kΩ

External Amplifier Interface

Electrical Specifications

Max Amplifier Enable Voltage	24V	
Max Amplifier Enable Current @24V	sink/source	25 mA
Motor Command Output Range	+/-10 VDC	
Motor Command Output Impedance	500 Ω	

Overview

The DMC-41x3 command voltage ranges between +/-10V and is output on the motor command line - MCMn (where n is A-H). This signal, along with GND, provides the input to the motor amplifiers. The amplifiers must be sized to drive the motors and load. For best performance, the amplifiers should be configured for a torque (current) mode of operation with no additional compensation. The gain should be set such that a 10 volt input results in the maximum required current.

The DMC-41x3 also provides an amplifier enable signal - AEN. This signal changes under the following conditions: the motor-off command, MO, is given, the watchdog timer activates, or the OE command (Enable Off-On-Error) is set and the position error exceeds the error limit or a limit switch is reached (see OE command in the Command Reference for more information).

The standard configuration of the amplifier enable signal is 5V active high amp enable (HAEN) sinking. In other words, the AEN signal will be high when the controller expects the amplifier to be enabled. The polarity and the amplitude can be changed by configuring the Amplifier Enable Circuit on the DMC-41x3.

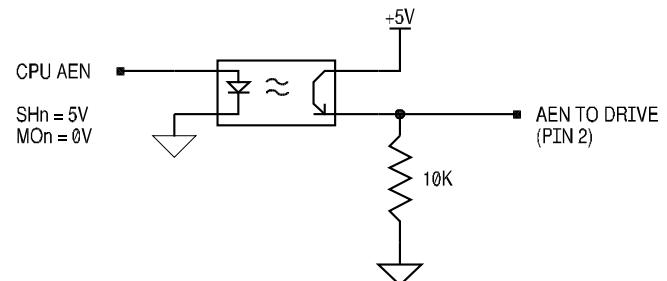
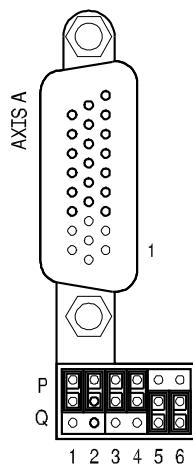
NOTE: Many amplifiers designate the enable input as ‘inhibit’.

Configuring the Amplifier Enable Circuit

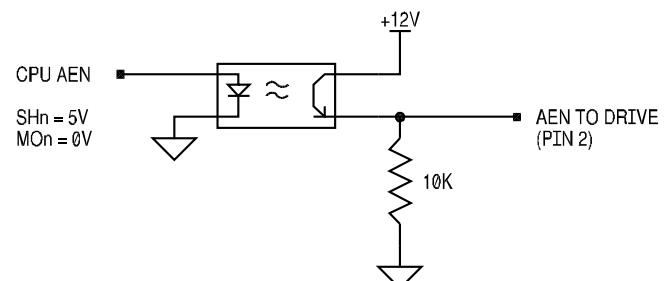
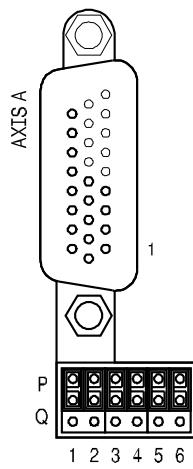
This section describes how to configure the DMC-41x3 for different Amplifier Enable configurations.

The DMC-41x3 is designed to be easily interfaced to multiple amplifier manufacturers. As a result, the amplifier enable circuit for each axis is individually configurable through jumper settings. The user can choose between High-Amp-Enable (HAEN), Low-Amp-Enable (LAEN), 5V logic, 12V logic, external voltage supplies up to 24V, sinking, or sourcing. The different configurations are described below with jumper settings and a basic schematics of the circuit.

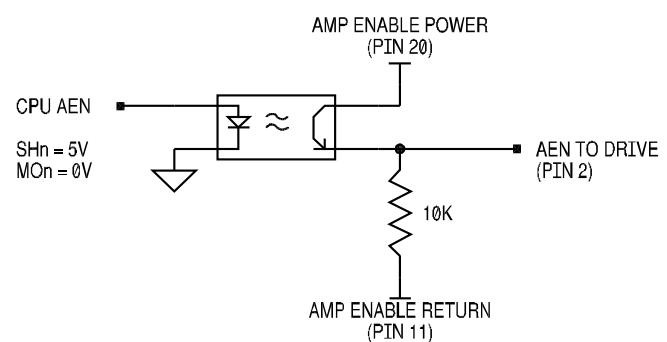
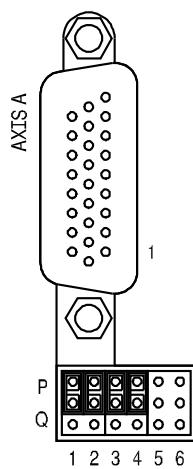
**+5V
HIGH AMP ENABLE
SOURCING**

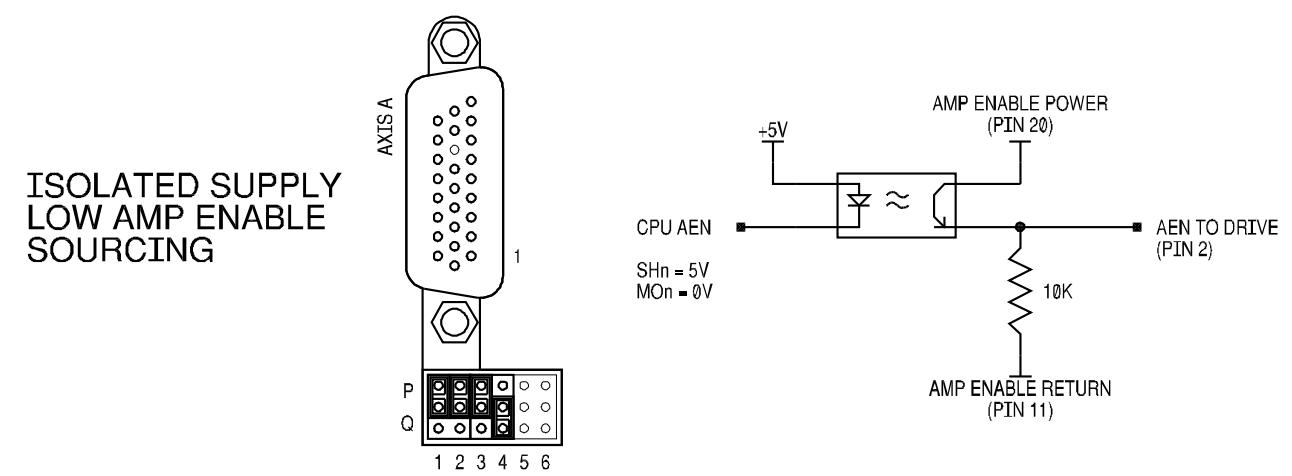
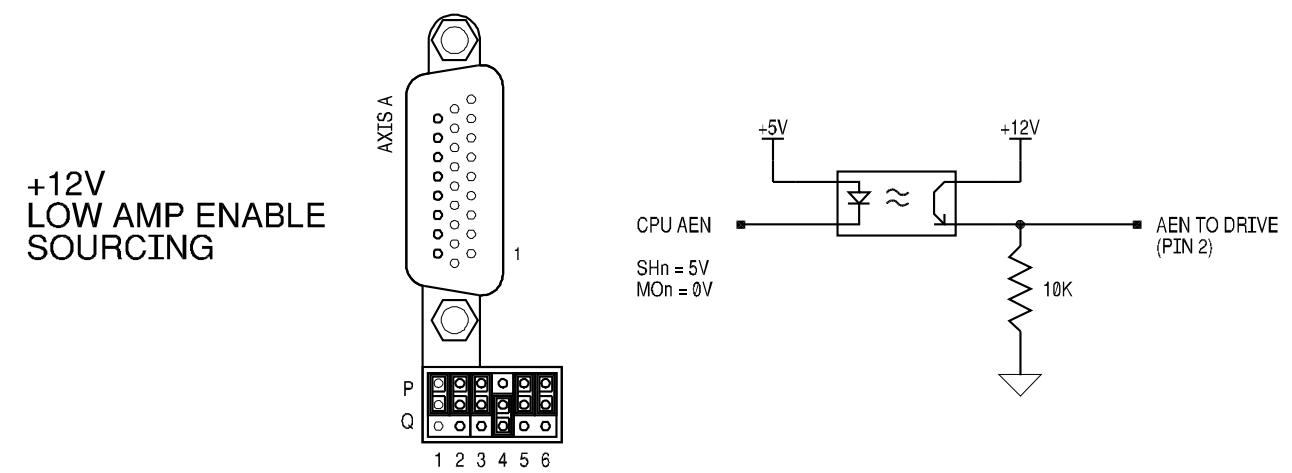
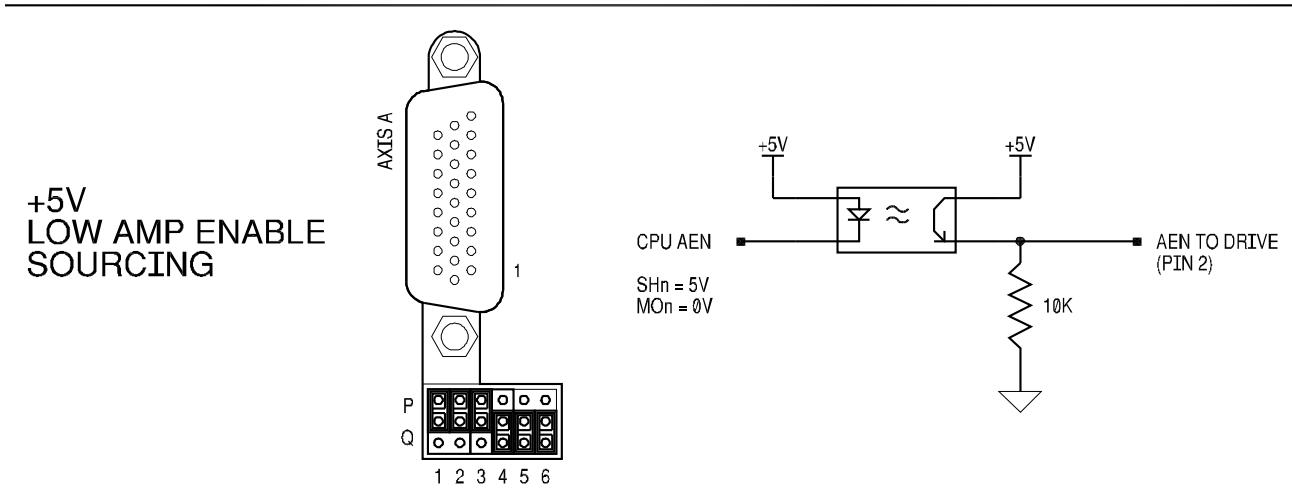


**+12V
HIGH AMP ENABLE
SOURCING**



**ISOLATED SUPPLY
HIGH AMP ENABLE
SOURCING**





Chapter 4 Software Tools and Communication

Introduction

The default configuration DMC-41x3 has one USB port, one RS-232 port and one Ethernet port. The auxiliary RS-232 port is the data term and can be configured with the software command CC. This configuration can be saved using the Burn (BN) instruction. The Ethernet port is a 10/100BASE-T connection that auto-negotiates the speed and half or full duplex.

The GalilTools software package is available for PC computers running Microsoft Windows or Linux to communicate with the DMC-41x3 controller. This software package has been developed to operate under Windows and Linux, and include all the necessary drivers to communicate to the controller. In addition, GalilTools includes a software development communication library which allows users to create their own application interfaces using programming environments such as C, C++, Visual Basic, and LabVIEW.

The following sections in this chapter are a description of the communications protocol, and a brief introduction to the software tools and communication techniques used by Galil. At the application level, GalilTools is the basic programs that the majority of users will need to communicate with the controller, to perform basic setup, and to develop application code (.dmc programs) that is downloaded to the controller. At the Galil API level, the GalilTools Communication Library is available for users who wish to develop their own custom application programs to communicate to the controller. Custom application programs can utilize API function calls directly to our DLL's. At the driver level, we provide fundamental hardware interface information for users who desire to create their own drivers.

Controller Response to Commands

Most DMC-41x3 instructions are represented by two characters followed by the appropriate parameters. Each instruction must be terminated by a carriage return. Multiple commands may be concatenated by inserting a semicolon between each command.

After the instruction is decoded, the DMC-41x3 returns a response to the port from which the command was generated. If the instruction was valid, the controller returns a colon (:) or the controller will respond with a question mark (?) if the instruction was not valid. For example, the controller will respond to commands which are sent via the USB port back through the USB port, and to commands which are sent via the Ethernet port back through the Ethernet port.

For instructions that return data, such as Tell Position (TP), the DMC-41x3 will return the data followed by a carriage return, line feed and :.

It is good practice to check for : after each command is sent to prevent errors. An echo function is provided to enable associating the DMC-41x3 response with the data sent. The echo is enabled by sending the command EO 1 to the controller.

Unsolicited Messages Generated by Controller

When the controller is executing a program, it may generate responses which will be sent via the USB port or Ethernet handles. This response could be generated as a result of messages using the MG command OR as a result of a command error. These responses are known as unsolicited messages since they are not generated as the direct response to a command.

Messages can be directed to a specific port using the specific Port arguments – see the MG and CF commands in the Command Reference. If the port is not explicitly given or the default is not changed with the CF command, unsolicited messages will be sent to the default port. The default port is the main serial port. When communicating via an Ethernet connection, the unsolicited messages must be sent through a handle that is not the main communication handle from the host. The GalilTools software automatically establishes this second communication handle.

The controller has a special command, CW, which can affect the format of unsolicited messages. This command is used by Galil Software to differentiate response from the command line and unsolicited messages. The command, CW1 causes the controller to set the high bit of ASCII characters to 1 of all unsolicited characters. This may cause characters to appear garbled to some terminals. This function can be disabled by issuing the command, CW2. For more information, see the CW command in the Command Reference.

USB and RS-232 Ports

USB Programming Port

The USB port on the DMC-41x3 is a USB to serial converter. It should be setup for 115.2kB, 8 Data bits, No Parity, 1 Stop Bit and Flow Control set for Hardware. The baud rate can be changed to 19200 baud by installing the 19.2 jumper on JP1, but this configuration is only recommended if a slower baud rate is required from the host communication. The USB port on the DMC-41x3 is a Female Type B USB port. The standard cable when communicating to a PC will be a Male Type A – Male Type B USB cable.

When connected to a PC, the USB connection will be available as a new serial port connection (ex. with GalilTools “COM3 115200”).

The USB port is not recommended when using the GalilTools Scope. In this case the Ethernet connection is advised for higher performance.

Baud Rate Selection

JP1 JUMPER SETTINGS	
19.2	BAUD RATE
ON	19200
OFF (recommended)	115200

USB Driver

The USB port on the DMC-41x3 utilizes a USB to serial converter. The driver for this device is expected to be loaded automatically upon connection of the controller in most OS's. If the driver does not load, or is not installed automatically, it can be downloaded from the mfg website here:

<http://www.ftdichip.com/Drivers/VCP.htm>

Auxiliary RS-232 Port Configuration

NOTE: If you are connecting the RS-232 auxiliary port to a terminal or any device which is a DATASET, it is necessary to use a connector adapter, which changes a dataset to a dataterm. This cable is also known as a 'null' modem cable.

RS232 - Auxiliary Port

1 No Connect	6 No Connect
2 Receive Data - input	7 Request To Send - output
3 Transmit Data - output	8 Clear To Send - input
4 No Connect	9 No Connect (Can be connected to 5V with APWR jumper)
5 Ground	

Handshaking

The auxiliary port of the DMC-41x3 can be configured either as a general port output port or setup for communication interrupts (CI command). When configured as a general port, the port can be commanded to send ASCII messages to another DMC-41x3 controller or to a display terminal or panel.

CC Command: (Configure Communication) at port 2. The command is in the format of (See CC in the Command Reference for more information):

CC m,n,r,p

where 'm' sets the baud rate, 'n' sets for either handshake or non-handshake mode, 'r' sets for general port or the auxiliary port, and 'p' turns echo on or off.

m - Baud Rate – 9600,19200

n - Handshake - 0=No; 1=Yes

r - Mode - 0=Disabled; 1=enabled

p - Echo - 0=Off; 1=On; Valid only if r=0

Hardware Handshaking: The RS-232 Aux port can be set for hardware handshaking with the second field of the CC command. Hardware Handshaking uses the RTS and CTS lines. The RTS line will go high whenever the DMC-41x3 is not ready to receive additional characters. The CTS line will inhibit the DMC-41x3 from sending additional characters. Note, the CTS line goes high for inhibit.

Example:

CC 19200,0,1,1 Configure auxiliary communication port for 19200 baud, no handshake, general port mode and echo turned on.

RS-422 Configuration

The DMC-41x3 can be ordered with the auxiliary port configured for RS-422 communication. RS-422 communication is a differentially driven serial communication protocol that should be used when long distance serial communication is required in an application.

For more information see RS-422 – Auxiliary Serial Port Serial Communication in the in Appendix.

Ethernet Configuration

Communication Protocols

The Ethernet is a local area network through which information is transferred in units known as packets. Communication protocols are necessary to dictate how these packets are sent and received. The DMC-41x3

supports two industry standard protocols, TCP/IP and UDP/IP. The controller will automatically respond in the format in which it is contacted.

TCP/IP is a "connection" protocol. The master, or client, connects to the slave, or server, through a series of packet handshakes in order to begin communicating. Each packet sent is acknowledged when received. If no acknowledgment is received, the information is assumed lost and is resent.

Unlike TCP/IP, UDP/IP does not require a "connection". If information is lost, the controller does not return a colon or question mark. Because UDP does not provide for lost information, the sender must re-send the packet.

It is recommended that the motion control network containing the controller and any other related devices be placed on a "closed" network. If this recommendation is followed, UDP/IP communication to the controller may be utilized instead of a TCP connection. With UDP there is less overhead, resulting in higher throughput. Also, there is no need to reconnect to the controller with a UDP connection. Because handshaking is built into the Galil communication protocol through the use of colon or question mark responses to commands sent to the controller, the TCP handshaking is not required.

Packets must be limited to 512 data bytes (including UDP/TCP IP Header) or less. Larger packets could cause the controller to lose communication.

NOTE: In order not to lose information in transit, the user must wait for the controller's response before sending the next packet.

Addressing

There are three levels of addresses that define Ethernet devices. The first is the MAC or hardware address. This is a unique and permanent 6 byte number. No other device will have the same MAC address. The DMC-41x3 MAC address is set by the factory and the last two bytes of the address are the serial number of the board. To find the Ethernet MAC address for a DMC-41x3 unit, use the TH command. A sample is shown here with a unit that has a serial number of 3:

Sample MAC Ethernet Address: 00-50-4C-38-00-03

The second level of addressing is the IP address. This is a 32-bit (or 4 byte) number that usually looks like this: 192.168.15.1. The IP address is constrained by each local network and must be assigned locally. Assigning an IP address to the DMC-41x3 controller can be done in a number of ways.

The first method for setting the IP address is using a DHCP server. The DH command controls whether the DMC-41x3 controller will get an IP address from the DHCP server. If the unit is set to DH1 (default) and there is a DHCP server on the network, the controller will be dynamically assigned an IP address from the server. Setting the board to DH0 will prevent the controller from being assigned an IP address from the server.

The second method to assign an IP address is to use the BOOT-P utility via the Ethernet connection. The BOOT-P functionality is only enabled when DH is set to 0. Either a BOOT-P server on the internal network or the Galil software may be used. When opening the Galil Software, it will respond with a list of all DMC-41x3's and other controllers on the network that do not currently have IP addresses. The user must select the board and the software will assign the specified IP address to it. This address will be burned into the controller (BN) internally to save the IP address to the non-volatile memory.

NOTE: if multiple boards are on the network – use the serial numbers to differentiate them.

CAUTION: Be sure that there is only one BOOT-P or DHCP server running. If your network has DHCP or BOOT-P running, it may automatically assign an IP address to the DMC-41x3 controller upon linking it to the network. In order to ensure that the IP address is correct, please contact your system administrator before connecting the I/O board to the Ethernet network.

The third method for setting an IP address is to send the IA command through the USB port. (Note: The IA command is only valid if DH0 is set). The IP address may be entered as a 4 byte number delimited by commas (industry standard uses periods) or a signed 32 bit number (e.g. IA 124,51,29,31 or IA 2083724575). Type in BN to save the IP address to the DMC-41x3 non-volatile memory.

NOTE: Galil strongly recommends that the IP address selected is not one that can be accessed across the Gateway. The Gateway is an application that controls communication between an internal network and the outside world.

The third level of Ethernet addressing is the UDP or TCP port number. The Galil board does not require a specific port number. The port number is established by the client or master each time it connects to the DMC-41x3 board. Typical port numbers for applications are:

Port 23: Telnet
Port 502: Modbus

Communicating with Multiple Devices

The DMC-41x3 is capable of supporting multiple masters and slaves. The masters may be multiple PC's that send commands to the controller. The slaves are typically peripheral I/O devices that receive commands from the controller.

NOTE: The term "Master" is equivalent to the internet "client". The term "Slave" is equivalent to the internet "server".

An Ethernet handle is a communication resource within a device. The DMC-41x3 can have a maximum of 8 Ethernet handles open at any time. When using TCP/IP, each master or slave uses an individual Ethernet handle. In UDP/IP, one handle may be used for all the masters, but each slave uses one. (Pings and ARPs do not occupy handles.) If all 8 handles are in use and a 9th master tries to connect, it will be sent a "reset packet" that generates the appropriate error in its windows application.

NOTE: There are a number of ways to reset the controller. Hardware reset (push reset button or power down controller) and software resets (through Ethernet or USB by entering RS).

When the Galil controller acts as the master, the IH command is used to assign handles and connect to its slaves. The IP address may be entered as a 4 byte number separated with commas (industry standard uses periods) or as a signed 32 bit number. A port number may also be specified, but if it is not, it will default to 1000. The protocol (TCP/IP or UDP/IP) to use must also be designated at this time. Otherwise, the controller will not connect to the slave. (Ex. IHB=151,25,255,9<179>2 This will open handle #2 and connect to the IP address 151.25.255.9, port 179, using TCP/IP)

Which devices receive what information from the controller depends on a number of things. If a device queries the controller, it will receive the response unless it explicitly tells the controller to send it to another device. If the command that generates a response is part of a downloaded program, the response will route to whichever port is specified as the default (unless explicitly told to go to another port with the CF command). To designate a specific destination for the information, add {Eh} to the end of the command. (Ex. MG{EC}"Hello" will send the message "Hello" to handle #3. TP,,?{EF} will send the z axis position to handle #6.)

Multicasting

A multicast may only be used in UDP/IP and is similar to a broadcast (where everyone on the network gets the information) but specific to a group. In other words, all devices within a specified group will receive the information that is sent in a multicast. There can be many multicast groups on a network and are differentiated by their multicast IP address. To communicate with all the devices in a specific multicast group, the information can be sent to the multicast IP address rather than to each individual device IP address. All Galil controllers belong to a default multicast address of 239.255.19.56. The controller's multicast IP address can be changed by using the IA> u command.

Using Third Party Software

Galil supports DHCP, ARP, BOOT-P, and Ping which are utilities for establishing Ethernet connections. DHCP is a protocol used by networked devices (clients) to obtain the parameters necessary for operation in an Internet Protocol network. ARP is an application that determines the Ethernet (hardware) address of a device at a specific IP address. BOOT-P is an application that determines which devices on the network do not have an IP address and assigns the

IP address you have chosen to it. Ping is used to check the communication between the device at a specific IP address and the host computer.

The DMC-41x3 can communicate with a host computer through any application that can send TCP/IP or UDP/IP packets. A good example of this is Telnet, a utility that comes with most Windows systems.

Modbus

An additional protocol layer is available for speaking to I/O devices. Modbus is an RS-485 protocol that packages information in binary packets that are sent as part of a TCP/IP packet. In this protocol, each slave has a 1 byte slave address. The DMC-41x3 can use a specific slave address or default to the handle number. The port number for Modbus is 502.

The Modbus protocol has a set of commands called function codes. The DMC-41x3 supports the 10 major function codes:

Function Code	Definition
01	Read Coil Status (Read Bits)
02	Read Input Status (Read Bits)
03	Read Holding Registers (Read Words)
04	Read Input Registers (Read Words)
05	Force Single Coil (Write One Bit)
06	Preset Single Register (Write One Word)
07	Read Exception Status (Read Error Code)
15	Force Multiple Coils (Write Multiple Bits)
16	Preset Multiple Registers (Write Words)
17	Report Slave ID

The DMC-41x3 provides three levels of Modbus communication. The first level allows the user to create a raw packet and receive raw data. It uses the MBh command with a function code of -1. The format of the command is

MBh = -1,len,array[] where len is the number of bytes
array[] is the array with the data

The second level incorporates the Modbus structure. This is necessary for sending configuration and special commands to an I/O device. The formats vary depending on the function code that is called. For more information refer to the Command Reference.

The third level of Modbus communication uses standard Galil commands. Once the slave has been configured, the commands that may be used are @IN[], @AN[], SB, CB, OB, and AO. For example, AO 2020,8.2 would tell I/O number 2020 to output 8.2 volts.

If a specific slave address is not necessary, the I/O number to be used can be calculated with the following:

$$\text{I/O Number} = (\text{HandleNum} * 1000) + ((\text{Module}-1)*4) + (\text{BitNum}-1)$$

Where HandleNum is the handle number from 1 (A) to 8 (8). Module is the position of the module in the rack from 1 to 16. BitNum is the I/O point in the module from 1 to 4.

Modbus Examples

Example #1

DMC-4143 connected as a Modbus master to a RIO-47120 via Modbus. The DMC-4143 will set or clear all 16 of the RIO's digital outputs

1. Begin by opening a connection to the RIO which in our example has IP address 192.168.1.120

IHB=192,168,1,120<502>2

(Issued to DMC-4143)

- Dimension an array to store the commanded values. Set array element 0 equal to 170 and array element 1 equal to 85. (array element 1 configures digital outputs 15-8 and array element 0 configures digital outputs 7-0)

```
DM myarray[2]
myarray[0] = 170
myarray[1] = 85
```

(which is 10101010 in binary)

(which is 01010101 in binary)

3. a) Send the appropriate MB command. Use function code 15. Start at output 0 and set/clear all 16 outputs based on the data in myarray[]

```
MBB=,15,0,16,myarray[]
```

3. b) Set the outputs using the SB command.

SB2001;SB2003;SB2005;SB2007;SB2008;SB2010;SB2012;SB2014;

Results:

Both steps 3a and 3b will result in outputs being activated as below. The only difference being that step 3a will set and clear all 16 bits where as step 3b will only set the specified bits and will have no affect on the others.

Bit Number	Status
0	0
1	1
2	0
3	1
4	0
5	1
6	0
7	1

Bit Number	Status
8	1
9	0
10	1
11	0
12	1
13	0
14	1
15	0

Example #2

DMC-4143 connected as a Modbus master to a 3rd party PLC. The DMC-4143 will read the value of analog inputs 3 and 4 on the PLC located at addresses 40006 and 40008 respectively. The PLC stores values as 32-bit floating point numbers which is common.

1. Begin by opening a connection to the PLC which has an IP address of 192.168.1.10 in our example

IHB=192, 168, 1, 10<502>2

- ## 2. Dimension an array to store the results

DM myanalog [4]

- Send the appropriate MB command. Use function code 4 (as specified per the PLC). Start at address 40006. Retrieve 4 modbus registers (2 modbus registers per 1 analog input, as specified by the PLC)

```
MBB=,4,40006,4,myanalog[]
```

Results:

Array elements 0 and 1 will make up the 32 bit floating point value for analog input 3 on the PLC and array elements 2 and 3 will combine for the value of analog input 4.

```
myanalog[0]=16412=0x401C
myanalog[1]=52429=0xCCCCD
myanalog[2]=49347=0xC0C3
myanalog[3]=13107=0x3333
```

Analog input 3 = 0x401CCCCD = 2.45V

Analog input 4 = 0xC0C33333 = -6.1V

Example #3

DMC-4143 connected as a Modbus master to a hydraulic pump. The DMC-4143 will set the pump pressure by writing to an analog output on the pump located at Modbus address 30000 and consisting of 2 Modbus registers forming a 32 bit floating point value.

- Begin by opening a connection to the pump which has an IP address of 192.168.1.100 in our example

```
IHB=192,168,1,100<502>2
```

- Dimension and fill an array with values that will be written to the PLC

```
DM pump[2]
pump[0]=16531=0x4093
pump[1]=13107=0x3333
```

- Send the appropriate MB command. Use function code 16. Start at address 30000 and write to 2 registers using the data in the array pump[]

```
MBB=,16,30000,2,pump[]
```

Results:

Analog output will be set to 0x40933333 which is 4.6V

To view an example procedure for communicating with an OPTO-22 rack, refer to Example- Communicating with OPTO-22 SNAP-B3000-ENET in the Appendices.

Data Record

The DMC-41x3 can provide a binary block of status information with the use of the QR and DR commands. These commands, along with the QZ command can be very useful for accessing complete controller status. The QR command will return 4 bytes of header information and specific blocks of information as specified by the command arguments:

QR ABCDEFGHST

Each argument corresponds to a block of information according to the Data Record Map below. If no argument is given, the entire data record map will be returned. Note that the data record size will depend on the number of axes.

The following is the byte map for the binary data.

NOTE: UB = Unsigned Byte (1), UW = Unsigned Word (2), SW = Signed Word (2), SL = Signed Long Record (4), UL = Unsigned Long (4)

ADDR	TYPE	ITEM
00	UB	1 st Byte of Header
01	UB	2 nd Byte of Header
02	UB	3 rd Byte of Header
03	UB	4 th Byte of Header
04-05	UW	sample number
06	UB	general input block 0 (inputs 1-8)
07	UB	general input block 1 (inputs 9-16)
08	UB	general input block 2 (inputs 17-24)
09	UB	general input block 3 (inputs 25-32)
10	UB	general input block 4 (inputs 33-40)
11	UB	general input block 5 (inputs 41-48)
12	UB	general input block 6 (inputs 49-56)
13	UB	general input block 7 (inputs 57-64)
14	UB	general input block 8 (inputs 65-72)
15	UB	general input block 9 (inputs 73-80)
16	UB	general output block 0 (outputs 1-8)
17	UB	general output block 1 (outputs 9-16)
18	UB	general output block 2 (outputs 17-24)
19	UB	general output block 3 (outputs 25-32)
20	UB	general output block 4 (outputs 33-40)
21	UB	general output block 5 (outputs 41-48)
22	UB	general output block 6 (outputs 49-56)
23	UB	general output block 7 (outputs 57-64)
24	UB	general output block 8 (outputs 65-72)
25	UB	general output block 9 (outputs 73-80)
26-27	SW	Reserved
28-29	SW	Reserved
30-31	SW	Reserved
32-33	SW	Reserved
34-35	SW	Reserved
36-37	SW	Reserved
38-39	SW	Reserved
40-41	SW	Reserved
42	UB	Ethernet Handle A Status
43	UB	Ethernet Handle B Status
44	UB	Ethernet Handle C Status
45	UB	Ethernet Handle D Status
46	UB	Ethernet Handle E Status
47	UB	Ethernet Handle F Status
48	UB	Ethernet Handle G Status
49	UB	Ethernet Handle H Status

50	UB	error code
51	UB	thread status – see bit field map below
52-55	UL	Amplifier Status
56-59	UL	Segment Count for Contour Mode
60-61	UW	Buffer space remaining – Contour Mode
62-63	UW	segment count of coordinated move for S plane
64-65	UW	coordinated move status for S plane – see bit field map below
66-69	SL	distance traveled in coordinated move for S plane
70-71	UW	Buffer space remaining – S Plane
72-73	UW	segment count of coordinated move for T plane
74-75	UW	Coordinated move status for T plane – see bit field map below
76-79	SL	distance traveled in coordinated move for T plane
80-81	UW	Buffer space remaining – T Plane
Axis information:		
82-83	UW	A axis status – see bit field map below
84	UB	A axis switches – see bit field map below
85	UB	A axis stop code
86-89	SL	A axis reference position
90-93	SL	A axis motor position
94-97	SL	A axis position error
98-101	SL	A axis auxiliary position
102-105	SL	A axis velocity
106-109	SL	A axis torque
110-111	SW or UW ¹	A axis analog input
112	UB	A Hall Input Status
113	UB	Reserved
114-117	SL	A User defined variable (ZA)
118-119	UW	B axis status – see bit field map below
120	UB	B axis switches – see bit field map below
121	UB	B axis stop code
122-125	SL	B axis reference position
126-129	SL	B axis motor position
130-133	SL	B axis position error
134-137	SL	B axis auxiliary position
138-141	SL	B axis velocity
142-145	SL	B axis torque
146-147	SW or UW ¹	B axis analog input
148	UB	B Hall Input Status
149	UB	Reserved
150-153	SL	B User defined variable (ZA)
154-155	UW	C axis status – see bit field map below
156	UB	C axis switches – see bit field map below
157	UB	C axis stop code
158-161	SL	C axis reference position
162-165	SL	C axis motor position

166-169	SL	C axis position error
170-173	SL	C axis auxiliary position
174-177	SL	C axis velocity
178-181	SL	C axis torque
182-183	SW or UW ¹	C axis analog input
184	UB	C Hall Input Status
185	UB	Reserved
186-189	SL	C User defined variable (ZA)
190-191	UW	D axis status – see bit field map below
192	UB	D axis switches – see bit field map below
193	UB	D axis stop code
194-197	SL	D axis reference position
198-201	SL	D axis motor position
202-205	SL	D axis position error
206-209	SL	D axis auxiliary position
210-213	SL	D axis velocity
214-217	SL	D axis torque
218-219	SW or UW ¹	D axis analog input
220	UB	D Hall Input Status
221	UB	Reserved
222-225	SL	D User defined variable (ZA)
226-227	UW	E axis status – see bit field map below
228	UB	E axis switches – see bit field map below
229	UB	E axis stop code
230-233	SL	E axis reference position
234-237	SL	E axis motor position
238-241	SL	E axis position error
242-245	SL	E axis auxiliary position
246-249	SL	E axis velocity
250-253	SL	E axis torque
254-255	SW or UW ¹	E axis analog input
256	UB	E Hall Input Status
257	UB	Reserved
258-261	SL	E User defined variable (ZA)
262-263	UW	F axis status – see bit field map below
264	UB	F axis switches – see bit field map below
265	UB	F axis stop code
266-269	SL	F axis reference position
270-273	SL	F axis motor position
274-277	SL	F axis position error
278-281	SL	F axis auxiliary position
282-285	SL	F axis velocity
286-289	SL	F axis torque
290-291	SW or UW ¹	F axis analog input

292	UB	F Hall Input Status
293	UB	Reserved
294-297	SL	F User defined variable (ZA)
298-299	UW	G axis status – see bit field map below
300	UB	G axis switches – see bit field map below
301	UB	G axis stop code
302-305	SL	G axis reference position
306-309	SL	G axis motor position
310-313	SL	G axis position error
314-317	SL	G axis auxiliary position
318-321	SL	G axis velocity
322-325	SL	G axis torque
326-327	SW or UW ¹	G axis analog input
328	UB	G Hall Input Status
329	UB	Reserved
330-333	SL	G User defined variable (ZA)
334-335	UW	H axis status – see bit field map below
336	UB	H axis switches – see bit field map below
337	UB	H axis stop code
338-341	SL	H axis reference position
342-345	SL	H axis motor position
346-349	SL	H axis position error
350-353	SL	H axis auxiliary position
354-357	SL	H axis velocity
358-361	SL	H axis torque
362-363	SW or UW ¹	H axis analog input
364	UB	H Hall Input Status
365	UB	Reserved
366-369	SL	H User defined variable (ZA)

1 Will be either a Signed Word or Unsigned Word depending upon AQ setting. See AQ in the Command Reference for more information.

Explanation Data Record Bit Fields

Header Information - Byte 0, 1 of Header:

BIT 15	BIT 14	BIT 13	BIT 12	BIT 11	BIT 10	BIT 9	BIT 8
1	N/A	N/A	N/A	N/A	I Block Present in Data Record	T Block Present in Data Record	S Block Present in Data Record
BIT 7	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0
H Block Present in Data Record	G Block Present in Data Record	F Block Present in Data Record	E Block Present in Data Record	D Block Present in Data Record	C Block Present in Data Record	B Block Present in Data Record	A Block Present in Data Record

Bytes 2, 3 of Header:

Bytes 2 and 3 make a word which represents the Number of bytes in the data record, including the header.

Byte 2 is the low byte and byte 3 is the high byte

NOTE: The header information of the data records is formatted in little endian (reversed network byte order).

Thread Status (1 Byte)

BIT 7	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0
Thread 7 Running	Thread 6 Running	Thread 5 Running	Thread 4 Running	Thread 3 Running	Thread 2 Running	Thread 1 Running	Thread 0 Running

Coordinated Motion Status for S or T Plane (2 Byte)

BIT 15	BIT 14	BIT 13	BIT 12	BIT 11	BIT 10	BIT 9	BIT 8
Move in Progress	N/A	N/A	N/A	N/A	N/A	N/A	N/A

BIT 7	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0
N/A	N/A	Motion is slewing	Motion is stopping due to ST or Limit Switch	Motion is making final decel.	N/A	N/A	N/A

Axis Status (1 Word)

BIT 15	BIT 14	BIT 13	BIT 12	BIT 11	BIT 10	BIT 9	BIT 8
Move in Progress	Mode of Motion PA or PR	Mode of Motion PA only	(FE) Find Edge in Progress	Home (HM) in Progress	1 st Phase of HM complete	2 nd Phase of HM complete or FI command issued	Mode of Motion Coord. Motion

BIT 7	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0
Negative Direction Move	Mode of Motion Contour	Motion is slewing	Motion is stopping due to ST of Limit Switch	Motion is making final decel.	Latch is armed	3rd Phase of HM in Progress	Motor Off

Axis Switches (1 Byte)

BIT 7	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0
Latch Occurred	State of Latch Input	N/A	N/A	State of Forward Limit	State of Reverse Limit	State of Home Input	Stepper Mode

Notes Regarding Velocity and Torque Information

The velocity information that is returned in the data record is 64 times larger than the value returned when using the command TV (Tell Velocity). See command reference for more information about TV.

The Torque information is represented as a number in the range of +/-32767. Maximum negative torque is -32767. Maximum positive torque is 32767. Zero torque is 0.

QZ Command

The QZ command can be very useful when using the QR command, since it provides information about the controller and the data record. The QZ command returns the following 4 bytes of information.

BYTE #	INFORMATION
0	Number of axes present
1	number of bytes in general block of data record
2	number of bytes in coordinate plane block of data record
3	Number of Bytes in each axis block of data record

GalilTools (Windows and Linux)

GalilTools is Galil's set of software tools for current Galil controllers. It is highly recommended for all first-time purchases of Galil controllers as it provides easy set-up, tuning and analysis. GalilTools replaces the WSDK Tuning software with an improved user-interface, real-time scopes and communications utilities.

The Galil Tools set contains the following tools: Scope, Editor, Terminal, Watch and Tuner, and a Communication Library for development with Galil Controllers.

The powerful Scope Tool is ideal for system analysis as it captures numerous types of data for each axis in real-time. Up to eight channels of data can be displayed at once, and additional real-time data can be viewed by changing the scope settings. This allows literally hundreds of parameters to be analyzed during a single data capture sequence. A rising or falling edge trigger feature is also included for precise synchronization of data.

The Program Editor Tool allows for easy writing of application programs and multiple editors to be open simultaneously.

The Terminal Tool provides a window for sending and receiving Galil commands and responses.

The Watch Tool displays controller parameters in a tabular format and includes units and scale factors for easy viewing.

The Tuning Tool helps select PID parameters for optimal servo performance.

The Communication Library provides function calls for communicating to Galil Controllers with C++ (Windows and Linux) and COM enabled languages such as VB C#, and Labview (Windows only).

GalilTools runs on Windows and Linux platforms as standard with other platforms available on request.

GalilTools-Lite is available at no charge and contains the Editor, Terminal, Watch and Communcition Library tools only.

The latest version of GalilTools can be downloaded from the Galil website at:

<http://www.galilmc.com/products/software/galitools.html>

For information on using GalilTools see the help menu in GalilTools, or the GalilTools user manual.

<http://www.galilmc.com/support/manuals/galitools/index.html>

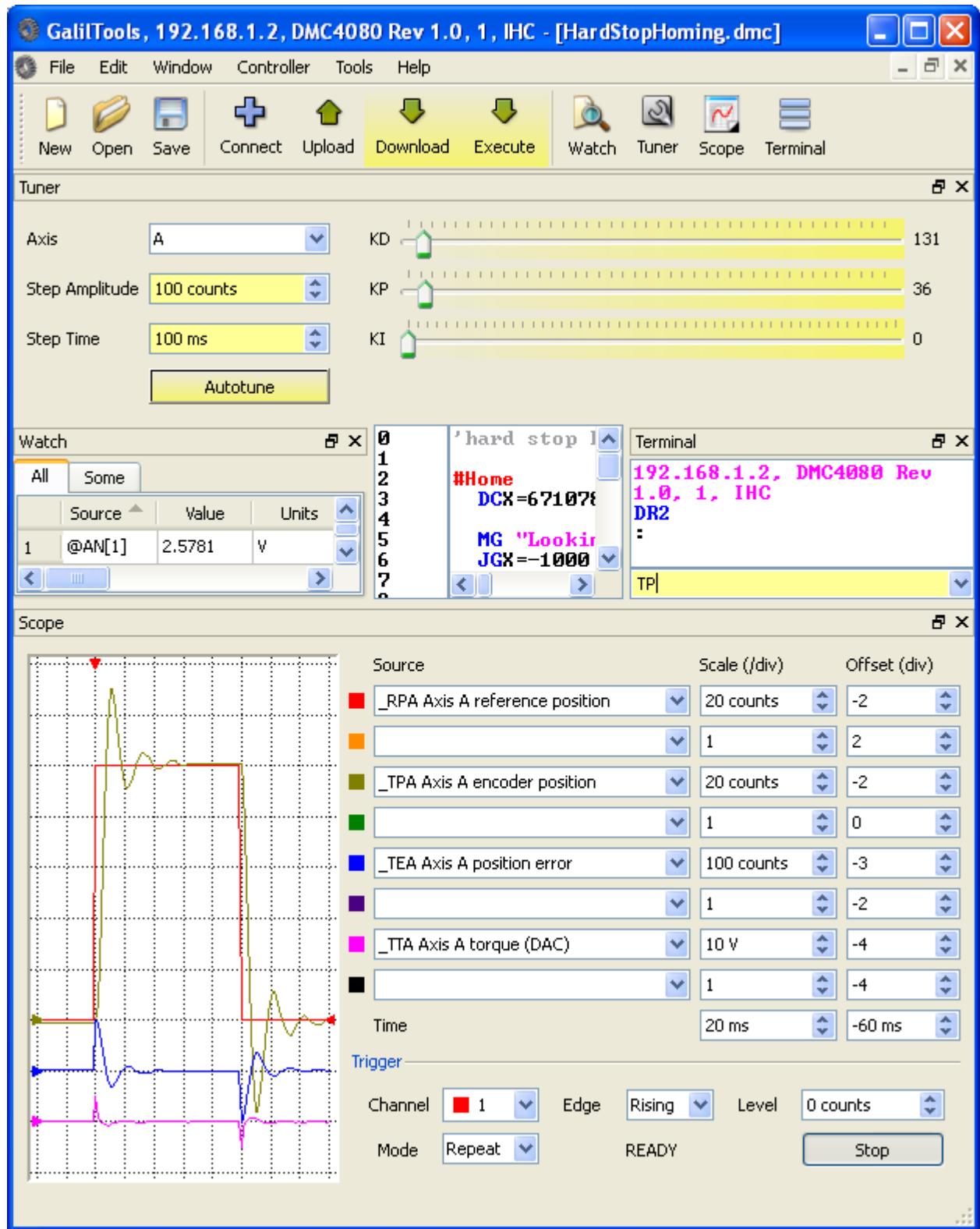


Figure 4.1: GalilTools Screen Capture

Creating Custom Software Interfaces

GalilTools provides a programming API so that users can develop their own custom software interfaces to a Galil controller. Information on this GalilTools Communication Library can be found in the GalilTools manual.

<http://www.galilmc.com/support/manuals/galitools/library.html>

HelloGalil – Quick Start to PC programming

For programmers developing Windows applications that communicate with a Galil controller, the HelloGalil library of quick start projects immediately gets you communicating with the controller from the programming language of your choice. In the "Hello World" tradition, each project contains the bare minimum code to demonstrate communication to the controller and simply prints the controller's model and serial numbers to the screen (Figure 4.2):

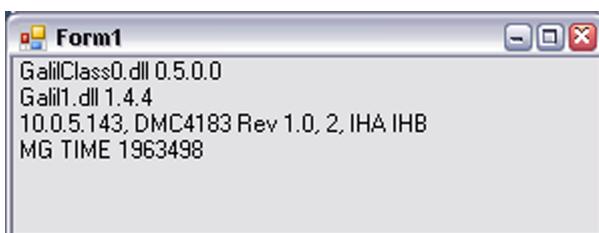


Figure 4.2: Sample program output

http://www.galilmc.com/support/hello_galil.html

GalilTools Communication Libraries

The GalilTools Communication Library (Galil class) provides methods for communication with a Galil motion controller over Ethernet, USB, RS-232 or PCI buses. It consists of a native C++ Library and a similar COM interface which extends compatibility to Windows programming languages (e.g. VB, C#, etc).

A Galil object (usually referred to in sample code as "g") represents a single connection to a Galil controller.

For Ethernet controllers, which support more than one connection, multiple objects may be used to communicate with the controller. An example of multiple objects is one Galil object containing a TCP handle to a DMC-41x3 for commands and responses, and one Galil object containing a UDP handle for unsolicited messages from the controller. If [recordsStart\(\)](#) is used to begin the automatic data record function, the library will open an additional UDP handle to the controller (transparent to the user).

The library is conceptually divided into six categories:

1. Connecting and Disconnecting - functions to establish and discontinue communication with a controller.
2. Basic Communication - The most heavily used functions for command-and-response and unsolicited messages.
3. Programs - Downloading and uploading embedded programs.
4. Arrays - Downloading and uploading array data.
5. Advanced - Lesser-used calls.
6. Data Record - Access to the data record in both synchronous and asynchronous modes.

C++ Library (Windows and Linux)

Both Full and Lite versions of GalilTools ship with a native C++ communication library. The Linux version (libGalil.so) is compatible with g++ and the Windows version (Galil1.dll) with Visual C++ 2008. Contact Galil if another version of the C++ library is required. See the [getting started guide](#) and the hello.cpp example in /lib.

COM (Windows)

To further extend the language compatibility on Windows, a COM (Component Object Model) class built on top of the C++ library is also provided with Windows releases. This COM wrapper can be used in any language and IDE supporting COM (Visual Studio 2005, 2008, etc). The COM wrapper includes all of the functionality of the base C++ class. See the [getting started guide](#) and the hello.* examples in \lib for more info.

For more information on the GalilTools Communications Library, see the online user manual.

<http://www.galilmc.com/support/manuals/galiltools/library.html>

Chapter 5 Command Basics

Introduction

The DMC-41x3 provides over 100 commands for specifying motion and machine parameters. Commands are included to initiate action, interrogate status and configure the digital filter. These commands are sent in ASCII.

The DMC-41x3 instruction set is BASIC-like and easy to use. Instructions consist of two uppercase letters that correspond phonetically with the appropriate function. For example, the instruction BG begins motion, and ST stops the motion.

Commands can be sent "live" over the communications port for immediate execution by the DMC-41x3, or an entire group of commands can be downloaded into the DMC-41x3 memory for execution at a later time. Combining commands into groups for later execution is referred to as Applications Programming and is discussed in the following chapter.

This section describes the DMC-41x3 instruction set and syntax. A summary of commands as well as a complete listing of all DMC-41x3 instructions is included in the *Command Reference*.

<http://www.galilmc.com/support/manuals.php>

Command Syntax - ASCII

DMC-41x3 instructions are represented by two ASCII upper case characters followed by applicable arguments. A space may be inserted between the instruction and arguments. A semicolon or <return> is used to terminate the instruction for processing by the DMC-41x3 command interpreter.

NOTE: If you are using a Galil terminal program, commands will not be processed until an <return> command is given. This allows the user to separate many commands on a single line and not begin execution until the user gives the <return> command.

IMPORTANT: All DMC-41x3 commands are sent in upper case.

For example, the command

PR 4000 <return> Position relative

Implicit Notation

PR is the two character instruction for position relative. 4000 is the argument which represents the required position value in counts. The <return> terminates the instruction. The space between PR and 4000 is optional.

For specifying data for the A,B,C and D axes, commas are used to separate the axes. If no data is specified for an axis, a comma is still needed as shown in the examples below. If no data is specified for an axis, the previous value is maintained.

To view the current values for each command, type the command followed by a ? for each axis requested.

PR 1000	Specify A only as 1000
PR ,2000	Specify B only as 2000
PR ,,3000	Specify C only as 3000
PR ,,,4000	Specify D only as 4000
PR 2000, 4000,6000, 8000	Specify A,B,C and D
PR ,8000,,9000	Specify B and D only
PR ?,?,?,?	Request A,B,C,D values
PR ,?	Request B value only

Explicit Notation

The DMC-41x3 provides an alternative method for specifying data. Here data is specified individually using a single axis specifier such as A, B, C or D. An equals sign is used to assign data to that axis. For example:

PRA=1000	Specify a position relative movement for the A axis of 1000
ACB=200000	Specify acceleration for the B axis as 200000

Instead of data, some commands request action to occur on an axis or group of axes. For example, ST AB stops motion on both the A and B axes. Commas are not required in this case since the particular axis is specified by the appropriate letter A, B, C or D. If no parameters follow the instruction, action will take place on all axes. Here are some examples of syntax for requesting action:

BG A	Begin A only
BG B	Begin B only
BG ABCD	Begin all axes
BG BD	Begin B and D only
BG	Begin all axes

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For controllers with 5 or more axes, the axes are referred to as A,B,C,D,E,F,G,H. The specifiers X,Y,Z,W and A,B,C,D may be used interchangeably.

BG ABCDEFGH	Begin all axes
BG D	Begin D only

Coordinated Motion with more than 1 axis

When requesting action for coordinated motion, the letter S or T is used to specify the coordinated motion. This allows for coordinated motion to be setup for two separate coordinate systems. Refer to the CA command in the Command Reference for more information on specifying a coordinate system. For example:

BG S	Begin coordinated sequence, S
BG TD	Begin coordinated sequence, T, and D axis

Controller Response to DATA

The DMC-41x3 returns a : for valid commands and a ? for invalid commands.

For example, if the command BG is sent in lower case, the DMC-41x3 will return a ?.

:bg invalid command, lower case

? DMC-41x3 returns a ?

When the controller receives an invalid command the user can request the error code. The error code will specify the reason for the invalid command response. To request the error code type the command TC1. For example:

?TC1	Tell Code command
1 Unrecognized	Returned response

There are many reasons for receiving an invalid command response. The most common reasons are: unrecognized command (such as typographical entry or lower case), command given at improper time (such as during motion), or a command out of range (such as exceeding maximum speed). A complete listing of all codes is listed in the TC command in the Command Reference section.

Interrogating the Controller

Interrogation Commands

The DMC-41x3 has a set of commands that directly interrogate the controller. When the command is entered, the requested data is returned in decimal format on the next line followed by a carriage return and line feed. The format of the returned data can be changed using the Position Format (PF), Variable Format (VF) and Leading Zeros (LZ) command. See Chapter 7 Application Programming and the Command Reference.

Summary of Interrogation Commands

RP	Report Command Position
RL	Report Latch
^R ^V	Firmware Revision Information
SC	Stop Code
TA	Tell Amplifier Error
TB	Tell Status
TC	Tell Error Code
TD	Tell Dual Encoder
TE	Tell Error
TI	Tell Input
TP	Tell Position
TR	Trace
TS	Tell Switches
TT	Tell Torque
TV	Tell Velocity

For example, the following example illustrates how to display the current position of the X axis:

TP A	Tell position A
0	Controllers Response
TP AB	Tell position A and B
0,0	Controllers Response

Interrogating Current Commanded Values.

Most commands can be interrogated by using a question mark (?) as the axis specifier. Type the command followed by a ? for each axis requested.

PR ?,?,?,?

Request A,B,C,D values

PR ,?

Request B value only

The controller can also be interrogated with operands.

Operands

Most DMC-41x3 commands have corresponding operands that can be used for interrogation. Operands must be used inside of valid DMC expressions. For example, to display the value of an operand, the user could use the command:

MG 'operand' where 'operand' is a valid DMC operand

All of the command operands begin with the underscore character (_). For example, the value of the current position on the A axis can be assigned to the variable 'V' with the command:

V=_TPA

The Command Reference denotes all commands which have an equivalent operand as "Operand Usage". Also, see description of operands in Chapter 7 Application Programming.

Command Syntax – Binary (advanced)

Some commands have an equivalent binary value. Binary communication mode can be executed about 20% faster than ASCII commands. Binary format can only be used when commands are sent from the PC and cannot be embedded in an application program.

Binary Command Format

All binary commands have a 4 byte header and is followed by data fields. The 4 bytes are specified in hexadecimal format.

Header Format:

Byte 1 specifies the command number between 80 to FF. The complete binary command number table is listed below.

Byte 2 specifies the # of bytes in each field as 0,1,2,4 or 6 as follows:

00	No data fields (i.e. SH or BG)
01	One byte per field
02	One word (2 bytes per field)
04	One long word (4 bytes) per field
06	Galil real format (4 bytes integer and 2 bytes fraction)

Byte 3 specifies whether the command applies to a coordinated move as follows:

00	No coordinated motion movement
01	Coordinated motion movement

For example, the command STS designates motion to stop on a vector move, S coordinate system. The third byte for the equivalent binary command would be 01.

Byte 4 specifies the axis # or data field as follows

- Bit 7 = H axis or 8th data field
- Bit 6 = G axis or 7th data field
- Bit 5 = F axis or 6th data field
- Bit 4 = E axis or 5th data field
- Bit 3 = D axis or 4th data field
- Bit 2 = C axis or 3rd data field
- Bit 1 = B axis or 2nd data field
- Bit 0 = A axis or 1st data field

Data fields Format

Data fields must be consistent with the format byte and the axes byte. For example, the command PR 1000,, -500 would be :

A7 02 00 05 03 E8 FE 0C

where A7 is the command number for PR

02 specifies 2 bytes for each data field

00 S is not active for PR

05 specifies bit 0 is active for A axis and bit 2 is active for C axis ($2^0 + 2^2 = 5$)

03 E8 represents 1000

FE OC represents -500

Example

The command ST XYZS would be :

A1 00 01 07

where A1 is the command number for ST

00 specifies 0 data fields

01 specifies stop the coordinated axes S

07 specifies stop X (bit 0), Y (bit 1) and Z (bit 2) $2^0 + 2^1 + 2^3 = 7$

Binary command table

Command	No.	Command	No.	Command	No.
reserved	80	reserved	ab	reserved	d6
KP	81	reserved	ac	reserved	d7
KI	82	reserved	ad	RP	d8
KD	83	reserved	ae	TP	d9
DV	84	reserved	af	TE	da
AF	85	LM	b0	TD	db
KS	86	LI	b1	TV	dc
PL	87	VP	b2	RL	dd
ER	88	CR	b3	TT	de
IL	89	TN	b4	TS	df
TL	8a	LE, VE	b5	TI	e0
MT	8b	reserved	b6	SC	e1
CE	8c	VA	b7	reserved	e2
OE	8d	VD	b8	reserved	e3
FL	8e	VS	b9	reserved	e4
BL	8f	VR	ba	TM	e5
AC	90	reserved	bb	CN	e6
DC	91	reserved	bc	LZ	e7
SP	92	CM	bd	OP	e8
IT	93	CD	be	OB	e9
FA	94	DT	bf	SB	ea
FV	95	ET	c0	CB	eb
GR	96	EM	c1	II	ec
DP	97	EP	c2	EI	ed
DE	98	EG	c3	AL	ee

OF	99	EB	c4	reserved	ef
GM	9a	EQ	c5	reserved	f0
reserved	9b	EC	c6	reserved	f1
reserved	9c	reserved	c7	reserved	f2
reserved	9d	AM	c8	reserved	f3
reserved	9e	MC	c9	reserved	f4
reserved	9f	TW	ca	reserved	f5
BG	a0	MF	cb	reserved	f6
ST	a1	MR	cc	reserved	f7
AB	a2	AD	cd	reserved	f8
HM	a3	AP	ce	reserved	f9
FE	a4	AR	cf	reserved	fa
FI	a5	AS	d0	reserved	fb
PA	a6	AI	d1	reserved	fc
PR	a7	AT	d2	reserved	fd
JG	a8	WT	d3	reserved	fe
MO	a9	reserved	d4	reserved	ff
SH	aa	reserved	d5		

Chapter 6 Programming Motion

Overview

The DMC-41x3 provides several modes of motion, including independent positioning and jogging, coordinated motion, electronic cam motion, and electronic gearing. Each one of these modes is discussed in the following sections.

The DMC-4113 are single axis controllers and use X-axis motion only. Likewise, the DMC-4123 use X and Y, the DMC-4133 use X,Y, and Z, and the DMC-4143 use X,Y,Z, and W. The DMC-4153 use A,B,C,D, and E. The DMC-4163 use A,B,C,D,E, and F. The DMC-4173 use A,B,C,D,E,F, and G. The DMC-4183 use the axes A,B,C,D,E,F,G, and H.

The example applications described below will help guide you to the appropriate mode of motion.

4183

For controllers with 5 or more axes, the specifiers, ABCDEFGH, are used. XYZ and W may be interchanged with ABCD.

EXAMPLE APPLICATION	MODE OF MOTION	COMMANDS
Absolute or relative positioning where each axis is independent and follows prescribed velocity profile.	Independent Axis Positioning	PA,PR SP,AC,DC
Velocity control where no final endpoint is prescribed. Motion stops on Stop command.	Independent Jogging	JG AC,DC ST
Absolute positioning mode where absolute position targets may be sent to the controller while the axis is in motion.	Position Tracking	PA, PT SP AC, DC
Motion Path described as incremental position points versus time.	Contour Mode	CM CD DT
Motion Path described as incremental position, velocity and delta time	PVT Mode	PV BT
2 to 8 axis coordinated motion where path is described by linear segments.	Linear Interpolation Mode	LM LI, LE VS,VR VA,VD

2-D motion path consisting of arc segments and linear segments, such as engraving or quilting.	Vector Mode: Linear and Circular Interpolation Motion	VM VP CR VS,VR VA,VD VE
Third axis must remain tangent to 2-D motion path, such as knife cutting.	Vector Mode: Linear and Circular Interpolation Motion with Tangent Motion:	VM VP CR VS,VA,VD TN VE
Electronic gearing where slave axes are scaled to master axis which can move in both directions.	Electronic Gearing	GA GD _GP GR GM (if gantry)
Master/slave where slave axes must follow a master such as conveyer speed.	Electronic Gearing and Ramped Gearing	GA GD _GP GR
Moving along arbitrary profiles or mathematically prescribed profiles such as sine or cosine trajectories.	Contour Mode	CM CD DT
Teaching or Record and Play Back	Contour Mode with Teach (Record and Play-Back)	CM CD DT RA RD RC
Backlash Correction	Dual Loop (Auxiliary Encoder)	DV
Following a trajectory based on a master encoder position	Electronic Cam	EA EM EP ET EB EG EQ
Smooth motion while operating in independent axis positioning	Motion Smoothing	IT
Smooth motion while operating in vector or linear interpolation positioning	Motion Smoothing	IT
Smooth motion while operating with stepper motors	Stepper Motion Smoothing	KS
Gantry - two axes are coupled by gantry	Electronic Gearing - Example - Gantry Mode	GR GM

Independent Axis Positioning

In this mode, motion between the specified axes is independent, and each axis follows its own profile. The user specifies the desired absolute position (PA) or relative position (PR), slew speed (SP), acceleration ramp (AC), and deceleration ramp (DC), for each axis. On begin (BG), the DMC-41x3 profiler generates the corresponding trapezoidal or triangular velocity profile and position trajectory. The controller determines a new command position along the trajectory every sample period until the specified profile is complete. Motion is complete when the last position command is sent by the DMC-41x3 profiler. Note: The actual motor motion may not be complete when the profile has been completed, however, the next motion command may be specified.

The Begin (BG) command can be issued for all axes either simultaneously or independently. XYZ or W axis specifiers are required to select the axes for motion. When no axes are specified, this causes motion to begin on all axes.

The speed (SP) and the acceleration (AC) can be changed at any time during motion, however, the deceleration (DC) and position (PR or PA) cannot be changed until motion is complete. Remember, motion is complete when the profiler is finished, not when the actual motor is in position. The Stop command (ST) can be issued at any time to decelerate the motor to a stop before it reaches its final position.

An incremental position movement (IP) may be specified during motion as long as the additional move is in the same direction. Here, the user specifies the desired position increment, n. The new target is equal to the old target plus the increment, n. Upon receiving the IP command, a revised profile will be generated for motion towards the new end position. The IP command does not require a begin. Note: If the motor is not moving, the IP command is equivalent to the PR and BG command combination.

Command Summary - Independent Axis

COMMAND	DESCRIPTION
PR x,y,z,w	Specifies relative distance
PA x,y,z,w	Specifies absolute position
SP x,y,z,w	Specifies slew speed
AC x,y,z,w	Specifies acceleration rate
DC x,y,z,w	Specifies deceleration rate
BG XYZW	Starts motion
ST XYZW	Stops motion before end of move
IP x,y,z,w	Changes position target
IT x,y,z,w	Time constant for independent motion smoothing
AM XYZW	Trippoint for profiler complete
MC XYZW	Trippoint for “in position”

The lower case specifiers (x,y,z,w) represent position values for each axis.

The DMC-41x3 also allows use of single axis specifiers such as PRY=2000

Operand Summary - Independent Axis

OPERAND	DESCRIPTION
_ACx	Return acceleration rate for the axis specified by ‘x’
_DCx	Return deceleration rate for the axis specified by ‘x’

<u>_SPx</u>	Returns the speed for the axis specified by 'x'
<u>_PAx</u>	Returns current destination if 'x' axis is moving, otherwise returns the current commanded position if in a move.
<u>_PRx</u>	Returns current incremental distance specified for the 'x' axis

Example - Absolute Position Movement

```

PA 10000,20000      Specify absolute X,Y position
AC 1000000,1000000   Acceleration for X,Y
DC 1000000,1000000   Deceleration for X,Y
SP 50000,30000       Speeds for X,Y
BG XY                 Begin motion

```

Example - Multiple Move Sequence

Required Motion Profiles:

X-Axis	500 counts	Position
	20000 count/sec	Speed
	500000 counts/sec ²	Acceleration
Y-Axis	1000 counts	Position
	10000 count/sec	Speed
	500000 counts/sec ²	Acceleration
Z-Axis	100 counts	Position
	5000 counts/sec	Speed
	500000 counts/sec ²	Acceleration

This example will specify a relative position movement on X, Y and Z axes. The movement on each axis will be separated by 20 msec Figure 6.1 shows the velocity profiles for the X,Y and Z axis.

```

#A                      Begin Program
PR 2000,500,100        Specify relative position movement of 2000, 500 and 100 counts for X,Y and Z axes.
SP 20000,10000,5000    Specify speed of 20000, 10000, and 5000 counts / sec
AC 500000,500000,500000 Specify acceleration of 500000 counts / sec2 for all axes
DC 500000,500000,500000 Specify deceleration of 500000 counts / sec2 for all axes
BG X                   Begin motion on the X axis
WT 20                  Wait 20 msec
BG Y                   Begin motion on the Y axis
WT 20                  Wait 20 msec
BG Z                   Begin motion on Z axis
EN                      End Program

```

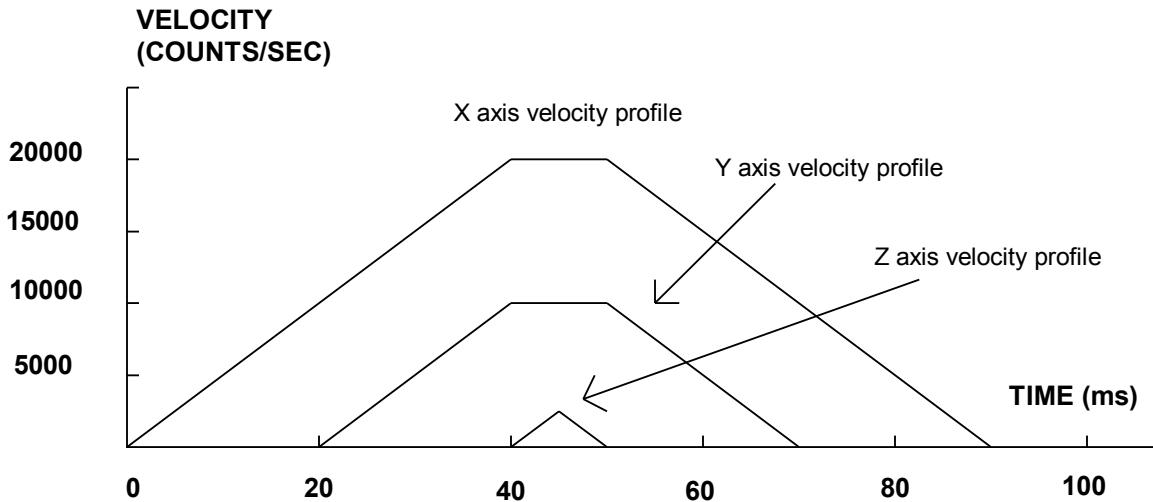


Figure 6.1: Velocity Profiles of XYZ

Notes on Figure 6.1: The X and Y axis have a ‘trapezoidal’ velocity profile, while the Z axis has a ‘triangular’ velocity profile. The X and Y axes accelerate to the specified speed, move at this constant speed, and then decelerate such that the final position agrees with the command position, PR. The Z axis accelerates, but before the specified speed is achieved, must begin deceleration such that the axis will stop at the commanded position. All 3 axes have the same acceleration and deceleration rate, hence, the slope of the rising and falling edges of all 3 velocity profiles are the same.

Independent Jogging

The jog mode of motion is very flexible because speed, direction and acceleration can be changed during motion. The user specifies the jog speed (JG), acceleration (AC), and the deceleration (DC) rate for each axis. The direction of motion is specified by the sign of the JG parameters. When the begin command is given (BG), the motor accelerates up to speed and continues to jog at that speed until a new speed or stop (ST) command is issued. If the jog speed is changed during motion, the controller will make a accelerated (or decelerated) change to the new speed.

An instant change to the motor position can be made with the use of the IP command. Upon receiving this command, the controller commands the motor to a position which is equal to the specified increment plus the current position. This command is useful when trying to synchronize the position of two motors while they are moving.

Note that the controller operates as a closed-loop position controller while in the jog mode. The DMC-41x3 converts the velocity profile into a position trajectory and a new position target is generated every sample period. This method of control results in precise speed regulation with phase lock accuracy.

Command Summary - Jogging

COMMAND	DESCRIPTION
AC x,y,z,w	Specifies acceleration rate
BG XYZW	Begins motion
DC x,y,z,w	Specifies deceleration rate
IP x,y,z,w	Increments position instantly
IT x,y,z,w	Time constant for independent motion smoothing
JG +/-x,y,z,w	Specifies jog speed and direction
ST XYZW	Stops motion

Parameters can be set with individual axes specifiers such as JGY=2000 (set jog speed for Y axis to 2000).

Operand Summary - Independent Axis

OPERAND	DESCRIPTION
_ACx	Return acceleration rate for the axis specified by 'x'
_DCx	Return deceleration rate for the axis specified by 'x'
_SPx	Returns the jog speed for the axis specified by 'x'
_TVx	Returns the actual velocity of the axis specified by 'x' (averaged over 0.25 sec)

Example - Jog in X only

Jog X motor at 50000 count/s. After X motor is at its jog speed, begin jogging Z in reverse direction at 25000 count/s.

```
#A
AC 20000,,20000      Specify X,Z acceleration of 20000 counts / sec
DC 20000,,20000      Specify X,Z deceleration of 20000 counts / sec
JG 50000,,-25000     Specify jog speed and direction for X and Z axis
BG X                 Begin X motion
AS X                 Wait until X is at speed
BG Z                 Begin Z motion
EN
```

Example - Joystick Jogging

The jog speed can also be changed using an analog input such as a joystick. Assume that for a 10 Volt input the speed must be 50000 counts/sec.

```
#JOY          Label
JGO          Set in Jog Mode
BGX          Begin motion
#B           Label for loop
V1 =@AN[1]   Read analog input
VEL=V1*50000/10 Compute speed
JG VEL       Change JG speed
JP #B        Loop
```

Position Tracking

The Galil controller may be placed in the position tracking mode to support changing the target of an absolute position move on the fly. New targets may be given in the same direction or the opposite direction of the current position target. The controller will then calculate a new trajectory based upon the new target and the acceleration, deceleration, and speed parameters that have been set. The motion profile in this mode is trapezoidal. There is not a set limit governing the rate at which the end point may be changed, however at the standard TM rate, the controller updates the position information at the rate of 1msec. The controller generates a profiled point every other sample, and linearly interpolates one sample between each profiled point. Some examples of applications that may use this mode are satellite tracking, missile tracking, random pattern polishing of mirrors or lenses, or any application that requires the ability to change the endpoint without completing the previous move.

The PA command is typically used to command an axis or multiple axes to a specific absolute position. For some applications such as tracking an object, the controller must proceed towards a target and have the ability to change

the target during the move. In a tracking application, this could occur at any time during the move or at regularly scheduled intervals. For example if a robot was designed to follow a moving object at a specified distance and the path of the object wasn't known the robot would be required to constantly monitor the motion of the object that it was following. To remain within a specified distance it would also need to constantly update the position target it is moving towards. Galil motion controllers support this type of motion with the position tracking mode. This mode will allow scheduled or random updates to the current position target on the fly. Based on the new target the controller will either continue in the direction it is heading, change the direction it is moving, or decelerate to a stop.

The position tracking mode shouldn't be confused with the contour mode. The contour mode allows the user to generate custom profiles by updating the reference position at a specific time rate. In this mode, the position can be updated randomly or at a fixed time rate, but the velocity profile will always be trapezoidal with the parameters specified by AC, DC, and SP. Updating the position target at a specific rate will not allow the user to create a custom profile.

The following example will demonstrate the possible different motions that may be commanded by the controller in the position tracking mode. In this example, there is a host program that will generate the absolute position targets. The absolute target is determined based on the current information the host program has gathered on the object that it is tracking. The position tracking mode does allow for all of the axes on the controller to be in this mode, but for the sake of discussion, it is assumed that the robot is tracking only in the X dimension.

The controller must be placed in the position tracking mode to allow on the fly absolute position changes. This is performed with the PT command. To place the X axis in this mode, the host would issue PT1 to the controller if both X and Y axes were desired the command would be PT 1,1. The next step is to begin issuing PA command to the controller. The BG command isn't required in this mode, the SP, AC, and DC commands determine the shape of the trapezoidal velocity profile that the controller will use.

Example - Motion 1:

The host program determines that the first target for the controller to move to is located at 5000 encoder counts. The acceleration and deceleration should be set to 150,000 countts/sec² and the velocity is set to 50,000 counts/sec. The command sequence to perform this is listed below.

```
#EX1
PT 1;          Place the X axis in Position tracking mode
AC 150000;    Set the X axis acceleration to 150000 counts/sec2
DC 150000;    Set the X axis deceleration to 150000 counts/sec2
SP 50000;     Set the X axis speed to 50000 counts/sec
PA 5000;      Command the X axis to absolute position 5000 encoder counts
EN
```

The output from this code can be seen in Figure 6.2, a screen capture from the GalilTools scope.

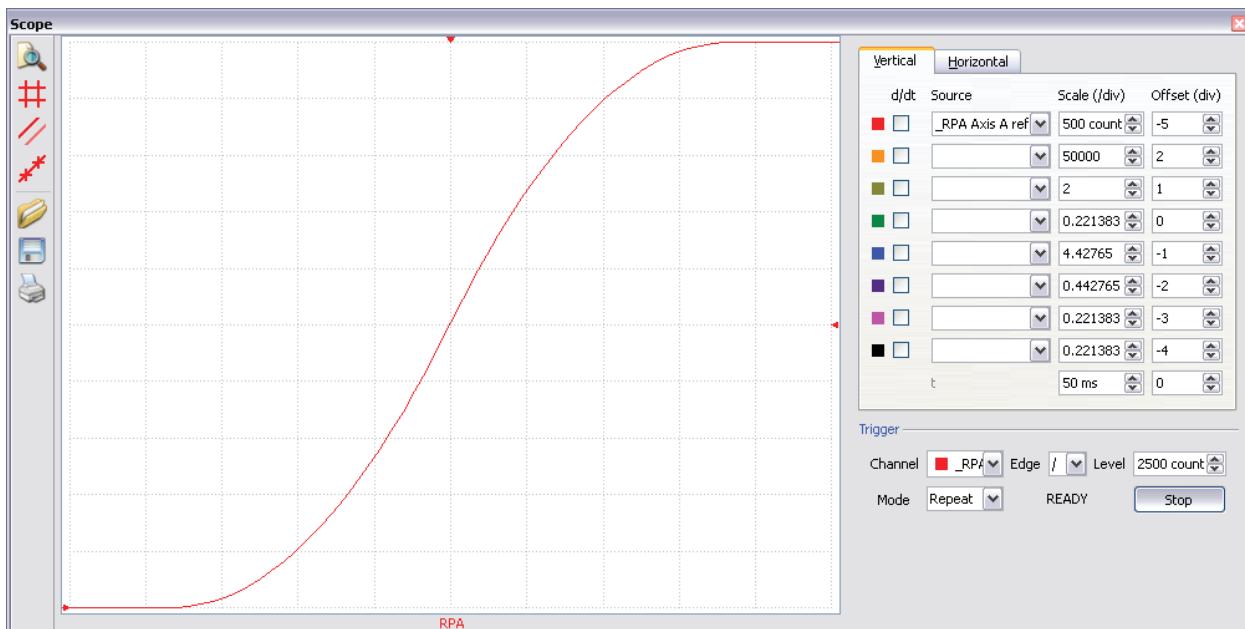


Figure 6.2: Position vs Time (msec) - Motion 1

Example - Motion 2:

The previous step showed the plot if the motion continued all the way to 5000, however partway through the motion, the object that was being tracked changed direction, so the host program determined that the actual target position should be 2000 counts at that time. Figure 6.2 shows what the position profile would look like if the move was allowed to complete to 5000 counts. The position was modified when the robot was at a position of 4200 counts(Figure 6.3). Note that the robot actually travels to a distance of almost 5000 counts before it turns around. This is a function of the deceleration rate set by the DC command. When a direction change is commanded, the controller decelerates at the rate specified by the DC command. The controller then ramps the velocity in up to the value set with SP in the opposite direction traveling to the new specified absolute position. In Figure 6.3 the velocity profile is triangular because the controller doesn't have sufficient time to reach the set speed of 50000 counts/sec before it is commanded to change direction.

The below code is used to simulate this scenario:

```
#EX2
PT 1;          Place the X axis in Position tracking mode
AC 150000;     Set the X axis acceleration to 150000 counts/sec2
DC 150000;     Set the X axis deceleration to 150000 counts/sec2
SP 50000;      Set the X axis speed to 50000 counts/sec
PA 5000;       Command the X axis to abs position 5000 encoder counts
MF 4200
PA 2000;       Change end point position to position 2000
EN
```

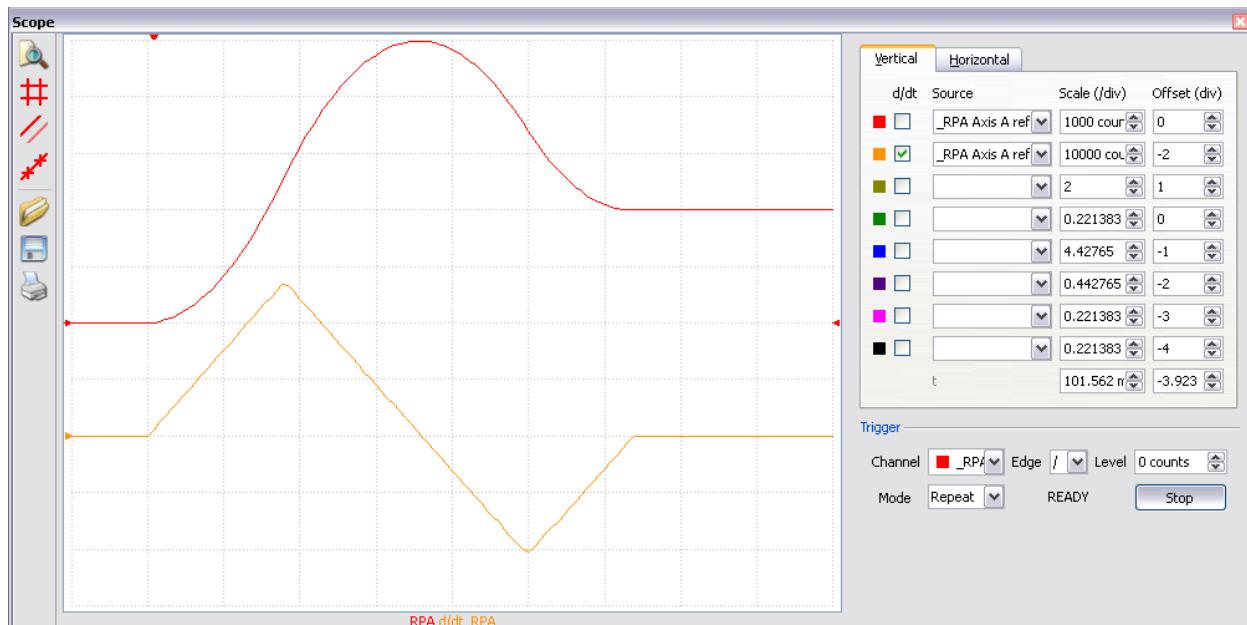


Figure 6.3: Position and Velocity vs Time(msec) for Motion 2

Example - Motion 3:

In this motion, the host program commands the controller to begin motion towards position 5000, changes the target to -2000, and then changes it again to 8000. Figure 6.4 shows the plot of position vs. time and velocity vs. time.

Below is the code that is used to simulate this scenario:

```
#EX3
PT 1;' Place the X axis in Position tracking mode
AC 150000;' Set the X axis acceleration to 150000 counts/sec2
DC 150000;' Set the X axis deceleration to 150000 counts/sec2
SP 50000;' Set the X axis speed to 50000 counts/sec
PA 5000;' Command the X axis to abs position 5000 encoder counts
WT 300
PA -2000;' Change end point position to -2000
WT 200
PA 8000;' Change end point position to 8000
EN
```

Figure 6.5 demonstrates the use of motion smoothing (IT) on the velocity profile in this mode. The jerk in the system is also affected by the values set for AC and DC.

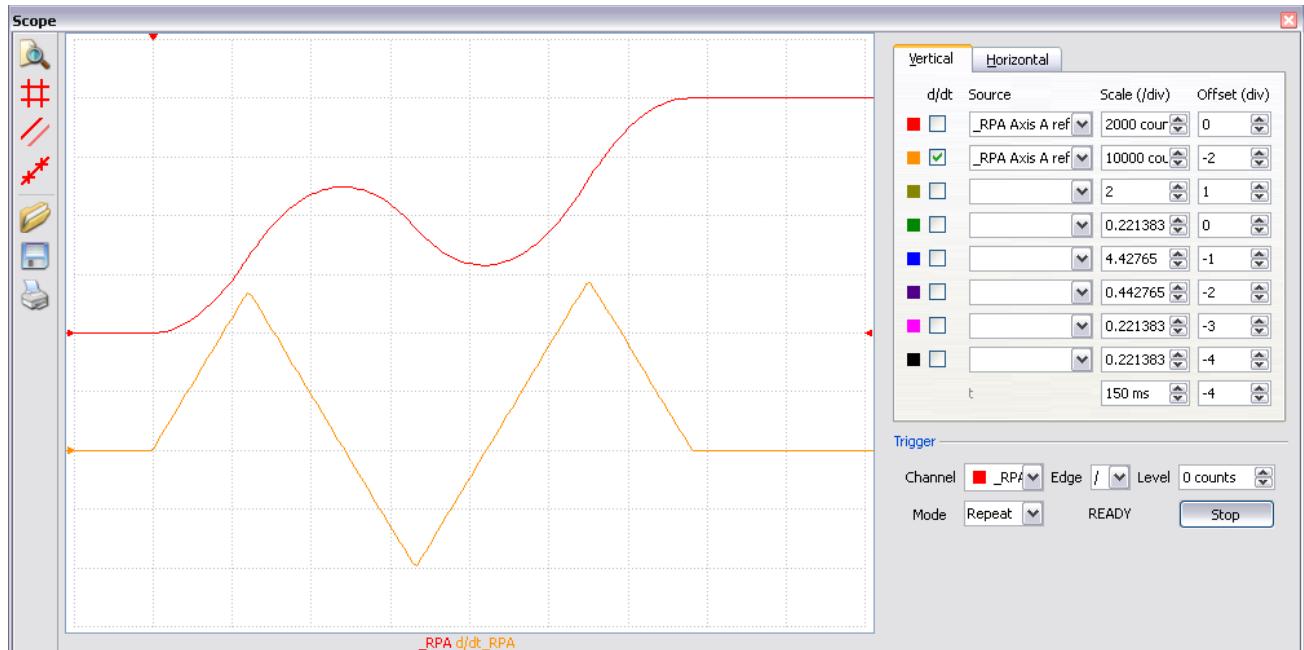


Figure 6.4: Position and Velocity vs Time (msec) for Motion 3

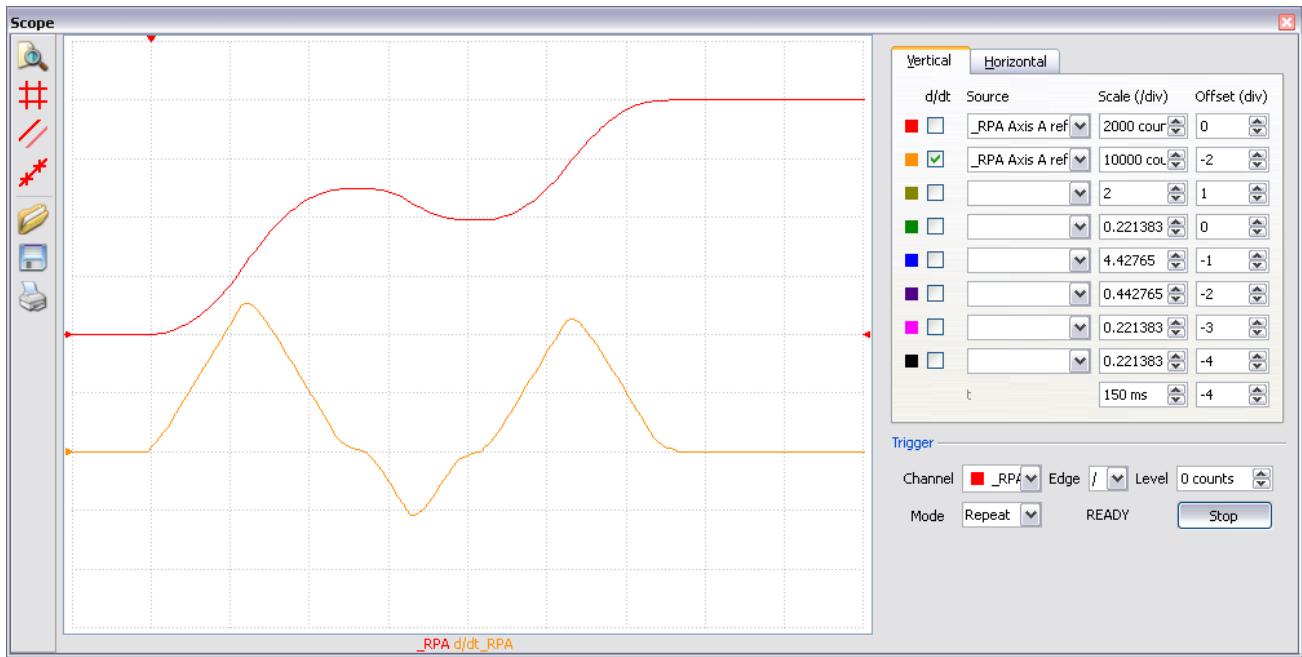


Figure 6.5: Position and Velocity vs Time (msec) for Motion 3 with IT 0.1

Note the controller treats the point where the velocity passes through zero as the end of one move, and the beginning of another move. IT is allowed, however it will introduce some time delay.

Trip Points

Most trip points are valid for use while in the position tracking mode. There are a few exceptions to this; the AM and MC commands may not be used while in this mode. It is recommended that AR, MF, MR, or AP be used, as they involve motion in a specified direction, or the passing of a specific absolute position.

Command Summary – Position Tracking Mode

COMMAND	DESCRIPTION
AC n,n,n,n,n,n,n	Acceleration settings for the specified axes
AP n,n,n,n,n,n,n	Trip point that holds up program execution until an absolute position has been reached
DC n,n,n,n,n,n,n	Deceleration settings for the specified axes
MF n,n,n,n,n,n,n	Trip point to hold up program execution until n number of counts have passed in the forward direction. Only one axis at a time may be specified.
MR n,n,n,n,n,n,n	Trip point to hold up program execution until n number of counts have passed in the reverse direction. Only one axis at a time may be specified.
PT n,n,n,n,n,n,n	Command used to enter and exit the Trajectory Modification Mode
PA n,n,n,n,n,n,n	Command Used to specify the absolute position target
SP n,n,n,n,n,n,n	Speed settings for the specified axes

Linear Interpolation Mode

The DMC-41x3 provides a linear interpolation mode for 2 or more axes. In linear interpolation mode, motion between the axes is coordinated to maintain the prescribed vector speed, acceleration, and deceleration along the specified path. The motion path is described in terms of incremental distances for each axis. An unlimited number of incremental segments may be given in a continuous move sequence, making the linear interpolation mode ideal for following a piece-wise linear path. There is no limit to the total move length.

The LM command selects the Linear Interpolation mode and axes for interpolation. For example, LM YZ selects only the Y and Z axes for linear interpolation.

When using the linear interpolation mode, the LM command only needs to be specified once unless the axes for linear interpolation change.

Specifying Linear Segments

The command LI x,y,z,w or LI a,b,c,d,e,f,g,h specifies the incremental move distance for each axis. This means motion is prescribed with respect to the current axis position. Up to 511 incremental move segments may be given prior to the Begin Sequence (BGS) command. Once motion has begun, additional LI segments may be sent to the controller.

The clear sequence (CS) command can be used to remove LI segments stored in the buffer prior to the start of the motion. To stop the motion, use the instructions STS or AB. The command, ST, causes a decelerated stop. The command, AB, causes an instantaneous stop and aborts the program, and the command AB1 aborts the motion only.

The Linear End (LE) command must be used to specify the end of a linear move sequence. This command tells the controller to decelerate to a stop following the last LI command. If an LE command is not given, an Abort AB1 must be used to abort the motion sequence.

It is the responsibility of the user to keep enough LI segments in the DMC-41x3 sequence buffer to ensure continuous motion. If the controller receives no additional LI segments and no LE command, the controller will stop motion instantly at the last vector. There will be no controlled deceleration. LM? or _LM returns the available spaces for LI segments that can be sent to the buffer. 511 returned means the buffer is empty and 511 LI segments can be sent. A zero means the buffer is full and no additional segments can be sent. As long as the buffer is not full, additional LI segments can be sent at PC bus speeds.

The instruction _CS returns the segment counter. As the segments are processed, _CS increases, starting at zero. This function allows the host computer to determine which segment is being processed.

Additional Commands

The commands VS n, VA n, and VD n are used to specify the vector speed, acceleration and deceleration. The DMC-41x3 computes the vector speed based on the axes specified in the LM mode. For example, LM XYZ designates linear interpolation for the X, Y and Z axes. The vector speed for this example would be computed using the equation:

VS2=XS2+YS2+ZS2, where XS, YS and ZS are the speed of the X, Y and Z axes.

The controller always uses the axis specifications from LM, not LI, to compute the speed.

IT is used to set the S-curve smoothing constant for coordinated moves. The command AV n is the ‘After Vector’ trippoint, which halts program execution until the vector distance of n has been reached.

An Example of Linear Interpolation Motion:

#LMOVE	label
DP 0,0	Define position of X and Y axes to be 0
LMXY	Define linear mode between X and Y axes.
LI 5000,0	Specify first linear segment
LI 0,5000	Specify second linear segment

LE	End linear segments
VS 4000	Specify vector speed
BGS	Begin motion sequence
AV 4000	Set trippoint to wait until vector distance of 4000 is reached
VS 1000	Change vector speed
AV 5000	Set trippoint to wait until vector distance of 5000 is reached
VS 4000	Change vector speed
EN	Program end

In this example, the XY system is required to perform a 90° turn. In order to slow the speed around the corner, we use the AV 4000 trippoint, which slows the speed to 1000 count/s. Once the motors reach the corner, the speed is increased back to 4000 counts / s.

Specifying Vector Speed for Each Segment

The instruction VS has an immediate effect and, therefore, must be given at the required time. In some applications, such as CNC, it is necessary to attach various speeds to different motion segments. This can be done by two functions: < n and > m

For example: LI x,y,z,w < n >m

The first command, < n, is equivalent to commanding VS_n at the start of the given segment and will cause an acceleration toward the new commanded speeds, subjects to the other constraints.

The second function, > m, requires the vector speed to reach the value m at the end of the segment. Note that the function > m may start the deceleration within the given segment or during previous segments, as needed to meet the final speed requirement, under the given values of VA and VD.

Note, however, that the controller works with one > m command at a time. As a consequence, one function may be masked by another. For example, if the function >100000 is followed by >5000, and the distance for deceleration is not sufficient, the second condition will not be met. The controller will attempt to lower the speed to 5000, but will reach that at a different point.

As an example, consider the following program.

#ALT	Label for alternative program
DP 0,0	Define Position of X and Y axis to be 0
LMXY	Define linear mode between X and Y axes.
LI 4000,0 <4000 >1000	Specify first linear segment with a vector speed of 4000 and end speed 1000
LI 1000,1000 < 4000 >1000	Specify second linear segment with a vector speed of 4000 and end speed 1000
LI 0,5000 < 4000 >1000	Specify third linear segment with a vector speed of 4000 and end speed 1000
LE	End linear segments
BGS	Begin motion sequence
EN	Program end

Changing Feed Rate:

The command VR n allows the feed rate, VS, to be scaled between 0 and 10 with a resolution of .0001. This command takes effect immediately and causes VS to be scaled. VR also applies when the vector speed is specified with the ‘<’ operator. This is a useful feature for feed rate override. VR does not ratio the accelerations. For example, VR .5 results in the specification VS 2000 to be divided in half.

Command Summary - Linear Interpolation

COMMAND	DESCRIPTION
LM xyzw LM abcdefgh	Specify axes for linear interpolation (same) controllers with 5 or more axes
LM?	Returns number of available spaces for linear segments in DMC-41x3 sequence buffer. Zero means buffer full. 511 means buffer empty.
LI x,y,z,w < n LI a,b,c,d,e,f,g,h < n	Specify incremental distances relative to current position, and assign vector speed n.
VS n	Specify vector speed
VA n	Specify vector acceleration
VD n	Specify vector deceleration
VR n	Specify the vector speed ratio
BGS	Begin Linear Sequence
CS	Clear sequence
LE	Linear End- Required at end of LI command sequence
LE?	Returns the length of the vector (resets after 2147483647)
AMS	Trippoint for After Sequence complete
AV n	Trippoint for After Relative Vector distance, n
IT	S curve smoothing constant for vector moves

Operand Summary - Linear Interpolation

OPERAND	DESCRIPTION
_AV	Return distance traveled
_CS	Segment counter - returns number of the segment in the sequence, starting at zero.
_LE	Returns length of vector (resets after 2147483647)
_LM	Returns number of available spaces for linear segments in DMC-41x3 sequence buffer. Zero means buffer full. 511 means buffer empty.
_VPm	Return the absolute coordinate of the last data point along the trajectory. (m=X,Y,Z or W or A,B,C,D,E,F,G or H)

To illustrate the ability to interrogate the motion status, consider the first motion segment of our example, #LMOVE, where the X axis moves toward the point X=5000. Suppose that when X=3000, the controller is interrogated using the command 'MG _AV'. The returned value will be 3000. The value of _CS, _VPX and _VPY will be zero.

Now suppose that the interrogation is repeated at the second segment when Y=2000. The value of _AV at this point is 7000, _CS equals 1, _VPX=5000 and _VPY=0.

Example - Linear Move

Make a coordinated linear move in the ZW plane. Move to coordinates 40000,30000 counts at a vector speed of 100000 counts/sec and vector acceleration of 1000000 counts/sec2.

LM ZW

Specify axes for linear interpolation

LI,,40000,30000	Specify ZW distances
LE	Specify end move
VS 100000	Specify vector speed
VA 1000000	Specify vector acceleration
VD 1000000	Specify vector deceleration
BGS	Begin sequence

Note that the above program specifies the vector speed, VS, and not the actual axis speeds VZ and VW. The axis speeds are determined by the controller from:

$$VS = \sqrt{VZ^2 + VW^2}$$

The result is shown in Figure 6.6.

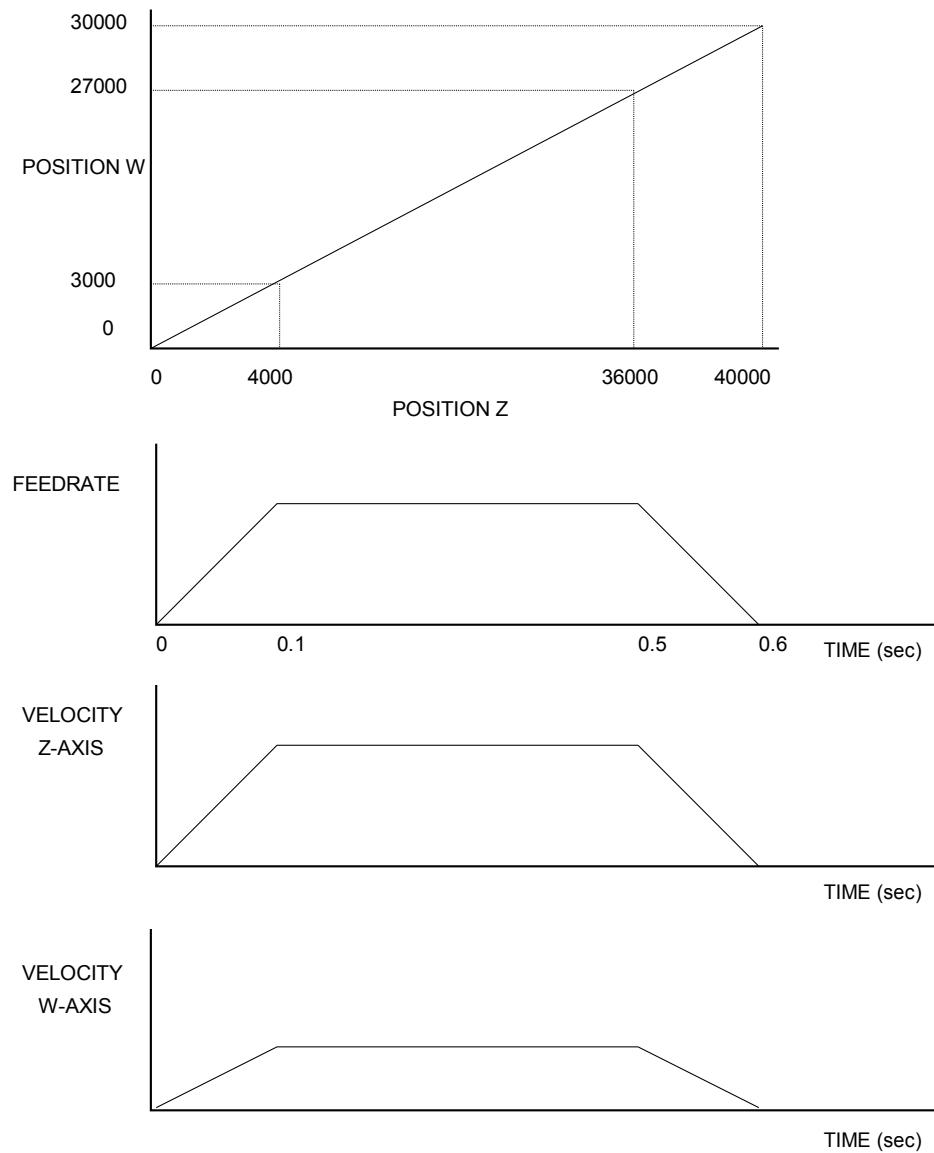


Figure 6.6: Linear Interpolation

Example - Multiple Moves

This example makes a coordinated linear move in the XY plane. The Arrays VX and VY are used to store 750 incremental distances which are filled by the program #LOAD.

#LOAD	Load Program
DM VX [750],VY [750]	Define Array
COUNT=0	Initialize Counter
N=0	Initialize position increment
#LOOP	LOOP
VX [COUNT]=N	Fill Array VX
VY [COUNT]=N	Fill Array VY
N=N+10	Increment position
COUNT=COUNT+1	Increment counter
JP #LOOP,COUNT<750	Loop if array not full
#A	Label
LM XY	Specify linear mode for XY
COUNT=0	Initialize array counter
#LOOP2;JP#LOOP2,_LM=0	If sequence buffer full, wait
JS#C,COUNT=500	Begin motion on 500 th segment
LI VX[COUNT],VY[COUNT]	Specify linear segment
COUNT=COUNT+1	Increment array counter
JP #LOOP2,COUNT<750	Repeat until array done
LE	End Linear Move
AMS	After Move sequence done
MG "DONE"	Send Message
EN	End program
#C;BGS;EN	Begin Motion Subroutine

Vector Mode: Linear and Circular Interpolation Motion

The DMC-41x3 allows a long 2-D path consisting of linear and arc segments to be prescribed. Motion along the path is continuous at the prescribed vector speed even at transitions between linear and circular segments. The DMC-41x3 performs all the complex computations of linear and circular interpolation, freeing the host PC from this time intensive task.

The coordinated motion mode is similar to the linear interpolation mode. Any pair of two axes may be selected for coordinated motion consisting of linear and circular segments. In addition, a third axis can be controlled such that it remains tangent to the motion of the selected pair of axes. Note that only one pair of axes can be specified for coordinated motion at any given time.

The command VM m,n,p where 'm' and 'n' are the coordinated pair and p is the tangent axis (Note: the commas which separate m,n and p are not necessary). For example, VM XWZ selects the XW axes for coordinated motion and the Z-axis as the tangent.

Specifying the Coordinate Plane

The DMC-41x3 allows for 2 separate sets of coordinate axes for linear interpolation mode or vector mode. These two sets are identified by the letters S and T.

To specify vector commands the coordinate plane must first be identified. This is done by issuing the command CAS to identify the S plane or CAT to identify the T plane. All vector commands will be applied to the active coordinate system until changed with the CA command.

Specifying Vector Segments

The motion segments are described by two commands; VP for linear segments and CR for circular segments. Once a set of linear segments and/or circular segments have been specified, the sequence is ended with the command VE. This defines a sequence of commands for coordinated motion. Immediately prior to the execution of the first coordinated movement, the controller defines the current position to be zero for all movements in a sequence. Note: This ‘local’ definition of zero does not affect the absolute coordinate system or subsequent coordinated motion sequences.

The command, VP x,y specifies the coordinates of the end points of the vector movement with respect to the starting point. Non-sequential axis do not require comma delimitation. The command, CR r,q,d define a circular arc with a radius r, starting angle of q, and a traversed angle d. The notation for q is that zero corresponds to the positive horizontal direction, and for both q and d, the counter-clockwise (CCW) rotation is positive.

Up to 511 segments of CR or VP may be specified in a single sequence and must be ended with the command VE. The motion can be initiated with a Begin Sequence (BGS) command. Once motion starts, additional segments may be added.

The Clear Sequence (CS) command can be used to remove previous VP and CR commands which were stored in the buffer prior to the start of the motion. To stop the motion, use the instructions STS or AB1. ST stops motion at the specified deceleration. AB1 aborts the motion instantaneously.

The Vector End (VE) command must be used to specify the end of the coordinated motion. This command requires the controller to decelerate to a stop following the last motion requirement. If a VE command is not given, an Abort (AB1) must be used to abort the coordinated motion sequence.

It is the responsibility of the user to keep enough motion segments in the DMC-41x3 sequence buffer to ensure continuous motion. If the controller receives no additional motion segments and no VE command, the controller will stop motion instantly at the last vector. There will be no controlled deceleration. LM? or _LM returns the available spaces for motion segments that can be sent to the buffer. 511 returned means the buffer is empty and 511 segments can be sent. A zero means the buffer is full and no additional segments can be sent. As long as the buffer is not full, additional segments can be sent at PC bus speeds.

The operand _CS can be used to determine the value of the segment counter.

Additional commands

The commands VS n, VA n and VD n are used for specifying the vector speed, acceleration, and deceleration.

IT is the s curve smoothing constant used with coordinated motion.

Specifying Vector Speed for Each Segment:

The vector speed may be specified by the immediate command VS. It can also be attached to a motion segment with the instructions

VP x,y <n>m

CR r,θ,δ <n>m

The first command, <n>, is equivalent to commanding VSn at the start of the given segment and will cause an acceleration toward the new commanded speeds, subjects to the other constraints.

The second function, >m, requires the vector speed to reach the value m at the end of the segment. Note that the function >m may start the deceleration within the given segment or during previous segments, as needed to meet the final speed requirement, under the given values of VA and VD.

Note, however, that the controller works with one >m command at a time. As a consequence, one function may be masked by another. For example, if the function >100000 is followed by >5000, and the distance for deceleration is not sufficient, the second condition will not be met. The controller will attempt to lower the speed to 5000, but will reach that at a different point.

Changing Feed Rate:

The command VR n allows the feed rate, VS, to be scaled between 0 and 10 with a resolution of .0001. This command takes effect immediately and causes VS scaled. VR also applies when the vector speed is specified with the ' $<$ ' operator. This is a useful feature for feed rate override. VR does not ratio the accelerations. For example, VR 0.5 results in the specification VS 2000 to be divided by two.

Compensating for Differences in Encoder Resolution:

By default, the DMC-41x3 uses a scale factor of 1:1 for the encoder resolution when used in vector mode. If this is not the case, the command, ES can be used to scale the encoder counts. The ES command accepts two arguments which represent the number of counts for the two encoders used for vector motion. The smaller ratio of the two numbers will be multiplied by the higher resolution encoder. For more information, see ES command in the Command Reference.

Trippoints:

The AV n command is the After Vector trippoint, which waits for the vector relative distance of n to occur before executing the next command in a program.

Tangent Motion:

Several applications, such as cutting, require a third axis (i.e. a knife blade), to remain tangent to the coordinated motion path. To handle these applications, the DMC-41x3 allows one axis to be specified as the tangent axis. The VM command provides parameter specifications for describing the coordinated axes and the tangent axis.

VM m,n,p m,n specifies coordinated axes p specifies tangent axis such as X,Y,Z,W p=N turns off tangent axis

Before the tangent mode can operate, it is necessary to assign an axis via the VM command and define its offset and scale factor via the TN m,n command. m defines the scale factor in counts/degree and n defines the tangent position that equals zero degrees in the coordinated motion plane. The operand _TN can be used to return the initial position of the tangent axis.

Example:

Assume an XY table with the Z-axis controlling a knife. The Z-axis has a 2000 quad counts/rev encoder and has been initialized after power-up to point the knife in the +Y direction. A 180° circular cut is desired, with a radius of 3000, center at the origin and a starting point at (3000,0). The motion is CCW, ending at (-3000,0). Note that the 0° position in the XY plane is in the +X direction. This corresponds to the position -500 in the Z-axis, and defines the offset. The motion has two parts. First, X, Y and Z are driven to the starting point, and later, the cut is performed. Assume that the knife is engaged with output bit 0.

```

#EXAMPLE          Example program
VM XYZ           XY coordinate with Z as tangent
TN 2000/360,-500 2000/360 counts/degree, position -500 is 0 degrees in XY plane
CR 3000,0,180    3000 count radius, start at 0 and go to 180 CCW
VE               End vector
CB0              Disengage knife
PA 3000,0,_TN   Move X and Y to starting position, move Z to initial tangent position
BG XYZ           Start the move to get into position
AM XYZ           When the move is complete
SB0              Engage knife
WT50             Wait 50 msec for the knife to engage
BGS              Do the circular cut
AMS              After the coordinated move is complete

```

CBO	Disengage knife
MG "ALL DONE"	
EN	End program

Command Summary - Coordinated Motion Sequence

COMMAND	DESCRIPTION.
VM m,n	Specifies the axes for the planar motion where m and n represent the planar axes and p is the tangent axis.
VP m,n	Return coordinate of last point, where m=X,Y,Z or W.
CR r,Θ, ±ΔΘ	Specifies arc segment where r is the radius, Θ is the starting angle and ΔΘ is the travel angle. Positive direction is CCW.
VS s,t	Specify vector speed or feed rate of sequence.
VA s,t	Specify vector acceleration along the sequence.
VD s,t	Specify vector deceleration along the sequence.
VR s,t	Specify vector speed ratio
BGST	Begin motion sequence, S or T
CSST	Clear sequence, S or T
AV s,t	Trippoint for After Relative Vector distance.
AMST	Holds execution of next command until Motion Sequence is complete.
TN m,n	Tangent scale and offset.
ES m,n	Ellipse scale factor.
IT s,t	S curve smoothing constant for coordinated moves
LM?	Return number of available spaces for linear and circular segments in DMC-41x3 sequence buffer. Zero means buffer is full. 511 means buffer is empty.
CAS or CAT	Specifies which coordinate system is to be active (S or T)

Operand Summary - Coordinated Motion Sequence

OPERAND	DESCRIPTION
_VPM	The absolute coordinate of the axes at the last intersection along the sequence.
_AV	Distance traveled.
_LM	Number of available spaces for linear and circular segments in DMC-41x3 sequence buffer. Zero means buffer is full. 511 means buffer is empty.
_CS	Segment counter - Number of the segment in the sequence, starting at zero.
_VE	Vector length of coordinated move sequence.

When AV is used as an operand, _AV returns the distance traveled along the sequence.

The operands _VPX and _VPY can be used to return the coordinates of the last point specified along the path.

Example:

Traverse the path shown in Figure 6.7. Feed rate is 20000 counts/sec. Plane of motion is XY

VM XY	Specify motion plane
VS 20000	Specify vector speed

VA 1000000	Specify vector acceleration
VD 1000000	Specify vector deceleration
VP -4000, 0	Segment AB
CR 1500, 270, -180	Segment BC
VP 0, 3000	Segment CD
CR 1500, 90, -180	Segment DA
VE	End of sequence
BGS	Begin Sequence

The resulting motion starts at the point A and moves toward points B, C, D, A. Suppose that we interrogate the controller when the motion is halfway between the points A and B.

The value of `_AV` is 2000

The value of `_CS` is 0

`_VPX` and `_VPY` contain the absolute coordinate of the point A

Suppose that the interrogation is repeated at a point, halfway between the points C and D.

The value of `_AV` is $4000 + 1500\pi + 2000 = 10,712$

The value of `_CS` is 2

`_VPX`, `_VPY` contain the coordinates of the point C

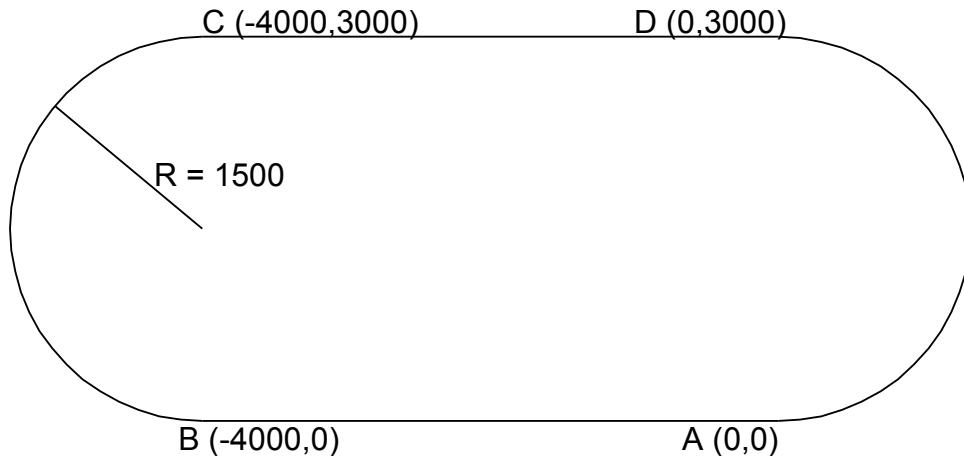


Figure 6.7: The Required Path

Electronic Gearing

This mode allows up to 8 axes to be electronically geared to some master axes. The masters may rotate in both directions and the geared axes will follow at the specified gear ratio. The gear ratio may be different for each axis and changed during motion.

The command `GAX yzw` or `GA ABCDEFGH` specifies the master axes. `GR x,y,z,w` specifies the gear ratios for the slaves where the ratio may be a number between $+-127.9999$ with a fractional resolution of .0001. There are two modes: standard gearing and gantry mode. The gantry mode (enabled with the command `GM`) allows the gearing to stay enabled even if a limit is hit or an `ST` command is issued. `GR 0,0,0,0` turns off gearing in both modes.

The command `GM x,y,z,w` select the axes to be controlled under the gantry mode. The parameter 1 enables gantry mode, and 0 disables it.

`GR` causes the specified axes to be geared to the actual position of the master. The master axis is commanded with motion commands such as `PR`, `PA` or `JG`.

When the master axis is driven by the controller in the jog mode or an independent motion mode, it is possible to define the master as the command position of that axis, rather than the actual position. The designation of the commanded position master is by the letter, C. For example, GACX indicates that the gearing is the commanded position of X.

An alternative gearing method is to synchronize the slave motor to the commanded vector motion of several axes performed by GAS. For example, if the X and Y motor form a circular motion, the Z axis may move in proportion to the vector move. Similarly, if X,Y and Z perform a linear interpolation move, W can be geared to the vector move.

Electronic gearing allows the geared motor to perform a second independent or coordinated move in addition to the gearing. For example, when a geared motor follows a master at a ratio of 1:1, it may be advanced an additional distance with PR, or JG, commands, or VP, or LI.

Ramped Gearing

In some applications, especially when the master is traveling at high speeds, it is desirable to have the gear ratio ramp gradually to minimize large changes in velocity on the slave axis when the gearing is engaged. For example if the master axis is already traveling at 500,000 counts/sec and the slave will be geared at a ratio of 1:1 when the gearing is engaged, the slave will instantly develop following error, and command maximum current to the motor. This can be a large shock to the system. For many applications it is acceptable to slowly ramp the engagement of gearing over a greater time frame. Galil allows the user to specify an interval of the master axis over which the gearing will be engaged. For example, the same master X axis in this case travels at 500,000 counts/sec, and the gear ratio is 1:1, but the gearing is slowly engaged over 30,000 counts of the master axis, greatly diminishing the initial shock to the slave axis. Figure 6.8 below shows the velocity vs. time profile for instantaneous gearing. Figure 6.9 shows the velocity vs. time profile for the gradual gearing engagement.

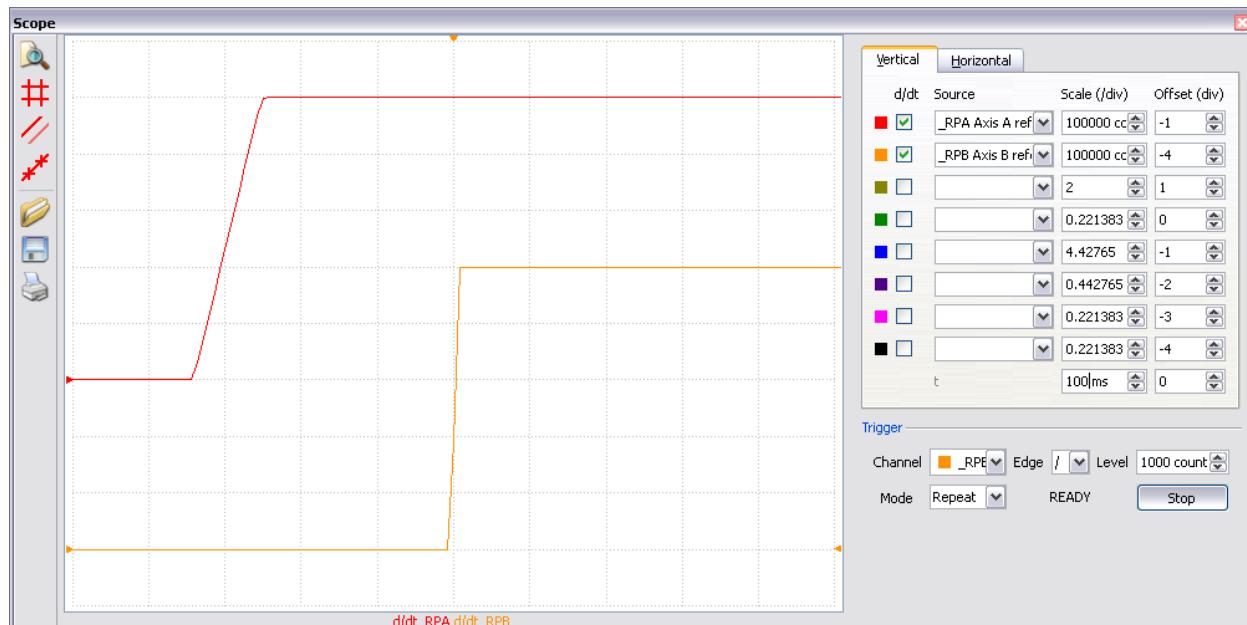


Figure 6.8: Velocity counts/sec vs. Time (msec) Instantaneous Gearing Engagement

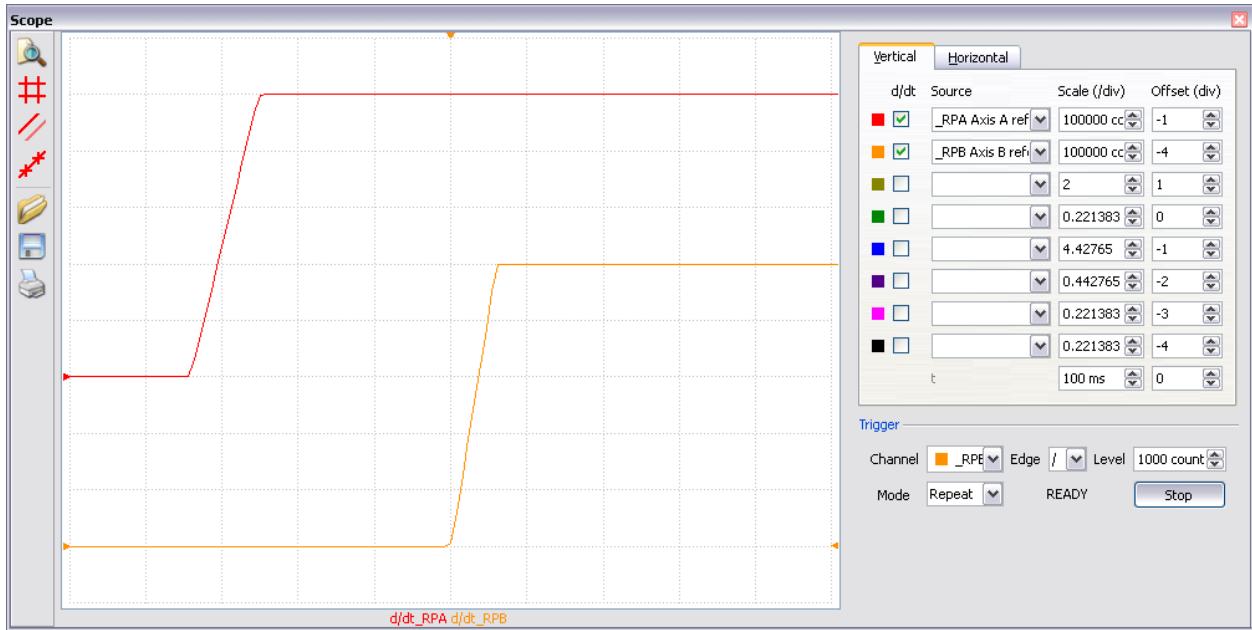


Figure 6.9: Velocity (counts/sec) vs. Time (msec) Ramped Gearing

The slave axis for each figure is shown on the bottom portion of the figure; the master axis is shown on the top portion. The shock to the slave axis will be significantly less in Figure 6.9 than in Figure 6.8. The ramped gearing does have one consequence. There isn't a true synchronization of the two axes, until the gearing ramp is complete. The slave will lag behind the true ratio during the ramp period. If exact position synchronization is required from the point gearing is initiated, then the position must be commanded in addition to the gearing. The controller keeps track of this position phase lag with the _GP operand. The following example will demonstrate how the command is used.

Example – Electronic Gearing Over a Specified Interval

Objective Run two geared motors at speeds of 1.132 and -.045 times the speed of an external master. Because the master is traveling at high speeds, it is desirable for the speeds to change slowly.

Solution: Use a DMC-4133 controller where the Z-axis is the master and X and Y are the geared axes. We will implement the gearing change over 6000 counts (3 revolutions) of the master axis.

MO Z	Turn Z off, for external master
GA Z, Z	Specify Z as the master axis for both X and Y.
GD 6000,6000	Specify ramped gearing over 6000 counts of the master axis.
GR 1.132,-.045	Specify gear ratios

Question: What is the effect of the ramped gearing?

Answer: Below, in the example titled Electronic Gearing, gearing would take effect immediately. From the start of gearing if the master traveled 6000 counts, the slaves would travel 6792 counts and 270 counts.

Using the ramped gearing, the slave will engage gearing gradually. Since the gearing is engaged over the interval of 6000 counts of the master, the slave will only travel ~3396 counts and ~135 counts respectively. The difference between these two values is stored in the _GPn operand. If exact position synchronization is required, the IP command is used to adjust for the difference.

Command Summary - Electronic Gearing

COMMAND	DESCRIPTION
GA n	Specifies master axes for gearing where: n = X,Y,Z or W or A,B,C,D,E,F,G,H for main encoder as master n = CX,CY,CZ, CW or CA, CB,CC,CD,CE,CF,CG,CH for commanded position. n = DX,DY,DZ or DW or DA, DB, DC, DD, DE, DF,DG,DH for auxiliary encoders n = S or T for gearing to coordinated motion.
GD a,b,c,d,e,f,g,h	Sets the distance the master will travel for the gearing change to take full effect.
_GPn	This operand keeps track of the difference between the theoretical distance traveled if gearing changes took effect immediately, and the distance traveled since gearing changes take effect over a specified interval.
GR a,b,c,d,e,f,g,h	Sets gear ratio for slave axes. 0 disables electronic gearing for specified axis.
GM a,b,c,d,e,f,g,h	X = 1 sets gantry mode, 0 disables gantry mode
MR x,y,z,w	Trippoint for reverse motion past specified value. Only one field may be used.
MF x,y,z,w	Trippoint for forward motion past specified value. Only one field may be used.

Example - Simple Master Slave

Master axis moves 10000 counts at slew speed of 100000 counts/sec. Y is defined as the master. X,Z,W are geared to master at ratios of 5,-.5 and 10 respectively.

GA Y,,Y,Y	Specify master axes as Y
GR 5,,-.5,10	Set gear ratios
PR ,10000	Specify Y position
SP ,100000	Specify Y speed
BGY	Begin motion

Example - Electronic Gearing

Objective: Run two geared motors at speeds of 1.132 and -0.045 times the speed of an external master. The master is driven at speeds between 0 and 1800 RPM (2000 counts/rev encoder).

Solution: Use a DMC-4133 controller, where the Z-axis is the master and X and Y are the geared axes.

MO Z	Turn Z off, for external master
GA Z, Z	Specify Z as the master axis for both X and Y.
GR 1.132, -.045	Specify gear ratios

Now suppose the gear ratio of the X-axis is to change on-the-fly to 2. This can be achieved by commanding:

GR 2	Specify gear ratio for X axis to be 2
------	---------------------------------------

Example - Gantry Mode

In applications where both the master and the follower are controlled by the DMC-41x3 controller, it may be desired to synchronize the follower with the commanded position of the master, rather than the actual position. This eliminates the coupling between the axes which may lead to oscillations.

For example, assume that a gantry is driven by two axes, X,Y, on both sides. This requires the gantry mode for strong coupling between the motors. The X-axis is the master and the Y-axis is the follower. To synchronize Y with the commanded position of X, use the instructions:

GA, CX	Specify the commanded position of X as master for Y.
--------	--

GR,1	Set gear ratio for Y as 1:1
GM,1	Set gantry mode
PR 3000	Command X motion
BG X	Start motion on X axis

You may also perform profiled position corrections in the electronic gearing mode. Suppose, for example, that you need to advance the slave 10 counts. Simply command

IP ,10	Specify an incremental position movement of 10 on Y axis.
--------	---

Under these conditions, this IP command is equivalent to:

PR,10	Specify position relative movement of 10 on Y axis
BGY	Begin motion on Y axis

Often the correction is quite large. Such requirements are common when synchronizing cutting knives or conveyor belts.

Example - Synchronize two conveyor belts with trapezoidal velocity correction

GA,X	Define X as the master axis for Y.
GR,2	Set gear ratio 2:1 for Y
PR,300	Specify correction distance
SP,5000	Specify correction speed
AC,100000	Specify correction acceleration
DC,100000	Specify correction deceleration
BGY	Start correction

Electronic Cam

The electronic cam is a motion control mode which enables the periodic synchronization of several axes of motion. Up to 7 axes can be slaved to one master axis. The master axis encoder must be input through a main encoder port.

The electronic cam is a more general type of electronic gearing which allows a table-based relationship between the axes. It allows synchronizing all the controller axes. For example, the DMC-4183 controllers may have one master and up to seven slaves.

To illustrate the procedure of setting the cam mode, consider the cam relationship for the slave axis Y, when the master is X. Such a graphic relationship is shown in Figure 6.10.

Step 1. Selecting the master axis

The first step in the electronic cam mode is to select the master axis. This is done with the instruction

EAp where p = X,Y,Z,W,E,F,G,H

p is the selected master axis

For the given example, since the master is x, we specify EAX

Step 2. Specify the master cycle and the change in the slave axis (or axes).

In the electronic cam mode, the position of the master is always expressed modulo one cycle. In this example, the position of x is always expressed in the range between 0 and 6000. Similarly, the slave position is also redefined such that it starts at zero and ends at 1500. At the end of a cycle when the master is 6000 and the slave is 1500, the positions of both x and y are redefined as zero. To specify the master cycle and the slave cycle change, we use the instruction EM.

EM x, y, z, w

where x,y,z,w specify the cycle of the master and the total change of the slaves over one cycle.

The cycle of the master is limited to 8,388,607 whereas the slave change per cycle is limited to 2,147,483,647. If the change is a negative number, the absolute value is specified. For the given example, the cycle of the master is 6000 counts and the change in the slave is 1500. Therefore, we use the instruction:

```
EM 6000,1500
```

Step 3. Specify the master interval and starting point.

Next we need to construct the ECAM table. The table is specified at uniform intervals of master positions. Up to 256 intervals are allowed. The size of the master interval and the starting point are specified by the instruction:

```
EP m,n
```

where m is the interval width in counts, and n is the starting point.

For the given example, we can specify the table by specifying the position at the master points of 0, 2000, 4000 and 6000. We can specify that by

```
EP 2000,0
```

Step 4. Specify the slave positions.

Next, we specify the slave positions with the instruction

```
ET [n]=x,y,z,w
```

where n indicates the order of the point.

The value, n, starts at zero and may go up to 256. The parameters x,y,z,w indicate the corresponding slave position. For this example, the table may be specified by

```
ET [0]=,0  
ET [1]=,3000  
ET [2]=,2250  
ET [3]=,1500
```

This specifies the ECAM table.

Step 5. Enable the ECAM

To enable the ECAM mode, use the command

```
EB n
```

where n=1 enables ECAM mode and n=0 disables ECAM mode.

Step 6. Engage the slave motion

To engage the slave motion, use the instruction

```
EG x,y,z,w
```

where x,y,z,w are the master positions at which the corresponding slaves must be engaged.

If the value of any parameter is outside the range of one cycle, the cam engages immediately. When the cam is engaged, the slave position is redefined, modulo one cycle.

Step 7. Disengage the slave motion

To disengage the cam, use the command

```
EQ x,y,z,w
```

where x,y,z,w are the master positions at which the corresponding slave axes are disengaged.

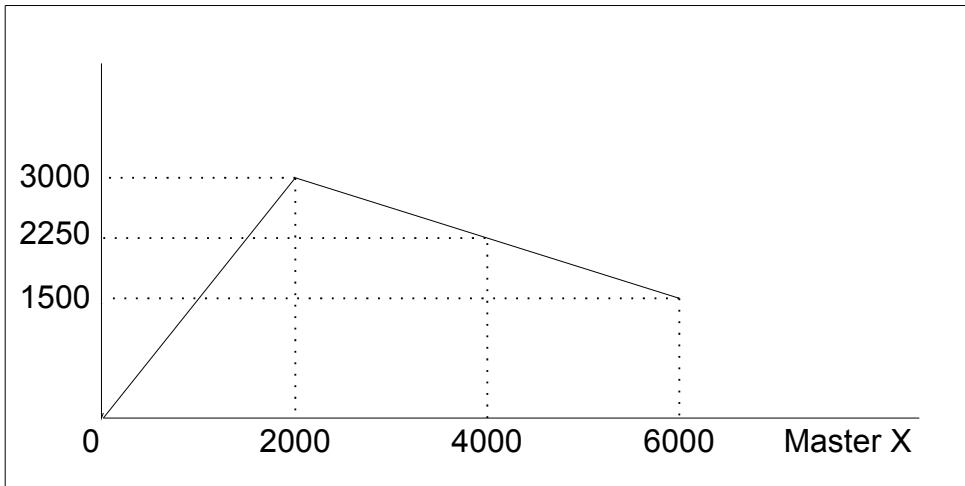


Figure 6.10: Electronic Cam Example

This disengages the slave axis at a specified master position. If the parameter is outside the master cycle, the stopping is instantaneous.

To illustrate the complete process, consider the cam relationship described by the equation:

$$Y = 0.5 * X + 100 \sin (0.18*X)$$

where X is the master, with a cycle of 2000 counts.

The cam table can be constructed manually, point by point, or automatically by a program. The following program includes the set-up.

The instruction EAX defines X as the master axis. The cycle of the master is 2000. Over that cycle, Y varies by 1000. This leads to the instruction EM 2000,1000.

Suppose we want to define a table with 100 segments. This implies increments of 20 counts each. If the master points are to start at zero, the required instruction is EP 20,0.

The following routine computes the table points. As the phase equals $0.18X$ and X varies in increments of 20, the phase varies by increments of 3.6° . The program then computes the values of Y according to the equation and assigns the values to the table with the instruction ET[N] = ,Y.

INSTRUCTION	INTERPRETATION
#SETUP	Label
EAX	Select X as master
EM 2000,1000	Cam cycles
EP 20,0	Master position increments
N = 0	Index
#LOOP	Loop to construct table from equation
P = N*3.6	Note $3.6 = 0.18 * 20$
S = @SIN [P]*100	Define sine position
Y = N*10+S	Define slave position
ET [N] =, Y	Define table
N = N+1	
JP #LOOP, N<=100	Repeat the process
EN	

Now suppose that the slave axis is engaged with a start signal, input 1, but that both the engagement and disengagement points must be done at the center of the cycle: X = 1000 and Y = 500. This implies that Y must be driven to that point to avoid a jump.

This is done with the program:

INSTRUCTION	INTERPRETATION
#RUN	Label
EB1	Enable cam
PA,500	starting position
SP,5000	Y speed
BGY	Move Y motor
AM	After Y moved
AI1	Wait for start signal
EG,1000	Engage slave
AI - 1	Wait for stop signal
EQ,1000	Disengage slave
EN	End

Command Summary - Electronic CAM

Command	Description
EA p	Specifies master axes for electronic cam where: p = X,Y,Z or W or A,B,C,D,E,F,G,H for main encoder as master or M or N a for virtual axis master
EB n	Enables the ECAM
EC n	ECAM counter - sets the index into the ECAM table
EG x,y,z,w	Engages ECAM
EM x,y,z,w	Specifies the change in position for each axis of the CAM cycle
EP m,n	Defines CAM table entry size and offset
EQ m,n	Disengages ECAM at specified position
ET[n]	Defines the ECAM table entries
EW	Widen Segment (see Application Note #2444)
EY	Set ECAM cycle count

Operand Summary - Electronic CAM

Command	Description
_EB	Contains State of ECAM
_EC	Contains current ECAM index
_EGx	Contains ECAM status for each axis
_EM	Contains size of cycle for each axis
_EP	Contains value of the ECAM table interval
_EQx	Contains ECAM status for each axis
_EY	Set ECAM cycle count

Example - Electronic CAM

The following example illustrates a cam program with a master axis, Z, and two slaves, X and Y.

INSTRUCTION	INTERPRETATION
#A;V1=0	Label; Initialize variable
PA 0,0;BGXY;AMXY	Go to position 0,0 on X and Y axes
EA Z	Z axis as the Master for ECAM
EM 0,0,4000	Change for Z is 4000, zero for X, Y
EP400,0	ECAM interval is 400 counts with zero start
ET[0]=0,0	When master is at 0 position; 1 st point.
ET[1]=0,0	2 nd point in the ECAM table
ET[2]=120,60	3 rd point in the ECAM table
ET[3]=240,120	4 th point in the ECAM table
ET[4]=360,180	5 th point in the ECAM table
ET[5]=360,180	6 th point in the ECAM table
ET[6]=360,180	7 th point in the ECAM table
ET[7]=240,120	8 th point in the ECAM table
ET[8]=120,60	9 th point in the ECAM table

ET[9]=0,0	10 th point in the ECAM table
ET[10]=0,0	Starting point for next cycle
EB 1	Enable ECAM mode
JGZ=4000	Set Z to jog at 4000
EG 0,0	Engage both X and Y when Master = 0
BGZ	Begin jog on Z axis
#LOOP;JP#LOOP,V1=0	Loop until the variable is set
EQ2000,2000	Disengage X and Y when Master = 2000
MF,, 2000	Wait until the Master goes to 2000
ST Z	Stop the Z axis motion
EB 0	Exit the ECAM mode
EN	End of the program

The above example shows how the ECAM program is structured and how the commands can be given to the controller. Figure 6.11 shows the GalilTools scope capture of the ECAM profile. This shows how the motion will be seen during the ECAM cycles. The first trace is for the A axis, the second trace shows the cycle on the B axis and the third trace shows the cycle of the C axis.

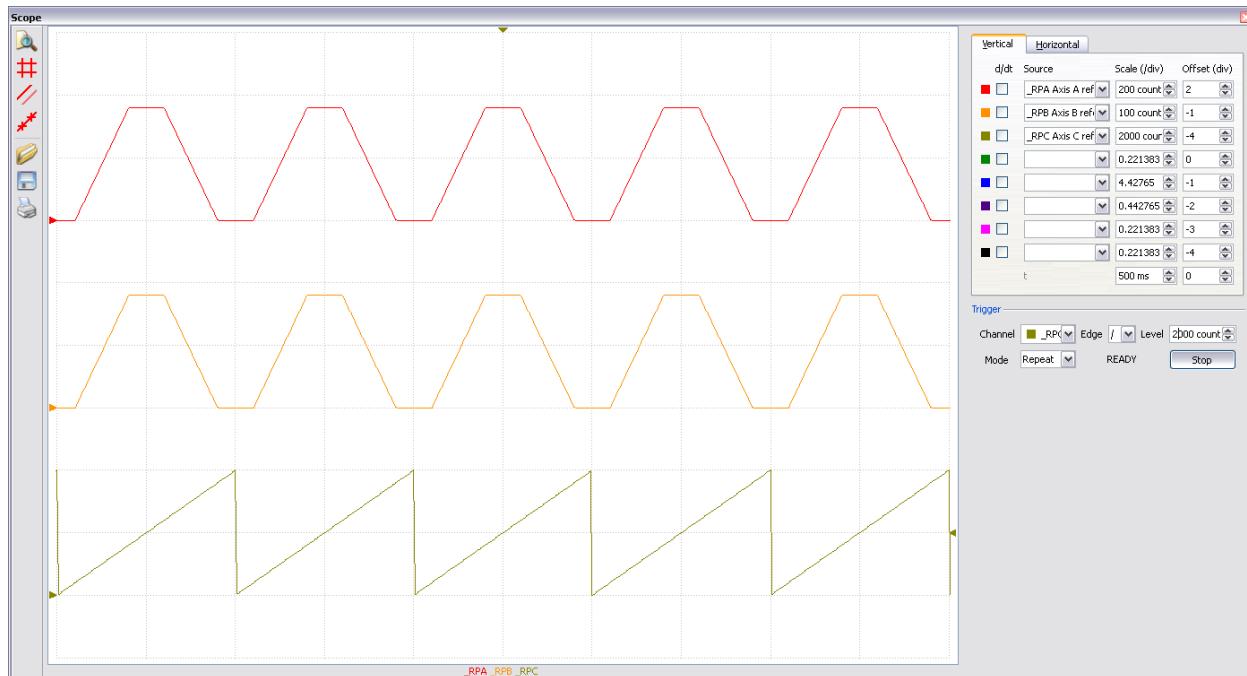


Figure 6.11: ECAM cycle with Z axis as master

PVT Mode

The DMC-41x3 controllers now supports a mode of motion referred to as “PVT.” This mode allows arbitrary motion profiles to be defined by position, velocity and time individually on all 8 axes. This motion is designed for systems where the load must traverse a series of coordinates with no discontinuities in velocity. By specifying the target position, velocity and time to achieve those parameters the user has control over the velocity profile. Taking advantage of the built in buffering the user can create virtually any profile including those with infinite path lengths.

Specifying PVT Segments

PVT segments must be entered one axis at a time using the PVn command. The PV command includes the target distance to be moved and target velocity to be obtained over the specified timeframe. Positions are entered as relative moves, similar to the standard PR command, in units of encoder counts and velocity is entered in counts/second. The controller will interpolate the motion profile between subsequent PV commands using a 3rd order polynomial equation. During a PV segment, jerk is held constant, and accelerations, velocities, and positions will be calculated every other sample.

Motion will not begin until a BT command is issued, much like the standard BG command. This means that the user can fill the PVT buffer for each axis prior to motion beginning. The BT command will ensure that all axes begin motion simultaneously. It is not required for the “t” value for each axis to be the same, however if they are then the axes will remain coordinated. Each axis has a 255 segment buffer. This buffer is a FIFO and the available space can be queried with the operand _PVn. As the buffer empties the user can add more PVT segments.

Exiting PVT Mode

To exit PVT mode the user must send the segment command PVn=0,0,0. This will exit the mode once the segment is reached in the buffer. To avoid an abrupt stop the user should slow the motion to a zero velocity prior to executing this command. The controller will instantly command a zero velocity once a PVn=0,0,0 is executed. In addition, a ST command will also exit PVT mode. Motion will come to a controlled stop using the DC value for deceleration. The same controlled stop will occur if a limit switch is activated in the direction of motion. As a result, the controller will be switched to a jog mode of motion.

Error Conditions and Stop Codes

If the buffer is allowed to empty while in PVT mode then the profiling will be aborted and the motor will come to a controlled stop on that axis with a deceleration specified by the DC command. Also, PVT mode will be exited and the stop code will be set to 32. During normal operation of PVT mode the stop code will be 30. If PVT mode is exited normally (PVn=0,0,0), then the stop code will be set to 31.

Additional PVT Information

It is the users’ responsibility to enter PVT data that the system’s mechanics and power system can respond to in a reasonable manner. Because this mode of motion is not constrained by the AC, DC or SP values, if a large velocity or position is entered with a short period to achieve it, the acceleration can be very high, beyond the capabilities of the system, resulting in excessive position error. The position and velocity at the end of the segment are guaranteed to be accurate but it is important to remember that the required path to obtain the position and velocity in the specified time may be different based on the PVT values. Mismatched values for PVT can result in different interpolated profiles than expected but the final velocity and position will be accurate.

The “t” value is entered in samples, which will depend on the TM setting. With the default TM of 1000, one sample is 976us. This means that a “t” value of 1024 will yield one second of motion. The velocity value, “v” will always be in units of counts per second, regardless of the TM setting. PVT mode is not available in the “-FAST” version of the firmware. If this is required please consult Galil.

Command Summary – PVT

COMMAND	DESCRIPTION
PVa = p,v,t	Specifies the segment of axis 'a' for a incremental PVT segment of 'p' counts, an end speed of 'v' counts/sec in a total time of 't' samples.
_PVa	Contains the number of PV segments available in the PV buffer for a specified axes.
BT	Begin PVT mode
_BTa	Contains the number PV segments that have executed

PVT Examples

Parabolic Velocity Profile

In this example we will assume that the user wants to start from zero velocity, accelerate to a maximum velocity of 1000 counts/second in 1 second and then back down to 0 counts/second within an additional second. The velocity profile would be described by the following equation and shown in Figure 6.12.

$$v(t) = -1000(t - 1)^2 + 1000$$

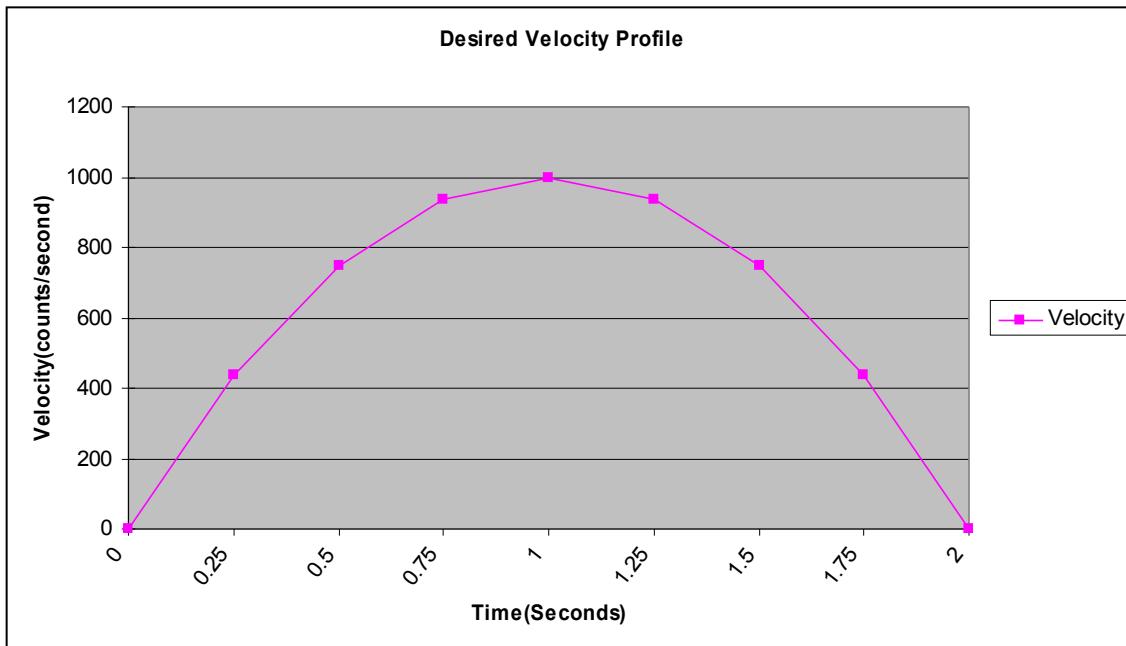


Figure 6.12: Parabolic Velocity Profile

To accomplish this we need to calculate the desired velocities and change in positions. In this example we will assume a delta time of $\frac{1}{4}$ of a second, which is 256 samples (1024 samples = 1 second with the default TM of 1000).

Velocity(counts/second)	Position(counts)
$v(t) = -1000(t - 1)^2 + 1000$	$p(t) = \int (-1000(t - 1)^2 + 1000)dt$

$v(.25) = 437.5$	$p(0 \text{ to } .25) = 57$
$v(.5) = 750$	$p(.25 \text{ to } .5) = 151$
$v(.75) = 937.5$	$p(.5 \text{ to } .75) = 214$
$v(1) = 1000$	$p(.75 \text{ to } 1) = 245$
$v(1.25) = 937.5$	$p(1 \text{ to } 1.25) = 245$
$v(1.5) = 750$	$p(1.25 \text{ to } 1.5) = 214$
$v(1.75) = 437.5$	$p(1.5 \text{ to } 1.75) = 151$
$v(2) = 0$	$p(1.75 \text{ to } 2) = 57$

The DMC program is shown below and the results can be seen in Figure 6.13.

INSTRUCTION	INTERPRETATION
#PVT	Label
PVX = 57,437,256	Incremental move of 57 counts in 256 samples with a final velocity of 437 counts/sec
PVX = 151,750,256	Incremental move of 151 counts in 256 samples with a final velocity of 750 counts/sec
PVX = 214,937,256	Incremental move of 214 counts in 256 samples with a final velocity of 937 counts/sec
PVX = 245,1000,256	Incremental move of 245 counts in 256 samples with a final velocity of 1000 counts/sec
PVX = 245,937,256	Incremental move of 245 counts in 256 samples with a final velocity of 937 counts/sec
PVX = 214,750,256	Incremental move of 214 counts in 256 samples with a final velocity of 750 counts/sec
PVX = 151,437,256	Incremental move of 151 counts in 256 samples with a final velocity of 437 counts/sec
PVX = 57,0,256	Incremental move of 57 counts in 256 samples with a final velocity of 0 counts/sec
PVX = 0,0,0	Termination of PVT buffer
BTX	Begin PVT
EN	

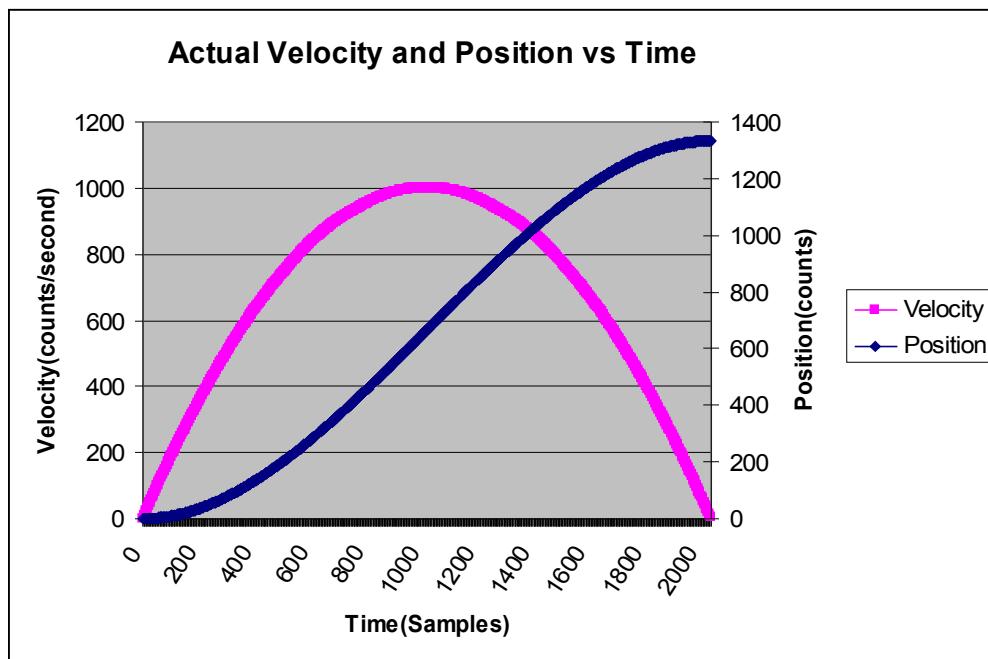


Figure 6.13: Actual Velocity and Position vs Time of Parabolic Velocity Profile

Multi-Axis Coordinated Move

Many applications require moving two or more axes in a coordinated move yet still require smooth motion at the same time. These applications are ideal candidates for PVT mode.

In this example we will have a 2 dimensional stage that needs to follow a specific profile. The application requires that the certain points be met however the path between points is not important. Smooth motion between points is critical.

X Axis	Y Axis
500	500
1500	5000
2500	4000
3300	4200
7300	3300

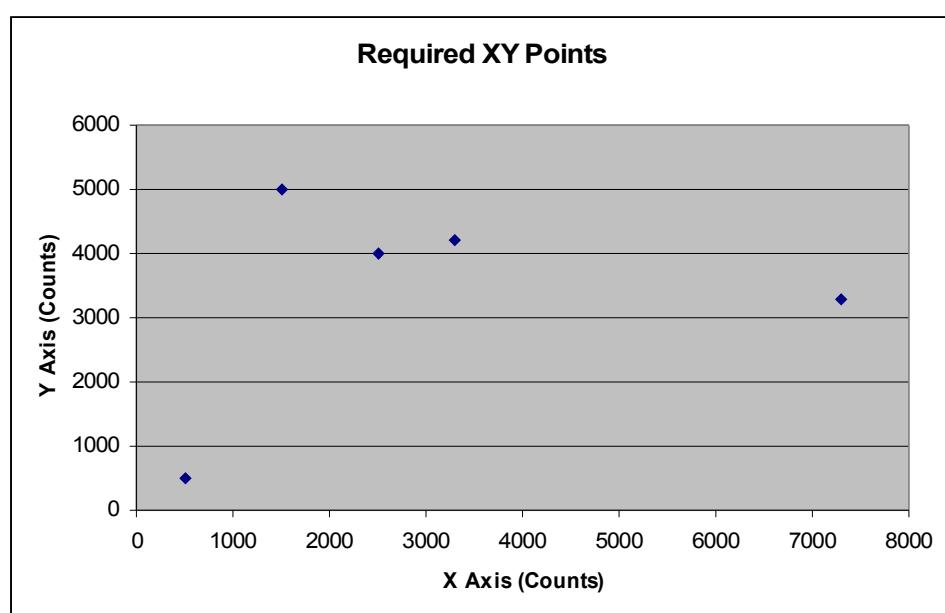


Figure 6.14: Required XY Points

The resultant DMC program is shown below. The position points are dictated by the application requirements and the velocities and times were chosen to create smooth yet quick motion. For example, in the second segment the B axis is slowed to 0 at the end of the move in anticipation of reversing direction during the next segment.

INSTRUCTION	INTERPRETATION
#PVT	Label
PVA = 500,2000,500	1 st point in Figure 6.14 - A axis
PVB = 500,5000,500	1 st point in Figure 6.14 - B axis
PVA = 1000,4000,1200	2 nd point in Figure 6.14 - A axis
PVB = 4500,0,1200	2 nd point in Figure 6.14 - B axis
PVA = 1000,4000,750	3 rd point in Figure 6.14 - A axis
PVB = -1000,1000,750	3 rd point in Figure 6.14 - B axis
BTAB	Begin PVT mode for A and B axes
PVA = 800,10000,250	4 th point in Figure 6.14 - A axis
PVB = 200,1000,250	4 th point in Figure 6.14 - B axis
PVA = 4000,0,1000	5 th point in Figure 6.14 - A axis
PVB = -900,0,1000	5 th point in Figure 6.14 - B axis
PVA = 0,0,0	Termination of PVT buffer for A axis
PVB = 0,0,0	Termination of PVT buffer for B axis
EN	

NOTE: The BT command is issued prior to filling the PVT buffers and additional PV commands are added during motion for demonstration purposes only. The BT command could have been issued at the end of all the PVT points in this example.

The resultant X vs. Y position graph is shown in Figure 6.15, with the specified PVT points enlarged.

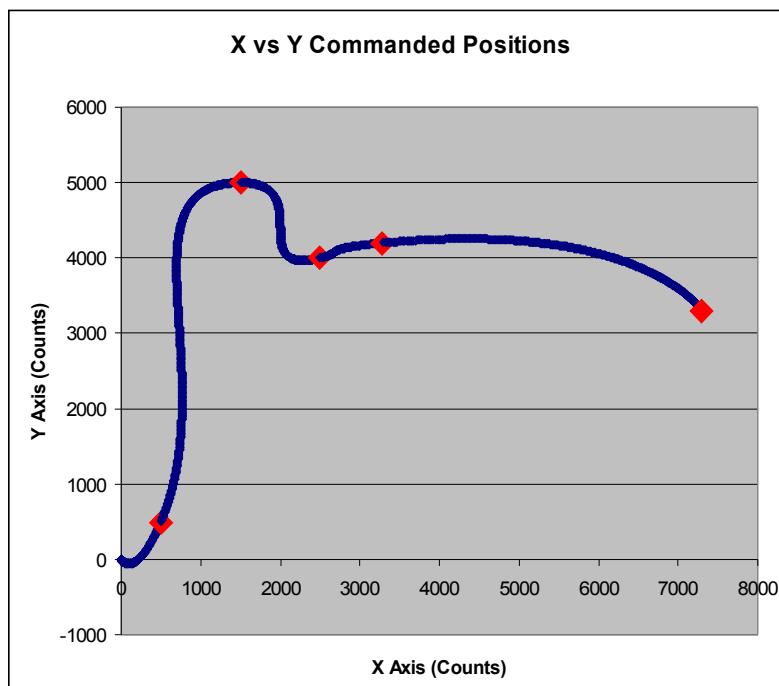


Figure 6.15: X vs Y Commanded Positions for Multi-Axis Coordinated Move

Contour Mode

The DMC-41x3 also provides a contouring mode. This mode allows any arbitrary position curve to be prescribed for 1 to 8 axes. This is ideal for following computer generated paths such as parabolic, spherical or user-defined profiles. The path is not limited to straight line and arc segments and the path length may be infinite.

Specifying Contour Segments

The Contour Mode is specified with the command, CM. For example, CMXZ specifies contouring on the X and Z axes. Any axes that are not being used in the contouring mode may be operated in other modes.

A contour is described by position increments which are described with the command, CD x,y,z,w over a time interval, DT n. The parameter, n, specifies the time interval. The time interval is defined as 2^n sample period (1 ms for TM1000), where n is a number between 1 and 8. The controller performs linear interpolation between the specified increments, where one point is generated for each sample. If the time interval changes for each segment, use CD x,y,z,w=n where n is the new DT value.

Consider, for example, the trajectory shown in Figure 6.16. The position X may be described by the points:

Point 1	X=0 at T=0ms
Point 2	X=48 at T=4ms
Point 3	X=288 at T=12ms
Point 4	X=336 at T=28ms

The same trajectory may be represented by the increments

Increment 1	DX=48	Time=4	DT=2
Increment 2	DX=240	Time=8	DT=3
Increment 3	DX=48	Time=16	DT=4

When the controller receives the command to generate a trajectory along these points, it interpolates linearly between the points. The resulting interpolated points include the position 12 at 1 msec, position 24 at 2 msec, etc.

The programmed commands to specify the above example are:

```
#A
CMX          Specifies X axis for contour mode
CD 48=2      Specifies first position increment and time interval,  $2^2$  ms
CD 240=3     Specifies second position increment and time interval,  $2^3$  ms
CD 48=4      Specifies the third position increment and time interval,  $2^4$  ms
CD 0=0        End Contour buffer
#Wait;JP#Wait,_CM<>511    Wait until path is done
EN
```

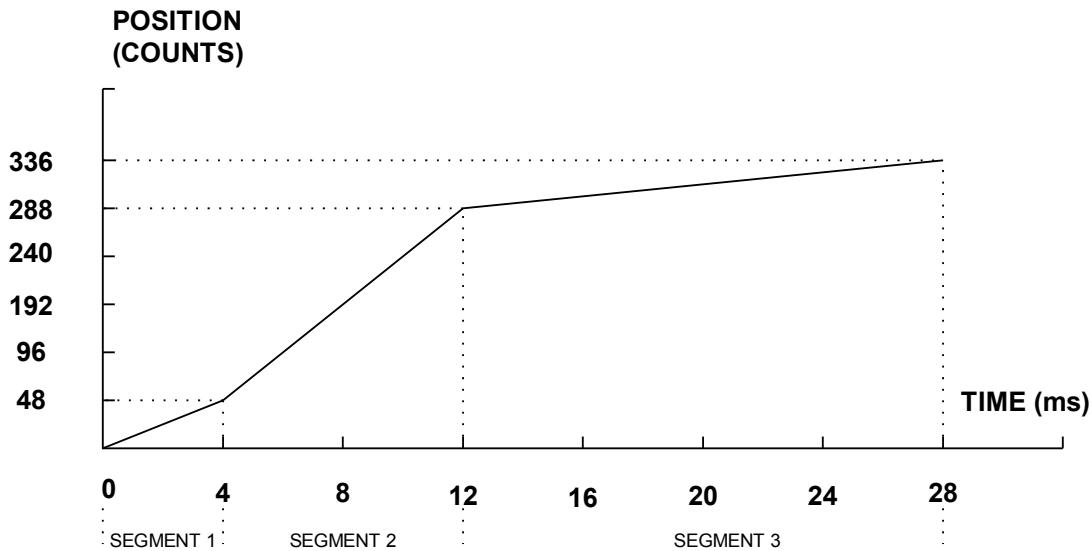


Figure 6.16: The Required Trajectory

Additional Commands

CM gives the amount of space available in the contour buffer (511 maximum). Zero parameters for DT followed by zero parameters for CD will exit the contour mode.

If no new data record is found and the controller is still in the contour mode, the controller waits for new data. No new motion commands are generated while waiting. If bad data is received, the controller responds with a ?.

Specifying a -1 for the DT or as the time interval in the CD command will pause the contour buffer.

Issuing the CM command will clear the contour buffer.

Command Summary - Contour Mode

COMMAND	DESCRIPTION
CM XYZW	Specifies which axes for contouring mode. Any non-contouring axes may be operated in other modes.
CM ABCDEFGH	Contour axes for DMC-4183
CD x,y,z,w	Specifies position increment over time interval. Range is +/-32,000. CD 0,0,0..=0 ends the contour buffer. This is much like the LE or VE commands.
CD a,b,c,d,e,f,g,h	Position increment data for DMC-4183
DT n	Specifies time interval 2^n sample periods (1 ms for TM1000) for position increment, where n is an integer between 1 and 8. Zero ends contour mode. If n does not change, it does not need to be specified with each CD.
_CM	Amount of space left in contour buffer (511 maximum)

General Velocity Profiles

The Contour Mode is ideal for generating any arbitrary velocity profiles. The velocity profile can be specified as a mathematical function or as a collection of points.

The design includes two parts: Generating an array with data points and running the program.

Generating an Array - An Example

Consider the velocity and position profiles shown in Figure 6.17. The objective is to rotate a motor a distance of 6000 counts in 120 ms. The velocity profile is sinusoidal to reduce the jerk and the system vibration. If we describe the position displacement in terms of A counts in B milliseconds, we can describe the motion in the following manner:

$$\omega = \frac{A}{B} (1 - \cos(2\pi / B))$$

$$X = \frac{AT}{B} - \frac{A}{2\pi} \sin(2\pi / B)$$

Note: ω is the angular velocity; X is the position; and T is the variable, time, in milliseconds.

In the given example, A=6000 and B=120, the position and velocity profiles are:

$$X = 50T - (6000/2\pi) \sin(2\pi T/120)$$

Note that the velocity, ω , in count/ms, is

$$\omega = 50 [1 - \cos 2\pi T/120]$$

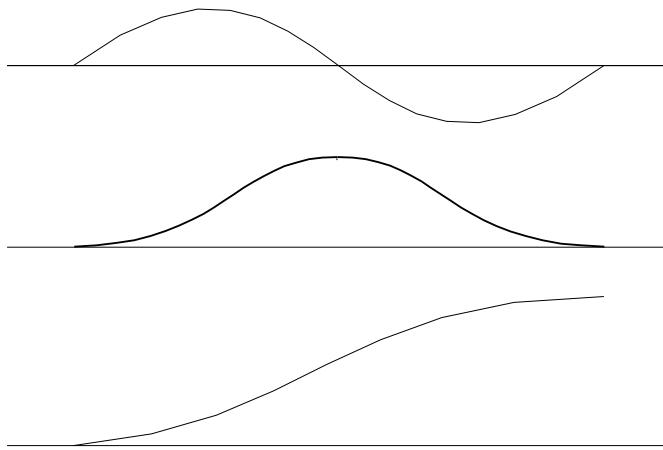


Figure 6.17: Velocity Profile with Sinusoidal Acceleration

The DMC-41x3 can compute trigonometric functions. However, the argument must be expressed in degrees. Using our example, the equation for X is written as:

$$X = 50T - 955 \sin 3T$$

A complete program to generate the contour movement in this example is given below. To generate an array, we compute the position value at intervals of 8 ms. This is stored at the array POS. Then, the difference between the positions is computed and is stored in the array DIF. Finally the motors are run in the contour mode.

Contour Mode Example

INSTRUCTION	INTERPRETATION
#POINTS	Program defines X points
DM POS[16]	Allocate memory
DM DIF[15]	
C=0	Set initial conditions, C is index
T=0	T is time in ms
#A	
V1=50*T	
V2=3*T	Argument in degrees
V3=-955*@SIN[V2]+V1	Compute position

```

V4=@INT[V3]           Integer value of V3
POS[C]=V4             Store in array POS
T=T+8
C=C+1
JP #A,C<16
#B                   Program to find position differences
C=0
#C
D=C+1
DIF[C]=POS[D]-POS[C] Compute the difference and store
C=C+1
JP #C,C<15

#RUN                 Program to run motor
CMX                  Contour Mode
DT3                  8 millisecond intervals
C=0
#E
CD DIF[C]            Contour Distance is in DIF
C=C+1
JP #E,C<15
CD 0=0               End contour buffer
#Wait;JP#Wait,_CM<>511 Wait until path is done
EN                  End the program

```

Teach (Record and Play-Back)

Several applications require teaching the machine a motion trajectory. Teaching can be accomplished using the DMC-41x3 automatic array capture feature to capture position data. The captured data may then be played back in the contour mode. The following array commands are used:

DM C[n]	Dimension array
RA C[]	Specify array for automatic record (up to 4 for DMC-4143)
RD _TPX	Specify data for capturing (such as _TPX or _TPZ)
RC n,m	Specify capture time interval where n is 2 ⁿ sample periods (1 ms for TM1000), m is number of records to be captured
RC? or _RC	Returns a 1 if recording

Record and Playback Example:

```

#RECORD                Begin Program
DM XPOS[501]            Dimension array with 501 elements
RA XPOS[]               Specify automatic record
RD _TPX                 Specify X position to be captured
MOX                     Turn X motor off
RC2                     Begin recording; 4 msec interval (at TM1000)
#A;JP#A,_RC=1            Continue until done recording
#COMPUTE                Compute DX
DM DX[500]               Dimension Array for DX
C=0                     Initialize counter
#L                      Label

```

```

D=C+1
DELTA=XPOS[D]-XPOS[C]      Compute the difference
DX[C]=DELTA                 Store difference in array
C=C+1                        Increment index
JP #L,C<500                  Repeat until done
#PLAYBCK                      Begin Playback
CMX                           Specify contour mode
DT2                           Specify time increment
I=0                            Initialize array counter
#B                            Loop counter
CD DX[I]; I=I+1              Specify contour data I=I+1 Increment array counter
JP #B,I<500                   Loop until done
CD 0=0                        End countour buffer
#Wait;JP#Wait,_CM<>511     Wait until path is done
EN                            End program

```

For additional information about automatic array capture, see [Chapter 7, Arrays](#).

Virtual Axis

The DMC-41x3 controller has two additional virtual axes designated as the M and N axes. These axes have no encoder and no DAC. However, they can be commanded by the commands:

AC, DC, JG, SP, PR, PA, BG, IT, GA, VM, VP, CR, ST, DP, RP

The main use of the virtual axes is to serve as a virtual master in ECAM modes, and to perform an unnecessary part of a vector mode. These applications are illustrated by the following examples.

ECAM Master Example

Suppose that the motion of the XY axes is constrained along a path that can be described by an electronic cam table. Further assume that the ecam master is not an external encoder but has to be a controlled variable.

This can be achieved by defining the N axis as the master with the command EAN and setting the modulo of the master with a command such as EMN= 4000. Next, the table is constructed. To move the constrained axes, simply command the N axis in the jog mode or with the PR and PA commands.

For example,

```

PAN = 2000
BGN

```

will cause the XY axes to move to the corresponding points on the motion cycle.

Sinusoidal Motion Example

The x axis must perform a sinusoidal motion of 10 cycles with an amplitude of 1000 counts and a frequency of 20 Hz.

This can be performed by commanding the X and N axes to perform circular motion. Note that the value of VS must be

$$VS=2\pi * R * F$$

where R is the radius, or amplitude and F is the frequency in Hz.

Set VA and VD to maximum values for the fastest acceleration.

INSTRUCTION	INTERPRETATION
VMXN	Select Axes

VA 68000000	Maximum Acceleration
VD 68000000	Maximum Deceleration
VS 125664	VS for 20 Hz
CR 1000, -90, 3600	Ten Cycles
VE	
BGS	

Stepper Motor Operation

When configured for stepper motor operation, several commands are interpreted differently than from servo mode. The following describes operation with stepper motors.

Specifying Stepper Motor Operation

Stepper motor operation is specified by the command MT. The argument for MT is as follows:

- 2 specifies a stepper motor with active low step output pulses
- 2 specifies a stepper motor with active high step output pulses
- 2.5 specifies a stepper motor with active low step output pulses and reversed direction
- 2.5 specifies a stepper motor with active high step output pulse and reversed direction

Stepper Motor Smoothing

The command, KS, provides stepper motor smoothing. The effect of the smoothing can be thought of as a simple Resistor-Capacitor (single pole) filter. The filter occurs after the motion profiler and has the effect of smoothing out the spacing of pulses for a more smooth operation of the stepper motor. Use of KS is most applicable when operating in full step or half step operation. KS will cause the step pulses to be delayed in accordance with the time constant specified.

When operating with stepper motors, you will always have some amount of stepper motor smoothing, KS. Since this filtering effect occurs after the profiler, the profiler may be ready for additional moves before all of the step pulses have gone through the filter. It is important to consider this effect since steps may be lost if the controller is commanded to generate an additional move before the previous move has been completed. See the discussion below, Monitoring Generated Pulses vs. Commanded Pulses.

The general motion smoothing command, IT, can also be used. The purpose of the command, IT, is to smooth out the motion profile and decrease 'jerk' due to acceleration.

Monitoring Generated Pulses vs. Commanded Pulses

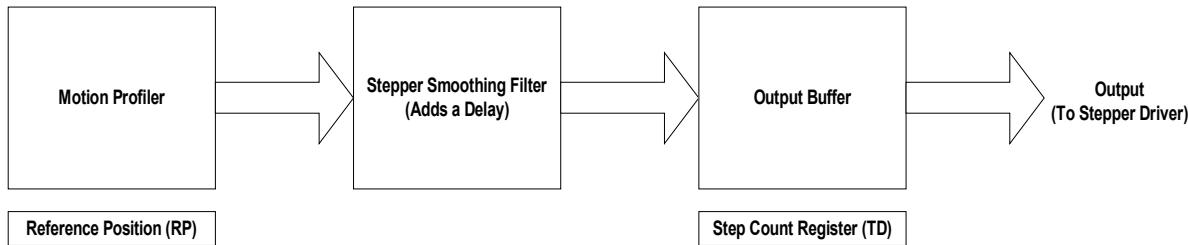
For proper controller operation, it is necessary to make sure that the controller has completed generating all step pulses before making additional moves. This is most particularly important if you are moving back and forth. For example, when operating with servo motors, the trippoint AM (After Motion) is used to determine when the motion profiler is complete and is prepared to execute a new motion command. However when operating in stepper mode, the controller may still be generating step pulses when the motion profiler is complete. This is caused by the stepper motor smoothing filter, KS. To understand this, consider the steps the controller executes to generate step pulses:

First, the controller generates a motion profile in accordance with the motion commands.

Second, the profiler generates pulses as prescribed by the motion profile. The pulses that are generated by the motion profiler can be monitored by the command, RP (Reference Position). RP gives the absolute value of the position as determined by the motion profiler. The command, DP, can be used to set the value of the reference position. For example, DP 0, defines the reference position of the X axis to be zero.

Third, the output of the motion profiler is filtered by the stepper smoothing filter. This filter adds a delay in the output of the stepper motor pulses. The amount of delay depends on the parameter which is specified by the command, KS. As mentioned earlier, there will always be some amount of stepper motor smoothing.

Fourth, the output of the stepper smoothing filter is buffered and is available for input to the stepper motor driver. The pulses which are generated by the smoothing filter can be monitored by the command, TD (Tell Dual). TD gives the absolute value of the position as determined by actual output of the buffer. The command, DP sets the value of the step count register as well as the value of the reference position. For example, DP 0, defines the reference position of the X axis to be zero.



Motion Complete Trippoint

When used in stepper mode, the MC command will hold up execution of the proceeding commands until the controller has generated the same number of steps out of the step count register as specified in the commanded position. The MC trippoint (Motion Complete) is generally more useful than AM trippoint (After Motion) since the step pulses can be delayed from the commanded position due to stepper motor smoothing.

Using an Encoder with Stepper Motors

An encoder may be used on a stepper motor to check the actual motor position with the commanded position. If an encoder is used, it must be connected to the main encoder input. Note: The auxiliary encoder is not available while operating with stepper motors. The position of the encoder can be interrogated by using the command, TP. The position value can be defined by using the command, DE.

Note: Closed loop operation with a stepper motor is not possible.

Command Summary - Stepper Motor Operation

COMMAND	DESCRIPTION
DE	Define Encoder Position (When using an encoder)
DP	Define Reference Position and Step Count Register
IT	Motion Profile Smoothing - Independent Time Constant
KS	Stepper Motor Smoothing
MT	Motor Type (2,-2,2.5 or -2.5 for stepper motors)
RP	Report Commanded Position
TD	Report number of step pulses generated by controller
TP	Tell Position of Encoder

Operand Summary - Stepper Motor Operation

OPERAND	DESCRIPTION
_DEx	Contains the value of the step count register for the 'x' axis
_DPx	Contains the value of the main encoder for the 'x' axis
_ITx	Contains the value of the Independent Time constant for the 'x' axis

<u>_KSx</u>	Contains the value of the Stepper Motor Smoothing Constant for the ‘x’ axis
<u>_MTx</u>	Contains the motor type value for the ‘x’ axis
<u>_RPx</u>	Contains the commanded position generated by the profiler for the ‘x’ axis
<u>_TDx</u>	Contains the value of the step count register for the ‘x’ axis
<u>_TPx</u>	Contains the value of the main encoder for the ‘x’ axis

Stepper Position Maintenance Mode (SPM)

The Galil controller can be set into the Stepper Position Maintenance (SPM) mode to handle the event of stepper motor position error. The mode looks at position feedback from the main encoder and compares it to the commanded step pulses. The position information is used to determine if there is any significant difference between the commanded and the actual motor positions. If such error is detected, it is updated into a command value for operator use. In addition, the SPM mode can be used as a method to correct for friction at the end of a microstepping move. This capability provides closed-loop control at the application program level. SPM mode can be used with Galil and non-Galil step drives.

SPM mode is configured, executed, and managed with seven commands. This mode also utilizes the #POSERR automatic subroutine allowing for automatic user-defined handling of an error event.

Internal Controller Commands (user can query):

QS Error Magnitude (pulses)

User Configurable Commands (user can query & change):

OE	Profiler Off-On Error
YA	Step Drive Resolution (pulses / full motor step)
YB	Step Motor Resolution (full motor steps / revolution)
YC	Encoder Resolution (counts / revolution)
YR	Error Correction (pulses)
YS	Stepper Position Maintenance enable, status

A pulse is defined by the resolution of the step drive being used. Therefore, one pulse could be a full step, a half step or a microstep.

When a Galil controller is configured for step motor operation, the step pulse output by the controller is internally fed back to the auxiliary encoder register. For SPM the feedback encoder on the stepper will connect to the main encoder port. Enabling the SPM mode on a controller with YS=1 executes an internal monitoring of the auxiliary and main encoder registers for that axis or axes. Position error is then tracked in step pulses between these two registers (QS command).

$$QS = TD - \frac{TP \times YA \times YB}{YC}$$

Where TD is the auxiliary encoder register(step pulses) and TP is the main encoder register(feedback encoder). Additionally, YA defines the step drive resolution where YA = 1 for full stepping or YA = 2 for half stepping. The full range of YA is up to YA = 9999 for microstepping drives.

Error Limit

The value of QS is internally monitored to determine if it exceeds a preset limit of three full motor steps. Once the value of QS exceeds this limit, the controller then performs the following actions:

1. The motion is maintained or is stopped, depending on the setting of the OE command. If OE=0 the axis stays in motion, if OE=1 the axis is stopped.
2. YS is set to 2, which causes the automatic subroutine labeled #POSERR to be executed.

Correction

A correction move can be commanded by assigning the value of QS to the YR correction move command. The correction move is issued only after the axis has been stopped. After an error correction move has completed and QS is less than three full motor steps, the YS error status bit is automatically reset back to 1; indicating a cleared error.

Example: SPM Mode Setup

The following code demonstrates what is necessary to set up SPM mode for a full step drive, a half step drive, and a 1/64th microstepping drive for an axis with a 1.8° step motor and 4000 count/rev encoder. Note the necessary difference is with the YA command.

Full-Stepping Drive, X axis:

```
#SETUP
OE1;          Set the profiler to stop axis upon error
KS16;         Set step smoothing
MT-2;         Motor type set to stepper
YA1;          Step resolution of the full-step drive
YB200;        Motor resolution (full steps per revolution)
YC4000;       Encoder resolution (counts per revolution)
SHX;          Enable axis
WT50;         Allow slight settle time
YS1;          Enable SPM mode
```

Half-Stepping Drive, X axis:

```
#SETUP
OE1;          Set the profiler to stop axis upon error
KS16;         Set step smoothing
MT-2;         Motor type set to stepper
YA2;          Step resolution of the half-step drive
YB200;        Motor resolution (full steps per revolution)
YC4000;       Encoder resolution (counts per revolution)
SHX;          Enable axis
WT50;         Allow slight settle time
YS1;          Enable SPM mode
```

1/64th Step Microstepping Drive, X axis:

```
#SETUP
OE1;          Set the profiler to stop axis upon error
KS16;         Set step smoothing
MT-2;         Motor type set to stepper
YA64;         Step resolution of the microstepping drive
YB200;        Motor resolution (full steps per revolution)
YC4000;       Encoder resolution (counts per revolution)
```

```

SHX;           Enable axis
WT50;          Allow slight settle time
YS1;           Enable SPM mode

```

Example: Error Correction

The following code demonstrates what is necessary to set up SPM mode for the X axis, detect error, stop the motor, correct the error, and return to the main code. The drive is a full step drive, with a 1.8° step motor and 4000 count/rev encoder.

```

#SETUP
OE1;           Set the profiler to stop axis upon error
KS16;          Set step smoothing
MT-2,-2,-2,-2; Motor type set to stepper
YA2;           Step resolution of the drive
YB200;          Motor resolution (full steps per revolution)
YC4000;         Encoder resolution (counts per revolution)
SHX;           Enable axis
WT100;          Allow slight settle time

#MOTION
SP512;          Perform motion
PR1000;         Set the speed
BGX;            Prepare mode of motion
#LOOP;JP#LOOP;  Begin motion
               Keep thread zero alive for #POSERR to run in

REM When error occurs, the axis will stop due to OE1. In
REM #POSERR, query the status YS and the error QS, correct,
REM and return to the main code.

#POSERR;        Automatic subroutine is called when YS=2
WT100;          Wait helps user see the correction
spsave=_SPX;    Save current speed setting
JP#RETURN,_YSX<>2; Return to thread zero if invalid error
SP64;           Set slow speed setting for correction
MG"ERROR= ",_QSX
YRX=_QSX;       Else, error is valid, use QS for correction
MCX;            Wait for motion to complete
MG"CORRECTED, ERROR NOW= ",_QSX
WT100;          Wait helps user see the correction

#RETURN
SPX=spsave;    Return the speed to previous setting
RE0;           Return from #POSERR

```

Example: Friction Correction

The following example illustrates how the SPM mode can be useful in correcting for X axis friction after each move when conducting a reciprocating motion. The drive is a 1/64th microstepping drive with a 1.8° step motor and 4000 count/rev encoder.

```
#SETUP;          Set the profiler to continue upon error
```

```

KS16;                      Set step smoothing
MT-2,-2,-2,-2;            Motor type set to stepper
YA64;                      Step resolution of the microstepping drive
YB200;                     Motor resolution (full steps per revolution)
YC4000;                    Encoder resolution (counts per revolution)
SHX;                       Enable axis
WT50;                      Allow slight settle time
YS1;                       Enable SPM mode

#MOTION;                   Perform motion
SP16384;                  Set the speed
PR10000;                  Prepare mode of motion
BGX;                      Begin motion
MCX
JS#CORRECT;                Move to correction
#MOTION2
SP16384;                  Set the speed
PR-10000;                 Prepare mode of motion
BGX;                      Begin motion
MCX
JS#CORRECT;                Move to correction
JP#MOTION
#CORRECT;                  Correction code
spx=_Spx
#LOOP;                     Save speed value
SP2048;                   Set a new slow correction speed
WT100;                     Stabilize
JP#END,@ABS[_QSX]<10;    End correction if error is within defined tolerance
YRX=_QSX;                  Correction move
MCX
WT100;                     Stabilize
JP#LOOP;                   Keep correcting until error is within tolerance
#END;                      End #CORRECT subroutine, returning to code
SPX=spx
EN

```

Dual Loop (Auxiliary Encoder)

The DMC-41x3 provides an interface for a second encoder for each axis except for axes configured for stepper motor operation and axis used in circular compare. When used, the second encoder is typically mounted on the motor or the load, but may be mounted in any position. The most common use for the second encoder is backlash compensation, described below.

The second encoder may be a standard quadrature type, or it may provide pulse and direction. The controller also offers the provision for inverting the direction of the encoder rotation. The main and the auxiliary encoders are configured with the CE command. The command form is CE x,y,z,w (or a,b,c,d,e,f,g,h for controllers with more than 4 axes) where the parameters x,y,z,w each equal the sum of two integers m and n. m configures the main encoder and n configures the auxiliary encoder.

Using the CE Command

m=	Main Encoder	n=	Second Encoder
0	Normal quadrature	0	Normal quadrature
1	Pulse & direction	4	Pulse & direction
2	Reverse quadrature	8	Reversed quadrature
3	Reverse pulse & direction	12	Reversed pulse & direction

For example, to configure the main encoder for reversed quadrature, m=2, and a second encoder of pulse and direction, n=4, the total is 6, and the command for the X axis is:

CE 6

Additional Commands for the Auxiliary Encoder

The command, DE x,y,z,w, can be used to define the position of the auxiliary encoders. For example,

DE 0,500,-30,300

sets their initial values. The positions of the auxiliary encoders may be interrogated with the command, DE?. For example:

DE ?,?,?

returns the value of the X and Z auxiliary encoders.

The auxiliary encoder position may be assigned to variables with the instructions

V1=_DEX

The command, TD XYZW, returns the current position of the auxiliary encoder.

The command, DV 1,1,1,1, configures the auxiliary encoder to be used for backlash compensation.

Backlash Compensation

There are two methods for backlash compensation using the auxiliary encoders:

1. Continuous dual loop
2. Sampled dual loop

To illustrate the problem, consider a situation in which the coupling between the motor and the load has a backlash. To compensate for the backlash, position encoders are mounted on both the motor and the load.

The continuous dual loop combines the two feedback signals to achieve stability. This method requires careful system tuning, and depends on the magnitude of the backlash. However, once successful, this method compensates for the backlash continuously.

The second method, the sampled dual loop, reads the load encoder only at the end point and performs a correction. This method is independent of the size of the backlash. However, it is effective only in point-to-point motion systems which require position accuracy only at the endpoint.

Continuous Dual Loop - Example

Connect the load encoder to the main encoder port and connect the motor encoder to the dual encoder port. The dual loop method splits the filter function between the two encoders. It applies the KP (proportional) and KI (integral) terms to the position error, based on the load encoder, and applies the KD (derivative) term to the motor encoder. This method results in a stable system.

The dual loop method is activated with the instruction DV (Dual Velocity), where

DV 1,1,1,1

activates the dual loop for the four axes and

DV 0,0,0,0

disables the dual loop.

NOTE: that the dual loop compensation depends on the backlash magnitude, and in extreme cases will not stabilize the loop. The proposed compensation procedure is to start with KP=0, KI=0 and to maximize the value of KD under the condition DV1. Once KD is found, increase KP gradually to a maximum value, and finally, increase KI, if necessary.

Sampled Dual Loop - Example

In this example, we consider a linear slide which is run by a rotary motor via a lead screw. Since the lead screw has a backlash, it is necessary to use a linear encoder to monitor the position of the slide. For stability reasons, it is best to use a rotary encoder on the motor.

Connect the rotary encoder to the X-axis and connect the linear encoder to the auxiliary encoder of X. Assume that the required motion distance is one inch, and that this corresponds to 40,000 counts of the rotary encoder and 10,000 counts of the linear encoder.

The design approach is to drive the motor a distance, which corresponds to 40,000 rotary counts. Once the motion is complete, the controller monitors the position of the linear encoder and performs position corrections.

This is done by the following program.

INSTRUCTION	INTERPRETATION
#DUALOOP	Label
CE 0	Configure encoder
DE0	Set initial value
PR 40000	Main move
BGX	Start motion
#Correct	Correction loop
AMX	Wait for motion completion
V1=10000-_DEX	Find linear encoder error
V2=-_TEX/4+V1	Compensate for motor error
JP#END,@ABS[V2]<2	Exit if error is small
PR V2*4	Correction move
BGX	Start correction
JP#CORRECT	Repeat
#END	
EN	

Motion Smoothing

The DMC-41x3 controller allows the smoothing of the velocity profile to reduce the mechanical vibration of the system.

Trapezoidal velocity profiles have acceleration rates which change abruptly from zero to maximum value. The discontinuous acceleration results in jerk which causes vibration. The smoothing of the acceleration profile leads to a continuous acceleration profile and reduces the mechanical shock and vibration.

Using the IT Command:



When operating with servo motors, motion smoothing can be accomplished with the IT command. This command filters the acceleration and deceleration functions to produce a smooth velocity profile. The resulting velocity profile, has continuous acceleration and results in reduced mechanical vibrations.

The smoothing function is specified by the following commands:

IT x,y,z,w Independent time constant

The command, IT, is used for smoothing independent moves of the type JG, PR, PA and to smooth vector moves of the type VM and LM.

The smoothing parameters, x,y,z,w and n are numbers between 0 and 1 and determine the degree of filtering. The maximum value of 1 implies no filtering, resulting in trapezoidal velocity profiles. Smaller values of the smoothing parameters imply heavier filtering and smoother moves.

The following example illustrates the effect of smoothing. Figure 6.18 shows the trapezoidal velocity profile and the modified acceleration and velocity.

Note that the smoothing process results in longer motion time.

Example - Smoothing

PR 20000	Position
AC 100000	Acceleration
DC 100000	Deceleration
SP 5000	Speed
IT .5	Filter for smoothing
BG X	Begin

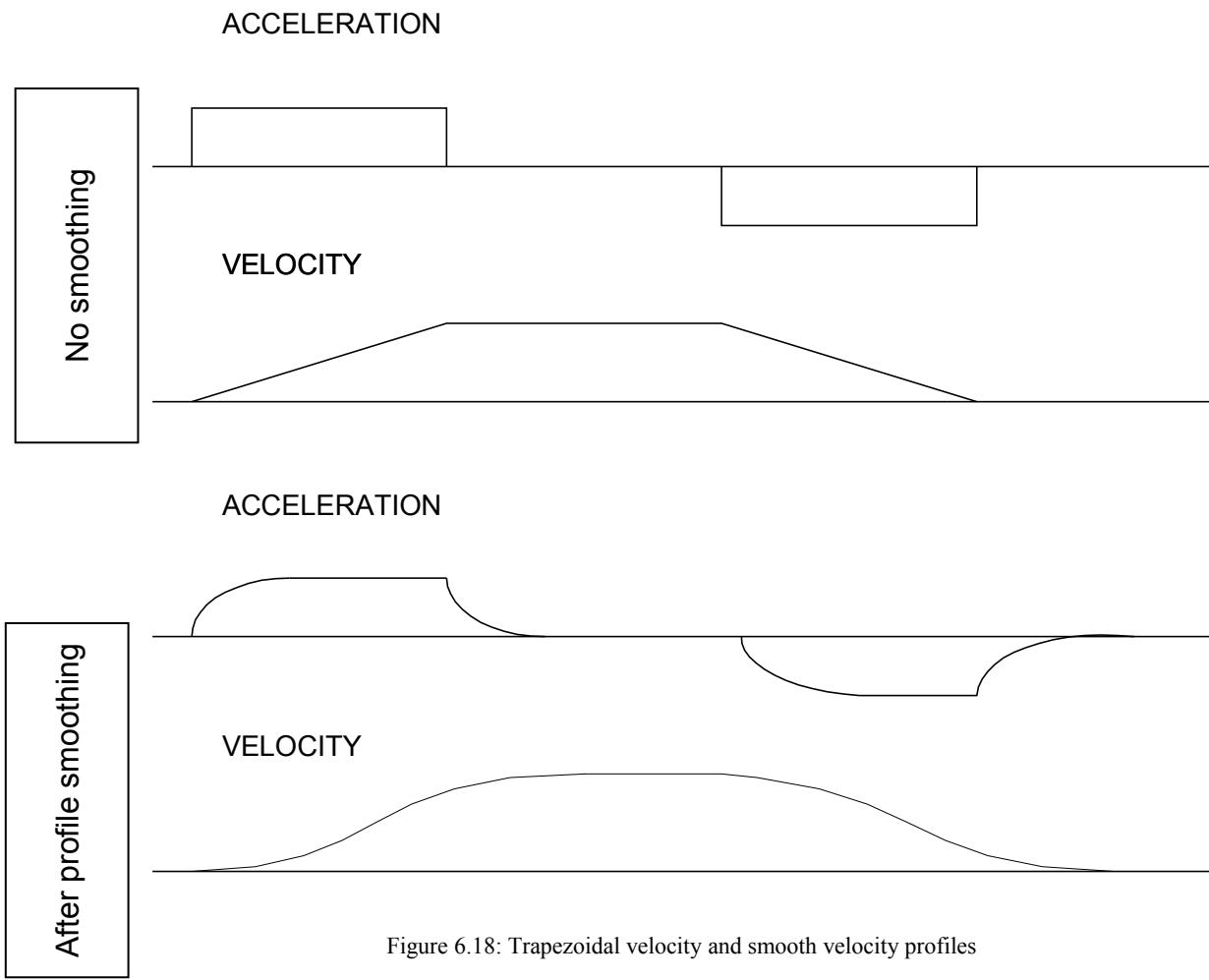


Figure 6.18: Trapezoidal velocity and smooth velocity profiles

Using the KS Command (Step Motor Smoothing):



When operating with step motors, motion smoothing can be accomplished with the command, KS. The KS command smoothes the frequency of step motor pulses. Similar to the command IT, this produces a smooth velocity profile.

The step motor smoothing is specified by the following command:

KS x,y,z,w where x,y,z,w is an integer from 0.5 to 128 and represents the amount of smoothing

The smoothing parameters, x,y,z,w and n are numbers between 0.5 and 128 and determine the degree of filtering. The minimum value of 0.5 implies the least filtering, resulting in trapezoidal velocity profiles. Larger values of the smoothing parameters imply heavier filtering and smoother moves.

Note that KS is valid only for step motors.

Homing

The Find Edge (FE) and Home (HM) instructions may be used to home the motor to a mechanical reference. This reference is connected to the Home input line. The HM command initializes the motor to the encoder index pulse in addition to the Home input. The configure command (CN) is used to define the polarity of the home input.

The Find Edge (FE) instruction is useful for initializing the motor to a home switch. The home switch is connected to the Homing Input. When the Find Edge command and Begin is used, the motor will accelerate up to the slew

speed and slew until a transition is detected on the Homing line. The motor will then decelerate to a stop. A high deceleration value must be input before the find edge command is issued for the motor to decelerate rapidly after sensing the home switch. The Home (HM) command can be used to position the motor on the index pulse after the home switch is detected. This allows for finer positioning on initialization. The HM command and BG command causes the following sequence of events to occur.

Stage 1:

Upon begin, the motor accelerates to the slew speed specified by the JG or SP commands. The direction of its motion is determined by the state of the homing input. If _HMX reads 1 initially, the motor will go in the reverse direction first (direction of decreasing encoder counts). If _HMX reads 0 initially, the motor will go in the forward direction first. CN is the command used to define the polarity of the home input. With CN,-1 (the default value) a normally open switch will make _HMX read 1 initially, and a normally closed switch will make _HMX read zero. Furthermore, with CN,1 a normally open switch will make _HMX read 0 initially, and a normally closed switch will make _HMX read 1. Therefore, the CN command will need to be configured properly to ensure the correct direction of motion in the home sequence.

Upon detecting the home switch changing state, the motor begins decelerating to a stop.

NOTE: The direction of motion for the FE command also follows these rules for the state of the home input.

Stage 2:

The motor then traverses at HV counts/sec in the opposite direction of Stage 1 until the home switch toggles again. If Stage 3 is in the opposite direction of Stage 2, the motor will stop immediately at this point and change direction. If Stage 2 is in the same direction as Stage 3, the motor will never stop, but will smoothly continue into Stage 3.

Stage 3:

The motor traverses forward at HV counts/sec until the encoder index pulse is detected. The motor then decelerates to a stop and goes back to the index.

The DMC-41x3 defines the home position as the position at which the index was detected and sets the encoder reading at this point to zero.

The 4 different motion possibilities for the home sequence are shown in the following table.

Switch Type	CN Setting	Initial _HMX state	Direction of Motion		
			Stage 1	Stage 2	Stage 3
Normally Open	CN,-1	1	Reverse	Forward	Forward
Normally Open	CN,1	0	Forward	Reverse	Forward
Normally Closed	CN,-1	0	Forward	Reverse	Forward
Normally Closed	CN,1	1	Reverse	Forward	Forward

Example: Homing

<u>Instruction</u>	<u>Interpretation</u>
#HOME	Label
CN,-1	Configure the polarity of the home input
AC 1000000	Acceleration Rate
DC 1000000	Deceleration Rate
SP 5000	Speed for Home Search
HM	Home

BG	Begin Motion
AM	After Complete
MG "AT HOME"	Send Message
EN	End

Figure 6.19 shows the velocity profile from the homing sequence of the example program above. For this profile, the switch is normally closed and CN,-1.

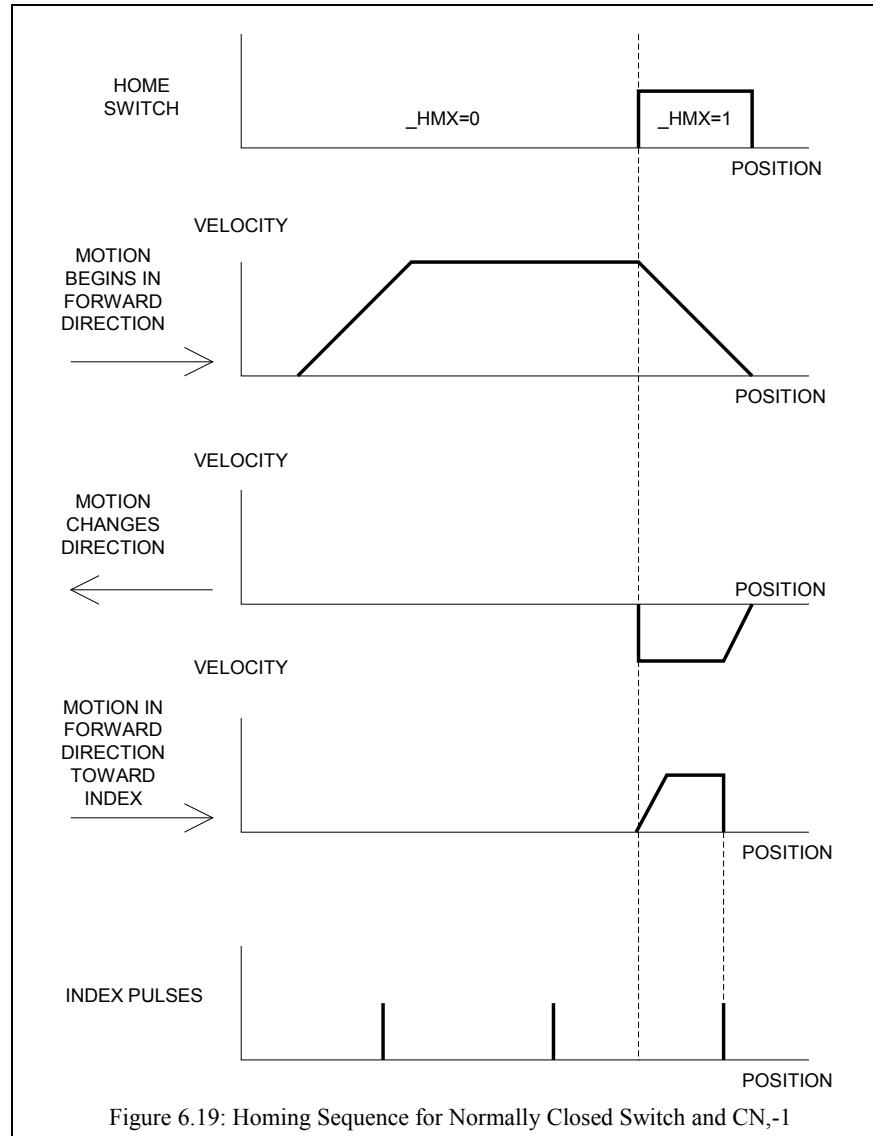


Figure 6.19: Homing Sequence for Normally Closed Switch and CN,-1

Example: Find Edge

#EDGE	Label
AC 2000000	Acceleration rate
DC 2000000	Deceleration rate
SP 8000	Speed
FE	Find edge command
BG	Begin motion
AM	After complete
MG "FOUND HOME"	Send message
DP 0	Define position as 0
EN	End

Command Summary - Homing Operation

command	description
FE XYZW	Find Edge Routine. This routine monitors the Home Input
FI XYZW	Find Index Routine - This routine monitors the Index Input
HM XYZW	Home Routine - This routine combines FE and FI as Described Above
SC XYZW	Stop Code
TS XYZW	Tell Status of Switches and Inputs

Operand Summary - Homing Operation

operand	Description
_HMx	Contains the value of the state of the Home Input
_SCx	Contains stop code
_TSx	Contains status of switches and inputs

High Speed Position Capture (The Latch Function)

Often it is desirable to capture the position precisely for registration applications. The DMC-41x3 provides a position latch feature. This feature allows the position of the main or auxiliary encoders of X,Y,Z or W to be captured within 25 microseconds of an external low input signal (or index pulse). The general inputs 1 through 4 and 9 thru 12 correspond to each axis.

1 through 4:	9 through 12
IN1 X-axis latch	IN9 E-axis latch
IN2 Y-axis latch	IN10 F-axis latch
IN3 Z-axis latch	IN11 G-axis latch
IN4 W-axis latch	IN12 H-axis latch

NOTE: To insure a position capture within 25 microseconds, the input signal must be a transition from high to low.

The DMC-41x3 software commands, AL and RL, are used to arm the latch and report the latched position. The steps to use the latch are as follows:

1. Give the AL XYZW command or ABCDEFGH for DMC-4183, to arm the latch for the main encoder and ALSXSYSZSW for the auxiliary encoders.
2. Test to see if the latch has occurred (Input goes low) by using the _AL X or Y or Z or W command. Example, V1=_ALX returns the state of the X latch into V1. V1 is 1 if the latch has not occurred.
3. After the latch has occurred, read the captured position with the RL XYZW command or _RL XYZW.

NOTE: The latch must be re-armed after each latching event.

Example:

```

#Latch           Latch program
JG,5000         Jog Y
BG Y            Begin motion on Y axis
AL Y            Arm Latch for Y axis
#Wait           #Wait label for loop
JP #Wait,_ALY=1 Jump to #Wait label if latch has not occurred
Result=_RLY     Set value of variable 'Result' equal to the report position of y axis
Result=         Print result
EN              End

```

Fast Update Rate Mode

The DMC-41x3 can operate with much faster servo update rates than the default of every millisecond. This mode is known as ‘fast mode’ and allows the controller to operate with the following update rates:

DMC-4113	62.5 µsec
DMC-4123	62.5 µsec
DMC-4133	125 µsec
DMC-4143	125 µsec
DMC-4153	187.5 µsec
DMC-4163	187.5 µsec
DMC-4173	250 µsec
DMC-4183	250 µsec

In order to run the DMC-41x3 motion controller in fast mode, the fast firmware must be uploaded. This can be done through the GalilTools communication software. The fast firmware is included with the original DMC-41x3 utilities.

In order to set the desired update rates, use the command TM.

When the controller is operating with the fast firmware, some functions are disabled. For details see Fast Update Rate Mode in the Appendix.

Chapter 7 Application Programming

Overview

The DMC-41x3 provides a powerful programming language that allows users to customize the controller for their particular application. Programs can be downloaded into the DMC-41x3 memory freeing the host computer for other tasks. However, the host computer can send commands to the controller at any time, even while a program is being executed. Only ASCII commands can be used for application programming.

In addition to standard motion commands, the DMC-41x3 provides commands that allow the DMC-41x3 to make its own decisions. These commands include conditional jumps, event triggers and subroutines. For example, the command JP#LOOP, n<10 causes a jump to the label #LOOP if the variable n is less than 10.

For greater programming flexibility, the DMC-41x3 provides user-defined variables, arrays and arithmetic functions. For example, with a cut-to-length operation, the length can be specified as a variable in a program which the operator can change as necessary.

The following sections in this chapter discuss all aspects of creating applications programs. The program memory size is 80 characters x 2000 lines.

Program Format

A DMC-41x3 program consists of DMC instructions combined to solve a machine control application. Action instructions, such as starting and stopping motion, are combined with Program Flow instructions to form the complete program. Program Flow instructions evaluate real-time conditions, such as elapsed time or motion complete, and alter program flow accordingly.

Each DMC-41x3 instruction in a program must be separated by a delimiter. Valid delimiters are the semicolon (;) or carriage return. The semicolon is used to separate multiple instructions on a single program line where the maximum number of instructions on a line is limited by 80 characters. A carriage return enters the final command on a program line.

Using Labels in Programs

All DMC-41x3 programs must begin with a label and end with an End (EN) statement. Labels start with the pound (#) sign followed by a maximum of seven characters. The first character must be a letter; after that, numbers are permitted. Spaces are not permitted in a label.

The maximum number of labels which may be defined is 510.

Valid labels

```
#BEGIN  
#SQUARE  
#X1  
#BEGIN1
```

Invalid labels

```
#1Square  
#123
```

A Simple Example Program:

#START	Beginning of the Program
PR 10000,20000	Specify relative distances on X and Y axes
BG XY	Begin Motion
AM	Wait for motion complete
WT 2000	Wait 2 sec
JP #START	Jump to label START
EN	End of Program

The above program moves X and Y 10000 and 20000 units. After the motion is complete, the motors rest for 2 seconds. The cycle repeats indefinitely until the stop command is issued.

Special Labels

The DMC-41x3 have some special labels, which are used to define input interrupt subroutines, limit switch subroutines, error handling subroutines, and command error subroutines. See section on _____

#AMPERR	Label for Amplifier error routine
#AUTO	Label that will automatically run upon the controller exiting a reset (power-on)
#AUTOERR	Label that will automatically run if there is an EEPROM error out of reset
#CMDERR	Label for incorrect command subroutine
#COMINT	Label for Communications Interrupt (See CC Command)
#ININT	Label for Input Interrupt subroutine (See II Command)
#LIMSWI	Label for Limit Switch subroutine
#MCTIME	Label for timeout on Motion Complete trip point
#POSERR	Label for excess Position Error subroutine
#TCPERR	Label for errors over a TCP connection (error code 123)

Commenting Programs

Using the command, NO or Apostrophe (')

The DMC-41x3 provides a command, NO, for commenting programs or single apostrophe. This command allows the user to include up to 78 characters on a single line after the NO command and can be used to include comments from the programmer as in the following example:

```
#PATH  
' 2-D CIRCULAR PATH  
VMXY  
' VECTOR MOTION ON X AND Y  
VS 10000  
' VECTOR SPEED IS 10000  
VP -4000,0  
' BOTTOM LINE  
CR 1500,270,-180  
' HALF CIRCLE MOTION  
VP 0,3000  
' TOP LINE
```

```

CR 1500,90,-180
' HALF CIRCLE MOTION
VE
' END VECTOR SEQUENCE
BGS
' BEGIN SEQUENCE MOTION
EN
' END OF PROGRAM

```

NOTE: The NO command is an actual controller command. Therefore, inclusion of the NO commands will require process time by the controller.

Difference between NO and ' using the GalilTools software

The GalilTools software will treat an apostrophe ('') command different from an NO when the compression algorithm is activated upon a program download (line > 80 characters or program memory > 2000 lines). In this case the software will remove all ('') comments as part of the compression and it will download all NO comments to the controller.

Executing Programs - Multitasking

The DMC-41x3 can run up to 8 independent programs simultaneously. These programs are called threads and are numbered 0 through 7, where 0 is the main thread. Multitasking is useful for executing independent operations such as PLC functions that occur independently of motion.

The main thread differs from the others in the following ways:

1. When input interrupts are implemented for limit switches, position errors or command errors, the subroutines are executed as thread 0.

To begin execution of the various programs, use the following instruction:

```
XQ #A, n
```

Where n indicates the thread number. To halt the execution of any thread, use the instruction

```
HX n
```

where n is the thread number.

Note that both the XQ and HX commands can be performed by an executing program.

The example below produces a waveform on Output 1 independent of a move.

```

#TASK1          Task1 label
ATO            Initialize reference time
CB1            Clear Output 1
#LOOP1         Loop1 label
AT 10          Wait 10 msec from reference time
SB1            Set Output 1
AT -40          Wait 40 msec from reference time, then initialize reference
CB1            Clear Output 1
JP #LOOP1       Repeat Loop1
#TASK2         Task2 label
XQ #TASK1,1     Execute Task1
#LOOP2         Loop2 label
PR 1000        Define relative distance

```

BGX	Begin motion
AMX	After motion done
WT 10	Wait 10 msec
JP #LOOP2,@IN[2]=1	Repeat motion unless Input 2 is low
HX	Halt all tasks

The program above is executed with the instruction XQ #TASK2,0 which designates TASK2 as the main thread (i.e. Thread 0). #TASK1 is executed within TASK2.

Debugging Programs

The DMC-41x3 provides commands and operands which are useful in debugging application programs. These commands include interrogation commands to monitor program execution, determine the state of the controller and the contents of the controllers program, array, and variable space. Operands also contain important status information which can help to debug a program.

Trace Commands

The trace command causes the controller to send each line in a program to the host computer immediately prior to execution. Tracing is enabled with the command, TR1. TR0 turns the trace function off. Note: When the trace function is enabled, the line numbers as well as the command line will be displayed as each command line is executed.

NOTE: When the trace function is enabled, the line numbers as well as the command line will be displayed as each command line is executed.

Error Code Command

When there is a program error, the DMC-41x3 halts the program execution at the point where the error occurs. To display the last line number of program execution, issue the command, MG _ED.

The user can obtain information about the type of error condition that occurred by using the command, TC1. This command reports back a number and a text message which describes the error condition. The command, TC0 or TC, will return the error code without the text message. For more information about the command, TC, see the Command Reference.

Stop Code Command

The status of motion for each axis can be determined by using the stop code command, SC. This can be useful when motion on an axis has stopped unexpectedly. The command SC will return a number representing the motion status. See the command reference for further information.

RAM Memory Interrogation Commands

For debugging the status of the program memory, array memory, or variable memory, the DMC-41x3 has several useful commands. The command, DM ?, will return the number of array elements currently available. The command, DA ?, will return the number of arrays which can be currently defined. For example, a standard DMC-14113 will have a maximum of 16000 array elements in up to 30 arrays. If an array of 100 elements is defined, the command DM ? will return the value 15900 and the command DA ? will return 29.

To list the contents of the variable space, use the interrogation command LV (List Variables). To list the contents of array space, use the interrogation command, LA (List Arrays). To list the contents of the Program space, use the interrogation command, LS (List). To list the application program labels only, use the interrogation command, LL (List Labels).

Operands

In general, all operands provide information which may be useful in debugging an application program. Below is a list of operands which are particularly valuable for program debugging. To display the value of an operand, the message command may be used. For example, since the operand, _ED contains the last line of program execution, the command MG _ED will display this line number.

- _ED contains the last line of program execution. Useful to determine where program stopped.
- _DL contains the number of available labels.
- _UL contains the number of available variables.
- _DA contains the number of available arrays.
- _DM contains the number of available array elements.
- _AB contains the state of the Abort Input
- _LFx contains the state of the forward limit switch for the ‘x’ axis
- _LRx contains the state of the reverse limit switch for the ‘x’ axis

Debugging Example:

The following program has an error. It attempts to specify a relative movement while the X-axis is already in motion. When the program is executed, the controller stops at line 003. The user can then query the controller using the command, TC1. The controller responds with the corresponding explanation:

```
Download Code
#A                      Program Label
PR1000                 Position Relative 1000
BGX                     Begin
PR5000                 Position Relative 5000
EN                      End

From Terminal
:XQ #A                  Execute #A
?003 PR5000              Error on Line 3
:TC1                     Tell Error Code
?7 Command not valid    Command not valid while running
while running.

                                                Change the BGX line to BGX;AMX and re-download the program.
:XQ #A                  Execute #A
```

Program Flow Commands

The DMC-41x3 provides instructions to control program flow. The controller program sequencer normally executes program instructions sequentially. The program flow can be altered with the use of event triggers, trippoints, and conditional jump statements.

Event Triggers & Trippoints

To function independently from the host computer, the DMC-41x3 can be programmed to make decisions based on the occurrence of an event. Such events include waiting for motion to be complete, waiting for a specified amount of time to elapse, or waiting for an input to change logic levels.

The DMC-41x3 provides several event triggers that cause the program sequencer to halt until the specified event occurs. Normally, a program is automatically executed sequentially one line at a time. When an event trigger instruction is decoded, however, the actual program sequence is halted. The program sequence does not continue until the event trigger is “tripped”. For example, the motion complete trigger can be used to separate two move sequences in a program. The commands for the second move sequence will not be executed until the motion is

complete on the first motion sequence. In this way, the controller can make decisions based on its own status or external events without intervention from a host computer.

DMC-41x3 Event Triggers

Command	Function
AM X Y Z W or S (A B C D E F G H)	Halts program execution until motion is complete on the specified axes or motion sequence(s). AM with no parameter tests for motion complete on all axes. This command is useful for separating motion sequences in a program.
AD X or Y or Z or W (A or B or C or D or E or F or G or H)	Halts program execution until position command has reached the specified relative distance from the start of the move. Only one axis may be specified at a time.
AR X or Y or Z or W (A or B or C or D or E or F or G or H)	Halts program execution until after specified distance from the last AR or AD command has elapsed. Only one axis may be specified at a time.
AP X or Y or Z or W (A or B or C or D or E or F or G or H)	Halts program execution until after absolute position occurs. Only one axis may be specified at a time.
MF X or Y or Z or W (A or B or C or D or E or F or G or H)	Halt program execution until after forward motion reached absolute position. Only one axis may be specified. If position is already past the point, then MF will trip immediately. Will function on geared axis or aux. inputs.
MR X or Y or Z or W (A or B or C or D or E or F or G or H)	Halt program execution until after reverse motion reached absolute position. Only one axis may be specified. If position is already past the point, then MR will trip immediately. Will function on geared axis or aux. inputs.
MC X or Y or Z or W (A or B or C or D or E or F or G or H)	Halt program execution until after the motion profile has been completed and the encoder has entered or passed the specified position. TW x,y,z,w sets timeout to declare an error if not in position. If timeout occurs, then the trippoint will clear and the stop code will be set to 99. An application program will jump to label #MCTIME.
AI +/- n	Halts program execution until after specified input is at specified logic level. n specifies input line. Positive is high logic level, negative is low level. n=1 through 8 for DMC-4113, 4123, 4133, 4143. n=1 through 16 for DMC-4153, 4163, 4173, 4183 Also n= 17-48
AS X Y Z W S (A B C D E F G H)	Halts program execution until specified axis has reached its slew speed.
AT +/-n,m	For m=omitted or 0, halts program execution until n msec from reference time. AT 0 sets reference. AT n waits n msec from reference. AT -n waits n msec from reference and sets new reference after elapsed time. For m=1. Same functionality except that n is number of samples rather than msec
AV n	Halts program execution until specified distance along a coordinated path has occurred.

WT n,m	For m=omitted or 0, halts program execution until specified time in msec has elapsed. For m=1. Same functionality except that n is number of samples rather than msec.
--------	---

Event Trigger Examples:

Event Trigger - Multiple Move Sequence

The AM tripoint is used to separate the two PR moves. If AM is not used, the controller returns a ? for the second PR command because a new PR cannot be given until motion is complete.

```
#TWO MOVE; '           Label
PR 2000; '            Position Command
BGX; '                Begin Motion
AMX; '                Wait for Motion Complete
PR 4000; '            Next Position Move
BGX; '                Begin 2nd move
EN; '                 End program
```

Event Trigger - Set Output after Distance

Set output bit 1 after a distance of 1000 counts from the start of the move. The accuracy of the tripoint is the speed multiplied by the sample period.

```
#SETBIT; '           Label
SP 10000; '          Speed is 10000
PA 20000; '          Specify Absolute position
BGX; '               Begin motion
AD 1000; '           Wait until 1000 counts
SB1; '                Set output bit 1
EN; '                 End program
```

Event Trigger - Repetitive Position Trigger

To set the output bit every 10000 counts during a move, the AR tripoint is used as shown in the next example.

```
#TRIP; '             Label
JG 50000; '          Specify Jog Speed
BGX; n=0; '           Begin Motion
#REPEAT; '            # Repeat Loop
AR 10000; '           Wait 10000 counts
TPX; '                Tell Position
SB1; '                Set output 1
WT50; '               Wait 50 msec
CB1; '                Clear output 1
n=n+1; '              Increment counter
JP #REPEAT,n<5; '     Repeat 5 times
STX; '                Stop
EN; '                 End
```

Event Trigger - Start Motion on Input

This example waits for input 1 to go low and then starts motion. Note: The AI command actually halts execution of the program until the input occurs. If you do not want to halt the program sequences, you can use the Input Interrupt function (II) or use a conditional jump on an input, such as JP#GO, @IN[1] = 1.

```
#INPUT; '           Program Label  
AI-1; '           Wait for input 1 low  
PR 10000; '        Position command  
BGX; '            Begin motion  
EN; '             End program
```

Event Trigger - Set output when At speed

```
#ATSPEED; '         Program Label  
JG 50000; '        Specify jog speed  
AC 10000; '        Acceleration rate  
BGX; '            Begin motion  
ASX; '             Wait for at slew speed 50000  
SB1; '             Set output 1  
EN; '              End program
```

Event Trigger - Change Speed along Vector Path

The following program changes the feed rate or vector speed at the specified distance along the vector. The vector distance is measured from the start of the move or from the last AV command.

```
#VECTOR; '          Label  
VMXY;VS 5000; '    Coordinated path  
VP 10000,20000; '  Vector position  
VP 20000,30000; '  Vector position  
VE; '              End vector  
BGS; '             Begin sequence  
AV 5000; '          After vector distance  
VS 1000; '          Reduce speed  
EN; '              End
```

Event Trigger - Multiple Move with Wait

This example makes multiple relative distance moves by waiting for each to be complete before executing new moves.

```
#MOVES; '           Label  
PR 12000; '         Distance  
SP 20000; '         Speed  
AC 100000; '        Acceleration  
BGX; '              Start Motion  
AD 10000; '         Wait a distance of 10,000 counts  
SP 5000; '           New Speed  
AMX; '              Wait until motion is completed  
WT 200; '            Wait 200 ms  
PR -10000; '         New Position  
SP 30000; '          New Speed  
AC 150000; '         New Acceleration  
BGX; '              Start Motion
```

```
EN; ' End
```

Define Output Waveform Using AT

The following program causes Output 1 to be high for 10 msec and low for 40 msec. The cycle repeats every 50 msec.

```
#OUTPUT; ' Program label
AT0; ' Initialize time reference
SB1; ' Set Output 1
#LOOP; ' Loop
AT 10; ' After 10 msec from reference,
CB1; ' Clear Output 1
AT -40; ' Wait 40 msec from reference and reset reference
SB1; ' Set Output 1
JP #LOOP; ' Loop
EN; ' End Program
```

Using AT/WT with non-default TM rates

By default both WT and AT are defined to hold up program execution for 'n' number of milliseconds (WT n or AT n). The second field of both AT and WT can be used to have the program execution be held-up for 'n' number of samples rather than milliseconds. For example WT 400 or WT 400,0 will hold up program execution for 400 msec regardless of what is set for TM. By contrast WT 400,1 will hold up program execution for 400 samples. For the default TM of 1000 the servo update rate is 976us per sample, so the difference between WT n,0 and WT n,1 is minimal. The difference comes when the servo update rate is changed. With a low servo update rate, it is often useful to be able to time loops based upon samples rather than msec, and this is where the "unscaled" WT and AT are useful. For example:

```
#MAIN; ' Label
TM 250; ' 250us update rate
#MOVE; ' Label
PRX=1000; ' Position Relative Move
BGX; ' Begin Motion
MCX; ' Wait for motion to complete
WT 2,1; ' Wait 2 samples (500us)
SB1; ' Set bit 1
EN; ' End Program
```

In the above example, without using an unscaled WT, the output would either need to be set directly after the motion was complete, or 2 ms after the motion was complete. By using WT n,1 and a lower TM, greater delay resolution was achieved.

Conditional Jumps

The DMC-41x3 provides Conditional Jump (JP) and Conditional Jump to Subroutine (JS) instructions for branching to a new program location based on a specified condition. The conditional jump determines if a condition is satisfied and then branches to a new location or subroutine. Unlike event triggers, the conditional jump instruction does not halt the program sequence. Conditional jumps are useful for testing events in real-time. They allow the controller to make decisions without a host computer. For example, the DMC-41x3 can decide between two motion profiles based on the state of an input line.

Command Format - JP and JS

FORMAT:	DESCRIPTION
---------	-------------

JS destination, logical condition	Jump to subroutine if logical condition is satisfied
JP destination, logical condition	Jump to location if logical condition is satisfied

The destination is a program line number or label where the program sequencer will jump if the specified condition is satisfied. Note that the line number of the first line of program memory is 0. The comma designates “IF”. The logical condition tests two operands with logical operators.

Logical operators:

OPERATOR	DESCRIPTION
<	less than
>	greater than
=	equal to
<=	less than or equal to
>=	greater than or equal to
◊	not equal

Conditional Statements

The conditional statement is satisfied if it evaluates to any value other than zero. The conditional statement can be any valid DMC-41x3 numeric operand, including variables, array elements, numeric values, functions, keywords, and arithmetic expressions. If no conditional statement is given, the jump will always occur.

Examples:

Number	v1=6
Numeric Expression	v1=v7*6 @ABS [v1]>10
Array Element	v1<count[2]
Variable	v1<v2
Internal Variable	_TPX=0 _TVX>500
I/O	v1>@AN[2] @IN[1]=0

Multiple Conditional Statements

The DMC-41x3 will accept multiple conditions in a single jump statement. The conditional statements are combined in pairs using the operands “&” and “|”. The “&” operand between any two conditions, requires that both statements must be true for the combined statement to be true. The “|” operand between any two conditions, requires that only one statement be true for the combined statement to be true.

NOTE: Each condition must be placed in parentheses for proper evaluation by the controller. In addition, the DMC-41x3 executes operations from left to right. See Mathematical and Functional Expressions for more information.

For example, using variables named v1, v2, v3 and v4:

```
JP #TEST, ((v1<v2) & (v3<v4))
```

In this example, this statement will cause the program to jump to the label #TEST if v1 is less than v2 and v3 is less than v4. To illustrate this further, consider this same example with an additional condition:

```
JP #TEST, ((v1<v2) & (v3<v4)) | (v5<v6)
```

This statement will cause the program to jump to the label #TEST under two conditions; 1. If v1 is less than v2 and v3 is less than v4. OR 2. If v5 is less than v6.

Using the JP Command:

If the condition for the JP command is satisfied, the controller branches to the specified label or line number and continues executing commands from this point. If the condition is not satisfied, the controller continues to execute the next commands in sequence.

Conditional	Meaning
JP #Loop, count<10	Jump to #Loop if the variable, count, is less than 10
JS #MOVE2, @IN[1]=1	Jump to subroutine #MOVE2 if input 1 is logic level high. After the subroutine MOVE2 is executed, the program sequencer returns to the main program location where the subroutine was called.
JP #BLUE, @ABS[v2]>2	Jump to #BLUE if the absolute value of variable, v2, is greater than 2
JP #C, v1*v7<=v8*v2	Jump to #C if the value of v1 times v7 is less than or equal to the value of v8*v2
JP#A	Jump to #A

Example Using JP command:

Move the X motor to absolute position 1000 counts and back to zero ten times. Wait 100 msec between moves.

```
#BEGIN          Begin Program
count=10        Initialize loop counter
#LOOP          Begin loop
PA 1000        Position absolute 1000
BGX            Begin move
AMX            Wait for motion complete
WT 100         Wait 100 msec
PA 0           Position absolute 0
BGX            Begin move
AMX            Wait for motion complete
WT 100         Wait 100 msec
count=count-1  Decrement loop counter
JP #LOOP, count>0 Test for 10 times thru loop
EN             End Program
```

Using If, Else, and Endif Commands

The DMC-41x3 provides a structured approach to conditional statements using IF, ELSE and ENDIF commands.

Using the IF and ENDIF Commands

An IF conditional statement is formed by the combination of an IF and ENDIF command. The IF command has as it's arguments one or more conditional statements. If the conditional statement(s) evaluates true, the command interpreter will continue executing commands which follow the IF command. If the conditional statement evaluates false, the controller will ignore commands until the associated ENDIF command is executed OR an ELSE command occurs in the program (see discussion of ELSE command below).

NOTE: An ENDIF command must always be executed for every IF command that has been executed. It is recommended that the user not include jump commands inside IF conditional statements since this causes re-direction of command execution. In this case, the command interpreter may not execute an ENDIF command.

Using the ELSE Command

The ELSE command is an optional part of an IF conditional statement and allows for the execution of command only when the argument of the IF command evaluates False. The ELSE command must occur after an IF command and has no arguments. If the argument of the IF command evaluates false, the controller will skip commands until

the ELSE command. If the argument for the IF command evaluates true, the controller will execute the commands between the IF and ELSE command.

Nesting IF Conditional Statements

The DMC-41x3 allows for IF conditional statements to be included within other IF conditional statements. This technique is known as ‘nesting’ and the DMC-41x3 allows up to 255 IF conditional statements to be nested. This is a very powerful technique allowing the user to specify a variety of different cases for branching.

Command Format - IF, ELSE and ENDIF

Format:	Description
IF conditional statement(s)	Execute commands proceeding IF command (up to ELSE command) if conditional statement(s) is true, otherwise continue executing at ENDIF command or optional ELSE command.
ELSE	Optional command. Allows for commands to be executed when argument of IF command evaluates not true. Can only be used with IF command.
ENDIF	Command to end IF conditional statement. Program must have an ENDIF command for every IF command.

Example using IF, ELSE and ENDIF:

```

#TEST                                Begin Main Program "TEST"
II,,3                                 Enable input interrupts on input 1 and input 2
MG "WAITING FOR INPUT 1, INPUT 2"      Output message
#LOOP                                 Label to be used for endless loop
JP #LOOP                               Endless loop
EN                                     End of main program
#ININT                                Input Interrupt Subroutine
IF (@IN[1]=0)                          IF conditional statement based on input 1
IF (@IN[2]=0)                          2nd IF conditional statement executed if 1st IF conditional true
MG "INPUT 1 AND INPUT 2 ARE ACTIVE"    Message to be executed if 2nd IF conditional is true
ELSE                                  ELSE command for 2nd IF conditional statement
MG "ONLY INPUT 1 IS ACTIVE"           Message to be executed if 2nd IF conditional is false
ENDIF                                 End of 2nd conditional statement
ELSE                                  ELSE command for 1st IF conditional statement
MG "ONLY INPUT 2 IS ACTIVE"           Message to be executed if 1st IF conditional statement is false
ENDIF                                 End of 1st conditional statement
#WAIT                                 Label to be used for a loop
JP#WAIT, (@IN[1]=0) | (@IN[2]=0)     Loop until both input 1 and input 2 are not active
RIO                                    End Input Interrupt Routine without restoring trippoints

```

Subroutines

A subroutine is a group of instructions beginning with a label and ending with an end command (EN). Subroutines are called from the main program with the jump subroutine instruction JS, followed by a label or line number, and conditional statement. Up to 8 subroutines can be nested. After the subroutine is executed, the program sequencer returns to the program location where the subroutine was called unless the subroutine stack is manipulated as described in the following section.

Example:

An example of a subroutine to draw a square 500 counts per side is given below. The square is drawn at vector position 1000,1000.

```

#M           Begin Main Program
CB1          Clear Output Bit 1 (pick up pen)
VP 1000,1000;LE;BGS Define vector position; move pen
AMS          Wait for after motion trippoint
SB1          Set Output Bit 1 (put down pen)
JS #Square;CB1 Jump to square subroutine
EN           End Main Program
#Square      Square subroutine
v1=500;JS #L Define length of side
v1=-v1;JS #L Switch direction
EN           End subroutine
#L;PR v1,v1;BGX Define X,Y; Begin X
AMX;BGY;AMY After motion on X, Begin Y
EN           End subroutine

```

Stack Manipulation

It is possible to manipulate the subroutine stack by using the ZS command. Every time a JS instruction, interrupt or automatic routine (such as #POSERR or #LIMSWI) is executed, the subroutine stack is incremented by 1. Normally the stack is restored with an EN instruction. Occasionally it is desirable not to return back to the program line where the subroutine or interrupt was called. The ZS1 command clears 1 level of the stack. This allows the program sequencer to continue to the next line. The ZS0 command resets the stack to its initial value. For example, if a limit occurs and the #LIMSWI routine is executed, it is often desirable to restart the program sequence instead of returning to the location where the limit occurred. To do this, give a ZS command at the end of the #LIMSWI routine.

Auto-Start Routine

The DMC-41x3 has a special label for automatic program execution. A program which has been saved into the controller's non-volatile memory can be automatically executed upon power up or reset by beginning the program with the label #AUTO. The program must be saved into non-volatile memory using the command, BP.

Automatic Subroutines for Monitoring Conditions

Often it is desirable to monitor certain conditions continuously without tying up the host or DMC-41x3 program sequences. The controller can monitor several important conditions in the background. These conditions include checking for the occurrence of a limit switch, a defined input, position error, or a command error. Automatic monitoring is enabled by inserting a special, predefined label in the applications program. The pre-defined labels are:

SUBROUTINE	DESCRIPTION
#LIMSWI	Limit switch on any axis goes low
#ININT	Input specified by II goes low
#POSERR	Position error exceeds limit specified by ER
#MCTIME	Motion Complete timeout occurred. Timeout period set by TW command
#CMDERR	Bad command given
#AUTO	Automatically executes on power up

#AUTOERR	Automatically executes when a checksum is encountered during #AUTO start-up. Check error condition with _RS. bit 0 for variable checksum error bit 1 for parameter checksum error bit 2 for program checksum error bit 3 for master reset error (there should be no program)
#AMPERR	Error from internal Galil amplifier

For example, the #POSERR subroutine will automatically be executed when any axis exceeds its position error limit. The commands in the #POSERR subroutine could decode which axis is in error and take the appropriate action. In another example, the #ININT label could be used to designate an input interrupt subroutine. When the specified input occurs, the program will be executed automatically.

NOTE: An application program must be running for #CMDERR to function.

Example - Limit Switch:

This program prints a message upon the occurrence of a limit switch. Note, for the #LIMSWI routine to function, the DMC-41x3 must be executing an applications program from memory. This can be a very simple program that does nothing but loop on a statement, such as #LOOP;JP #LOOP;EN. Motion commands, such as JG 5000 can still be sent from the PC even while the “dummy” applications program is being executed.

#LOOP	Dummy Program
JP #LOOP;EN	Jump to Loop
#LIMSWI	Limit Switch Label
MG “LIMIT OCCURRED”	Print Message
RE	Return to main program
	Download Program
:XQ #LOOP	Execute Dummy Program
:JG 5000	Jog
:BGX	Begin Motion

Now, when a forward limit switch occurs on the X axis, the #LIMSWI subroutine will be executed.

Notes regarding the #LIMSWI Routine:

- 1) The RE command is used to return from the #LIMSWI subroutine.
- 2) The #LIMSWI subroutine will be re-executed if the limit switch remains active.

The #LIMSWI routine is only executed when the motor is being commanded to move.

Example - Position Error

#LOOP	Dummy Program
JP #LOOP;EN	Loop
#POSERR	Position Error Routine
V1=_TEX	Read Position Error
MG “EXCESS POSITION ERROR”	Print Message
MG “ERROR=”,V1=	Print Error
RE	Return from Error
	Download program
:XQ #LOOP	Execute Dummy Program
:JG 100000	Jog at High Speed
:BGX	Begin Motion

Example - Input Interrupt

#A	Label
II1	Input Interrupt on 1
JG 30000,,,60000	Jog
BGXW	Begin Motion
#LOOP;JP#LOOP;EN	Loop
#ININT	Input Interrupt
STXW;AM	Stop Motion
#TEST;JP #TEST, @IN[1]=0	Test for Input 1 still low
JG 30000,,,6000	Restore Velocities
BGXW	Begin motion
RIO	Return from interrupt routine to Main Program and do not re-enable tripoints

Example - Motion Complete Timeout

#BEGIN	Begin main program
TW 1000	Set the time out to 1000 ms
PA 10000	Position Absolute command
BGX	Begin motion
MCX	Motion Complete trip point
EN	End main program
#MCTIME	Motion Complete Subroutine
MG "X fell short"	Send out a message
EN	End subroutine

This simple program will issue the message “X fell short” if the X axis does not reach the commanded position within 1 second of the end of the profiled move.

Example - Command Error

#BEGIN	Begin main program
speed = 2000	Set variable for speed
JG speed;BGX;	Begin motion
#LOOP	
JG speed;WT100	Update Jog speed based upon speed variable
JP #LOOP	
EN	End main program
#CMDERR	Command error utility
JP#DONE,_ED<>2	Check if error on line 2
JP#DONE,_TC<>6	Check if out of range
MG "SPEED TOO HIGH"	Send message
MG "TRY AGAIN"	Send message
ZS1	Adjust stack
JP #BEGIN	Return to main program
#DONE	End program if other error
ZS0	Zero stack
EN	End program

The above program prompts the operator to enter a jog speed. If the operator enters a number out of range (greater than 8 million), the #CMDERR routine will be executed prompting the operator to enter a new number.

In multitasking applications, there is an alternate method for handling command errors from different threads. Using the XQ command along with the special operands described below allows the controller to either skip or retry invalid commands.

OPERAND	FUNCTION
_ED1	Returns the number of the thread that generated an error
_ED2	Retry failed command (operand contains the location of the failed command)
_ED3	Skip failed command (operand contains the location of the command after the failed command)

The operands are used with the XQ command in the following format:

XQ _ED2 (or _ED3), _ED1,1

Where the “1” at the end of the command line indicates a restart; therefore, the existing program stack will not be removed when the above format executes.

The following example shows an error correction routine which uses the operands.

Example - Command Error w/Multitasking

```

#A                                Begin thread 0 (continuous loop)
JP#A
EN                                 End of thread 0

#B                                Begin thread 1
N=-1                               Create new variable
KP N                               Set KP to value of N, an invalid value
TY                                 Issue invalid command
EN                                 End of thread 1

#CMDERR                            Begin command error subroutine
IF _TC=6                           If error is out of range (KP -1)
N=1                               Set N to a valid number
XQ _ED2,_ED1,1                     Retry KP N command
ENDIF
IF _TC=1                           If error is invalid command (TY)
XQ _ED3,_ED1,1                     Skip invalid command
ENDIF
EN                                 End of command error routine

```

Example - Communication Interrupt

A DMC-4113 is used to move the A axis back and forth from 0 to 10000. This motion can be paused, resumed and stopped via input from an auxiliary port terminal.

```

#BEGIN                             Label for beginning of program
CC 9600,0,1,0                      Setup communication configuration for auxiliary serial port
CI 2                                Setup communication interrupt for auxiliary serial port
MG {P2}"Type 0 to stop motion"      Message out of auxiliary port
MG {P2}"Type 1 to pause motion"     Message out of auxiliary port
MG {P2}"Type 2 to resume motion"    Message out of auxiliary port
rate=2000                            Variable to remember speed
SPA=rate                            Set speed of A axis motion
#LOOP                               Label for Loop

```

```

PAA=10000           Move to absolute position 10000
BGA                 Begin Motion on A axis
AMA                 Wait for motion to be complete
PAA=0               Move to absolute position 0
BGA                 Begin Motion on A axis
AMA                 Wait for motion to be complete
JP #LOOP             Continually loop to make back and forth motion
EN                  End main program
#COMINT             Interrupt Routine
JP #STOP,P2CH="0"   Check for S (stop motion)
JP #PAUSE,P2CH="1"  Check for P (pause motion)
JP #RESUME,P2CH="2" Check for R (resume motion)
EN1,1               Do nothing
#STOP               Routine for stopping motion
STA;ZS;EN          Stop motion on A axis; Zero program stack; End Program
#PAUSE              Routine for pausing motion
rate=_SPA           Save current speed setting of A axis motion
SPA=0               Set speed of A axis to zero (allows for pause)
EN1,1               Re-enable trip-point and communication interrupt
#RESUME             Routine for resuming motion
SPA=rate            Set speed on A axis to original speed
EN1,1               Re-enable trip-point and communication interrupt

```

For additional information, see section on Using Communication Interrupt.

Example – Ethernet Communication Error

This simple program executes in the DMC-41x3 and indicates (via the serial port) when a communication handle fails. By monitoring the serial port, the user can re-establish communication if needed.

```

#LOOP                Simple program loop
JP#LOOP
EN
#TCPERR              Ethernet communication error auto routine
MG {P1}_IA4          Send message to serial port indicating
                      which handle did not receive proper
                      acknowledgment.

RE

```

Example – Amplifier Error

The program below will execute upon the detection of an error from an internal Galil Amplifier. The bits in TA1 will be set for all axes that have an invalid hall state even if BR1 is set for those axes, this is handled with the mask variable shown in the code below.

```

#AMPERR
REM mask out axes that are in brushed mode for _TA1
mask=(_BRH*128)+(_BRG*64)+(_BRF*32)+(_BRE*16)+(_BRD*8)+(_BRC*4)+(_BRB*2)+_BRA
mask=_COM[mask]
mask=(_TA1&mask)&$0000FFFF
REM amplifier error status
MG"A-ER TAO",_TA0
MG"A-ER TA1",mask
MG"A-ER TA2",_TA2
MG"A-ER TA3",_TA3
WT5000

```

```

REM the sum of the amperr bits should be 0 with no amplifier error
er=_TA0+mask+_TA2+_TA3
JP#AMPERR,er0
REM Notify user amperr has cleared
MG"AMPERR RESOLVED"
WT3000
RE

```

JS Subroutine Stack Variables (^a, ^b, ^c, ^d, ^e, ^f, ^g, ^h)

There are 8 variables that may be passed on the subroutine stack when using the JS command. Passing values on the stack is advanced DMC programming, and is recommended for experienced DMC programmers familiar with the concept of passing arguments by value and by reference.

Notes:

1. Passing parameters has no type checking, so it is important to exercise good programming style when passing parameters. See examples below for recommended syntax.
2. Do not use spaces in expressions containing ^.
3. Global variables MUST be assigned prior to any use in subroutines where variables are passed by reference.
4. Please refer to the JS command in the controller's command reference for further important information.

Example: A Simple Adding Function

```

#Add
JS#SUM(1,2,3,4,5,6,7,8)           ;' call subroutine, pass values
MG_JS                            ;' print return value
EN
'
#SUM                                ;NO(^a,^b,^c,^d,^e,^f,^g,^h) syntax note for use
EN,,(^a+^b+^c+^d+^e+^f+^g+^h)      ;' return sum

:Executed program from program1.dmc
36.0000

```

Example: Variable, and an Important Note about Creating Global Variables

```

#Var
value=5                           ;'a value to be passed by reference
global=8                          ;'a global variable
JS#SUM(&value,1,2,3,4,5,6,7)       ;'note first arg passed by reference
MG value                          ;'message out value after subroutine.
MG _JS                            ;'message out returned value
EN
'
#SUM                                ;NO(* ^a,^b,^c,^d,^e,^f,^g)
^a=^b+^c+^d+^e+^f+^g+^h+global
EN,,^a
'notes:
'do not use spaces when working with ^
'If using global variables, they MUST be created before the subroutine is run

Executed program from program2.dmc
36.0000
36.0000

```

Example: Working with Arrays

```
#Array
DM speeds[8]
DM other[256]
JS#zeroAry("speeds",0) ;'zero out all buckets in speeds[]
JS#zeroAry("other",0) ;'zero out all buckers in other[]
EN
'
#zeroAry ;NO(array ^a, ^b) zeros array starting at index ^b
^a[^b]=0
^b=^b+1
JP#zeroAry, (^b<^a[-1]) ;'[-1] returns the length of an array
EN
```

Example: Abstracting Axes

```
#Axes
JS#runMove(0,10000,1000,100000,100000)
MG "Position:",_JS
EN
'
#runMove ;NO(axis ^a, PR ^b, SP ^c, AC ^d, DC ^e) Profile movement for axis
~a=~a ;'~a is global, so use carefully in subroutines
        'try one variable axis a-h for each thread A-H
PR~a=~b
SP~a=~c
AC~a=~d
DC~a=~e
BG~a
MC~a
EN,,_TP~a
```

Example: Local Scope

```
#Local
JS#POWER(2,2)
MG _JS
JS#POWER(2,16)
MG _JS
JS#POWER(2,-8)
MG _JS
'
#POWER ;NO(base ^a,exponent^b) Returns base^exponent power. +/- integer only
^c=1 ;'unpassed variable space (^c-^h) can be used as local scope variables
IF ^b=0 ;'special case, exponent = 0
EN,,1
ENDIF
IF ^b<0 ;'special case, exponent < 0, invert result
^d=1
^b=@ABS[^b]
ELSE
^d=0
ENDIF
#PWRHLPR
^c=^c*^a
```

```

^b=^b-1
JP#PWRHLPR, ^b>0
IF ^d=1           ;'if inversion required
  ^c=(1/^c)
ENDIF
EN,,^c

Executed program from program1.dmc
4.0000
65536.0000
0.0039

```

Example: Recursion

```

'although the stack depth is only 16, Galil DMC code does support recursion
JS#AxsInfo(0)
MG{Z2.0}"Recurse through ",_JS," stacks"
EN
'
#AxsInfo                               ;NO(axis ^a) List info for axes
~h=^a
^b=(^a+$41)*$1000000                  ;'convert to Galil String
MG^b{S1}, " Axis: "{N}
MG{F8.0}"Position: ",_TP~h," Error:",_TE~h," Torque:",_TT~h{F1.4}
IF ^a=7                                ;'recursion exit condition
EN,,1
ENDIF
JS#AxsInfo(^a + 1)                     ;'stack up recursion
EN,,_JS+1                               ;' as recursion closes, add up stack depths

```

```

Executed program from program1.dmc
A Axis: Position: 00029319 Error: 00001312 Torque: 9.9982
B Axis: Position: -00001612 Error: 00000936 Torque: 1.7253
C Axis: Position: 00001696 Error:-00001076 Torque:-1.9834
D Axis: Position: -00002020 Error: 00001156 Torque: 2.1309
E Axis: Position: 00000700 Error:-00001300 Torque:-2.3963
F Axis: Position: 00000156 Error:-00000792 Torque:-1.4599
G Axis: Position: -00002212 Error: 00001732 Torque: 3.1926
H Axis: Position: 00002665 Error:-00001721 Torque:-3.1723
Recurse through 8 stacks

```

General Program Flow and Timing information

This section will discuss general programming flow and timing information for Galil programming.

REM vs. NO or ' comments

There are 2 ways to add comments to a .dmc program. REM statements or NO/ ' comments. The main difference between the 2 is that REM statements are stripped from the program upon download to the controller and NO or ' comments are left in the program. In most instances the reason for using REM statements instead of NO or ' is to save program memory. The other benefit to using REM commands comes when command execution of a loop, thread or any section of code is critical. Although they do not take much time, NO and ' comments still take time to process. So when command execution time is critical, REM statements should be used. The 2 examples below demonstrate the difference in command execution of a loop containing comments.

The GalilTools software will treat an apostrophe ('') comment different from an NO when the compression algorithm is activated upon a program download (line > 80 characters or program memory > 2000 lines). In this case the software will remove all ('') comments as part of the compression and it will download all NO comments to the controller.

Note: Actual processing time will vary depending upon number of axes, communication activity, number of threads currently executing etc.

```
#a
i=0;'initialize a counter
t= TIME;' set an initial time reference
#loop
NO this comment takes time to process
'this comment takes time to process
i=i+1;'this comment takes time to process
JP#loop,i<1000
MG TIME-t;'display number of samples from initial time reference
EN
```

When executed on a DMC-4123, the output from the above program returned a 116, which indicates that it took 116 samples (TM 1000) to process the commands from 't=TIME' to 'MG TIME-t'. This is about 114ms +/-2ms.

Now when the comments inside of the #loop routine are changed into REM statements (a REM statement must always start on a new line), the processing is greatly reduced.

When executed on the same DMC-4123, the output from the program shown below returned a 62, which indicates that it took 62 samples to process the commands from 't=TIME' to 'MG TIME-t'. This is about 60ms +/-2ms, and about 50% faster than when the comments where downloaded to the controller.

```
#a
i=0;'initialize a counter
t= TIME;' set an initial time reference
#loop
REM this comment is removed upon download and takes no time to process
REM this comment is removed upon download and takes no time to process
i=i+1
REM this comment is removed upon download and takes no time to process
JP#loop,i<1000
MG TIME-t;'display number of samples from initial time reference
EN
```

WT vs AT and coding deterministic loops

The main difference between WT and AT is that WT will hold up execution of the next command for the specified time from the execution of the WT command, AT will hold up execution of the next command for the specified time from the last time reference set with the AT command.

```
#A
AT0;'set initial AT time reference
WT 1000,1;'wait 1000 samples
t1=TIME
AT 4000,1;'wait 4000 samples from last time reference
t2=TIME-t1
REM in the above scenario, t2 will be ~3000 because AT 4000,1 will have
REM paused program execution from the time reference of AT0
REM since the WT 1000,1 took 1000 samples, there was only 3000 samples left
```

```

REM of the "4000" samples for AT 4000,1
MG t,t2;'this should output 1000,3000
EN;'End program

```

Where the functionality of the operation of the AT command is very useful is when it is required to have a deterministic loop operating on the controller. These instances range from writing PLC-type scan threads to writing custom control algorithms. The key to having a deterministic loop time is to have a trippoint that will wait a specified time independent of the time it took to execute the loop code. In this definition, the AT command is a perfect fit. The below code is an example of a PLC-type scan thread that runs at a 500ms loop rate. A typical implementation would be to run this code in a separate thread (ex XQ#plcscan,2).

```

REM this code will set output 3 high if
REM inputs 1 and 2 are high, and input 3 is low
REM else output 3 will be low
REM if input 4 is low, output 1 will be high
REM and ouput 3 will be low regardless of the
REM states of inputs 1,2 or 3
#plcscan
AT0;'set initial time reference
#scan
REM mask inputs 1-4
ti=_TI0&$F
REM variables for bit 1 and bit 3
b1=0;b3=0
REM if input 4 is high set bit 1 and clear bit 3
REM ti&8 - gets 4th bit, if 4th bit is high result = 8
IF ti&8=8;b1=1;ELSE
REM ti&7 get lower 3 bits, if 011 then result = 3
IF ti&7=3;b3=1;ENDIF;ENDIF
REM set output bits 1 and 3 accordingly
REM set outputs at the end for a PLC scan
OB1,b1;OB3,b3
REM wait 500ms (for 500 samples use AT-500,1)
REM the '-' will reset the time reference
AT-500
JP#scan

```

Mathematical and Functional Expressions

Mathematical Operators

For manipulation of data, the DMC-41x3 provides the use of the following mathematical operators:

Operator	Function
+	Addition
-	Subtraction
*	Multiplication
/	Division
%	Modulus

&	Logical And (Bit-wise)
	Logical Or (On some computers, a solid vertical line appears as a broken line)
()	Parenthesis

The numeric range for addition, subtraction and multiplication operations is +/-2,147,483,647.9999. The precision for division is 1/65,000.

Mathematical operations are executed from left to right. Calculations within parentheses have precedence.

Examples:

speed = 7.5*V1/2	The variable, speed, is equal to 7.5 multiplied by V1 and divided by 2
count = count+2	The variable, count, is equal to the current value plus 2.
result =_TPX-(@COS[45]*40)	Puts the position of X - 28.28 in result. 40 * cosine of 45° is 28.28
temp = @IN[1]&@IN[2]	temp is equal to 1 only if Input 1 and Input 2 are high

Bit-Wise Operators

The mathematical operators & and | are bit-wise operators. The operator, &, is a Logical And. The operator, |, is a Logical Or. These operators allow for bit-wise operations on any valid DMC-41x3 numeric operand, including variables, array elements, numeric values, functions, keywords, and arithmetic expressions. The bit-wise operators may also be used with strings. This is useful for separating characters from an input string. When using the input command for string input, the input variable will hold up to 6 characters. These characters are combined into a single value which is represented as 32 bits of integer and 16 bits of fraction. Each ASCII character is represented as one byte (8 bits), therefore the input variable can hold up to six characters. The first character of the string will be placed in the top byte of the variable and the last character will be placed in the lowest significant byte of the fraction. The characters can be individually separated by using bit-wise operations as illustrated in the following example:

```

#TEST
len="123456"
Flen=@FRAC[len]
Flen=$10000*Flen
len1=(Flen&$00FF)
len2=(Flen&$FF00)/$100
len3=len&$000000FF
len4=(len&$0000FF00)/$100
len5=(len&$00FF0000)/$10000
len6=(len&$FF000000)/$1000000
MG len6 {S4}
MG len5 {S4}
MG len4 {S4}
MG len3 {S4}
MG len2 {S4}
MG len1 {S4}
EN

Begin main program
Set len to a string value
Define variable 'Flen' as fractional part of variable 'len'
Shift Flen by 32 bits (IE - convert fraction, Flen, to integer)
Mask top byte of Flen and set this value to variable 'len1'
Let variable, 'len2' = top byte of Flen
Let variable, 'len3' = bottom byte of len
Let variable, 'len4' = second byte of len
Let variable, 'len5' = third byte of len
Let variable, 'len6' = fourth byte of len
Display 'len6' as string message of up to 4 chars
Display 'len5' as string message of up to 4 chars
Display 'len4' as string message of up to 4 chars
Display 'len3' as string message of up to 4 chars
Display 'len2' as string message of up to 4 chars
Display 'len1' as string message of up to 4 chars

```

This program will accept a string input of up to 6 characters, parse each character, and then display each character. Notice also that the values used for masking are represented in hexadecimal (as denoted by the preceding '\$'). For more information, see section Sending Messages.

To illustrate further, if the user types in the string "TESTME" at the input prompt, the controller will respond with the following:

T	Response from command MG len6 {S4}
E	Response from command MG len5 {S4}

S	Response from command MG len4 {S4}
T	Response from command MG len3 {S4}
M	Response from command MG len2 {S4}
E	Response from command MG len1 {S4}

Functions

FUNCTION	DESCRIPTION
@SIN[n]	Sine of n (n in degrees, with range of -32768 to 32767 and 16-bit fractional resolution)
@COS[n]	Cosine of n (n in degrees, with range of -32768 to 32767 and 16-bit fractional resolution)
@TAN[n]	Tangent of n (n in degrees, with range of -32768 to 32767 and 16-bit fractional resolution)
@ASIN*[n]	Arc Sine of n, between -90° and +90°. Angle resolution in 1/64000 degrees.
@ACOS*[n]	Arc Cosine of n, between 0 and 180°. Angle resolution in 1/64000 degrees.
@ATAN*[n]	Arc Tangent of n, between -90° and +90°. Angle resolution in 1/64000 degrees
@COM[n]	1's Complement of n
@ABS[n]	Absolute value of n
@FRAC[n]	Fraction portion of n
@INT[n]	Integer portion of n
@RND[n]	Round of n (Rounds up if the fractional part of n is .5 or greater)
@SQR[n]	Square root of n (Accuracy is +/- .004)
@IN[n]	Return digital input at general input n (where n starts at 1)
@OUT[n]	Return digital output at general output n (where n starts at 1)
@AN[n]	Return analog input at general analog in n (where n starts at 1)

*Note that these functions are multi-valued. An application program may be used to find the correct band.

Functions may be combined with mathematical expressions. The order of execution of mathematical expressions is from left to right and can be over-ridden by using parentheses.

Examples:

```
v1=@ABS[V7]      The variable, v1, is equal to the absolute value of variable v7.
v2=5*@SIN[pos]  The variable, v2, is equal to five times the sine of the variable, pos.
v3=@IN[1]         The variable, v3, is equal to the digital value of input 1.
v4=2*(5+@AN[5]) The variable, v4, is equal to the value of analog input 5 plus 5, then
                  multiplied by 2.
```

Variables

For applications that require a parameter that is variable, the DMC-41x3 provides 510 variables. These variables can be numbers or strings. A program can be written in which certain parameters, such as position or speed, are defined as variables. The variables can later be assigned by the operator or determined by program calculations. For example, a cut-to-length application may require that a cut length be variable.

Example:

```
posx=5000          Assigns the value of 5000 to the variable posx
PR posx            Assigns variable posx to PR command
JG rpmY*70         Assigns variable rpmY multiplied by 70 to JG command.
```

Programmable Variables

The DMC-41x3 allows the user to create up to 510 variables. Each variable is defined by a name which can be up to eight characters. The name must start with an alphabetic character; however, numbers are permitted in the rest of the name. Spaces are not permitted. Variable names should not be the same as DMC-41x3 instructions. For example, PR is not a good choice for a variable name.

NOTE: It is generally a good idea to use lower-case variable names so there is no confusion between Galil commands and variable names.

Examples of valid and invalid variable names are:

Valid Variable Names

```
posx  
pos1  
speedz
```

Invalid Variable Names

```
RealLongName ; 'Cannot have more than 8 characters  
123 ; 'Cannot begin variable name with a number  
speed z ; 'Cannot have spaces in the name
```

Assigning Values to Variables:

Assigned values can be numbers, internal variables and keywords, functions, controller parameters and strings. The range for numeric variable values is 4 bytes of integer (231) followed by two bytes of fraction (+/- 2,147,483,647.9999).

Numeric values can be assigned to programmable variables using the equal sign.

Any valid DMC-41x3 function can be used to assign a value to a variable. For example, v1=@ABS[v2] or v2=@IN[1]. Arithmetic operations are also permitted.

To assign a string value, the string must be in quotations. String variables can contain up to six characters which must be in quotation.

Examples:

posX=_TPX	Assigns returned value from TPX command to variable posx.
speed=5.75	Assigns value 5.75 to variable speed
input=@IN[2]	Assigns logical value of input 2 to variable input
v2=v1+v3*v4	Assigns the value of v1 plus v3 times v4 to the variable v2.
var="CAT"	Assign the string, CAT, to var
MG var{S3}	Displays the variable var - (CAT)

Assigning Variable Values to Controller Parameters

Variable values may be assigned to controller parameters such as SP or PR.

PR v1	Assign v1 to PR command
SP vS*2000	Assign vS*2000 to SP command

Displaying the value of variables at the terminal

Variables may be sent to the screen using the format, variable=. For example, v1= , returns the value of the variable v1.

Example - Using Variables for Joystick

The example below reads the voltage of an X-Y joystick and assigns it to variables vX and vY to drive the motors at proportional velocities, where:

10 Volts = 3000 rpm = 200000 c/sec

Speed/Analog input = 200000/10 = 20000

#JOYSTICK	Label
JG 0, 0	Set in Jog mode
BGXY	Begin Motion
AT0	Set AT time reference
#LOOP	Loop
vX=@AN[1]*20000	Read joystick X
vY=@AN[2]*20000	Read joystick Y
JG vX, vY	Jog at variable vX, vY
AT-4	Wait 4ms from last time reference, creates a deterministic loop time
JP#LOOP	Repeat
EN	End

Operands

Operands allow motion or status parameters of the DMC-41x3 to be incorporated into programmable variables and expressions. Most DMC commands have an equivalent operand - which are designated by adding an underscore (_) prior to the DMC-41x3 command. The command reference indicates which commands have an associated operand.

Status commands such as Tell Position return actual values, whereas action commands such as KP or SP return the values in the DMC-41x3 registers. The axis designation is required following the command.

Examples of Internal Variables:

posX=_TPX	Assigns value from Tell Position X to the variable posX.
deriv=_KDX*2	Assigns value from KDX multiplied by two to variable, deriv.
JP #LOOP,_TEX>5	Jump to #LOOP if the position error of X is greater than 5
JP #ERROR,_TC=1	Jump to #ERROR if the error code equals 1.

Operands can be used in an expression and assigned to a programmable variable, but they cannot be assigned a value. For example: _KDX=2 is invalid.

Special Operands (Keywords)

The DMC-41x3 provides a few additional operands which give access to internal variables that are not accessible by standard DMC-41x3 commands.

Keyword	Function
_BGn	*Returns a 1 if motion on axis 'n' is complete, otherwise returns 0.
_BN	*Returns serial # of the board.
_DA	*Returns the number of arrays available
_DL	*Returns the number of available labels for programming
_DM	*Returns the available array memory
_HMn	*Returns status of Home Switch (equals 0 or 1)
_LFn	Returns status of Forward Limit switch input of axis 'n' (equals 0 or 1)
_LRX	Returns status of Reverse Limit switch input of axis 'n' (equals 0 or 1)
_UL	*Returns the number of available variables

TIME	Free-Running Real Time Clock (off by 2.4% - Resets with power-on). Note: TIME does not use an underscore character (_) as other keywords.
------	--

* - These keywords have corresponding commands while the keywords _LF, _LR, and TIME do not have any associated commands. All keywords are listed in the Command Reference.

Examples of Keywords:

```
v1=_LFX      Assign v1 the logical state of the Forward Limit Switch on the X-axis
v3=TIME     Assign v3 the current value of the time clock
v4=_HMW      Assign v4 the logical state of the Home input on the W-axis
```

Arrays

For storing and collecting numerical data, the DMC-41x3 provides array space for 16000 elements. The arrays are one dimensional and up to 30 different arrays may be defined. Each array element has a numeric range of 4 bytes of integer (2^{31}) followed by two bytes of fraction (+/-2,147,483,647.9999).

Arrays can be used to capture real-time data, such as position, torque and analog input values. In the contouring mode, arrays are convenient for holding the points of a position trajectory in a record and playback application.

Defining Arrays

An array is defined with the command DM. The user must specify a name and the number of entries to be held in the array. An array name can contain up to eight characters, starting with an uppercase alphabetic character. The number of entries in the defined array is enclosed in [].

Example:

```
DM posx[7]           Defines an array names 'posx' with seven entries
DM speed[100]         Defines an array named speed with 100 entries
DA posx[]             Frees array space
```

Assignment of Array Entries

Like variables, each array element can be assigned a value. Assigned values can be numbers or returned values from instructions, functions and keywords.

Array elements are addressed starting at count 0. For example the first element in the 'posx' array (defined with the DM command, DM posx[7]) would be specified as posx[0].

Values are assigned to array entries using the equal sign. Assignments are made one element at a time by specifying the element number with the associated array name.

NOTE: Arrays must be defined using the command, DM, before assigning entry values.

Examples:

```
DM speed[10]          Dimension speed Array
speed[0]=7650.2       Assigns the first element of the array, 'speed' the value
                      7650.2
speed[0]=              Returns array element value
posx[9]=_TPX          Assigns the 10th element of the array 'posx' the returned value
                      from the tell position command.
con[1]=@COS[pos]*2    Assigns the second element of the array 'con' the cosine of
                      the variable POS multiplied by 2.
timer[0]=TIME         Assigns the first element of the array timer the returned
                      value of the TIME keyword.
```

Using a Variable to Address Array Elements

An array element number can also be a variable. This allows array entries to be assigned sequentially using a counter.

Example:

```
#A          Begin Program
count=0;DM pos[10]   Initialize counter and define array
#LOOP      Begin loop
WT 10      Wait 10 msec
pos[count]=_TPX    Record position into array element
pos[count]=       Report position
count=count+1     Increment counter
JP #LOOP, count<10 Loop until 10 elements have been stored
EN          End Program
```

The above example records 10 position values at a rate of one value per 10 msec. The values are stored in an array named 'pos'. The variable, 'count', is used to increment the array element counter. The above example can also be executed with the automatic data capture feature described below.

Uploading and Downloading Arrays to On Board Memory

The GalilTools software is recommended for downloading and uploading array data from the controller. The GalilTools Communication library also provides function calls for downloading and uploading array data from the controller to/from a buffer or a file.

Arrays may also be uploaded and downloaded using the QU and QD commands.

QU array[],start,end,delim

QD array[],start,end

where array is an array name such as A[].

start is the first element of array (default=0)

end is the last element of array (default=last element)

delim specifies whether the array data is separated by a comma (delim=1) or a carriage return (delim=0).

The file is terminated using <control>Z, <control>Q, <control>D or \.

Automatic Data Capture into Arrays

The DMC-41x3 provides a special feature for automatic capture of data such as position, position error, inputs or torque. This is useful for teaching motion trajectories or observing system performance. Up to eight types of data can be captured and stored in eight arrays. The capture rate or time interval may be specified. Recording can done as a one time event or as a circular continuous recording.

Command Summary - Automatic Data Capture

Command	Description
RA n[],m[],o[],p[]	Selects up to eight arrays for data capture. The arrays must be defined with the DM command.
RD type1,type2,type3,type4	Selects the type of data to be recorded, where type1, type2, type3, and type 4 represent the various types of data (see table below). The order of data type is important and corresponds with the order of n,m,o,p arrays in the RA command.

RC n,m	The RC command begins data collection. Sets data capture time interval where n is an integer between 1 and 8 and designates 2^n msec between data. m is optional and specifies the number of elements to be captured. If m is not defined, the number of elements defaults to the smallest array defined by DM. When m is a negative number, the recording is done continuously in a circular manner. _RD is the recording pointer and indicates the address of the next array element. n=0 stops recording.
RC?	Returns a 0 or 1 where, 0 denotes not recording, 1 specifies recording in progress

Data Types for Recording:

Data type	Description
TIME	Controller time as reported by the TIME command
_AFn	Analog input (n=X,Y,Z,W,E,F,G,H, for AN inputs 1-8)
_DEX	2 nd encoder position (dual encoder)
_NOX	Status bits
_OP	Output
_RLX	Latched position
_RPX	Commanded position
_SCX	Stop code
_TEX	Position error
_TI	Inputs
_TPX	Encoder position
_TSX	Switches (only bit 0-4 valid)
_TTX	Torque (reports digital value +/-32544)

NOTE: X may be replaced by Y,Z or W for capturing data on other axes.

Operand Summary - Automatic Data Capture

_RC	Returns a 0 or 1 where, 0 denotes not recording, 1 specifies recording in progress
_RD	Returns address of next array element.

Example - Recording into An Array

During a position move, store the X and Y positions and position error every 2 msec.

```

#RECORD           Begin program
DM XPOS[300],YPOS[300] Define X,Y position arrays
DM XERR[300],YERR[300] Define X,Y error arrays
RA XPOS[],XERR[],YPOS[],YERR[] Select arrays for capture
RD _TPX,_TEX,_TPY,_TEY Select data types
PR 10000,20000 Specify move distance
RC1               Start recording now, at rate of 2 msec
BG XY             Begin motion
#A;JP #A,_RC=1   Loop until done
MG "DONE"         Print message
EN                End program
#PLAY              Play back
N=0               Initial Counter
JP# DONE,N>300    Exit if done
N=                Print Counter

```

X POS[N]=	Print X position
Y POS[N]=	Print Y position
XERR[N]=	Print X error
YERR[N]=	Print Y error
N=N+1	Increment Counter
#DONE	Done
EN	End Program

De-allocating Array Space

Array space may be de-allocated using the DA command followed by the array name. DA*[0] deallocates all the arrays.

Input of Data (Numeric and String)

NOTE: The IN command has been removed from the DMC-41x3 firmware. Variables should be entered by sending data directly from the host application.

Sending Data from a Host

The DMC-41x3 can accept ASCII strings from a host. This is the most common way to send data to the controller such as setting variables to numbers or strings. Any variable can be stored in a string format up to 6 characters by simply specifying defining that variable to the string value with quotes, for example:

```
varS = "STRING"
```

Will assign the variable 'varS' to a string value of "STRING".

To assign a variable a numerical value, the direct number is used, for example:

```
varN = 123456
```

Will assign the variable 'varN' to a number of 123,456.

All variables on the DMC-41x3 controller are stored with 6 bytes of integer and 4 bytes of fractional data.

Operator Data Entry Mode

The Operator Data Entry Mode provides for un-buffered data entry through the auxiliary RS-232 port. In this mode, the DMC-41x3 provides a buffer for receiving characters. This mode may only be used when executing an applications program.

The Operator Data Entry Mode may be specified for Port 2 only. This mode may be exited with the \ or <escape> key.

NOTE: Operator Data Entry Mode cannot be used for high rate data transfer.

Set the third field of the CC command to one to set the Operator Data Entry Mode.

To capture and decode characters in the Operator Data Mode, the DMC-41x3 provides special the following keywords:

Keyword	Function
P2CH	Contains the last character received
P2ST	Contains the received string
P2NM	Contains the received number

P2CD	Contains the status code: -1 mode disabled 0 nothing received 1 received character, but not <enter> 2 received string, not a number 3 received number
------	--

NOTE: The value of P2CD returns to zero after the corresponding string or number is read.

These keywords may be used in an applications program to decode data and they may also be used in conditional statements with logical operators.

Example

Instruction	Interpretation
JP #LOOP, P2CD< >3	Checks to see if status code is 3 (number received)
JP #P, P2CH="V"	Checks if last character received was a V
PR P2NM	Assigns received number to position
JS #XAXIS, P2ST="X"	Checks to see if received string is X

Using Communication Interrupt

The DMC-41x3 provides a special interrupt for communication allowing the application program to be interrupted by input from the user. The interrupt is enabled using the CI command. The syntax for the command is CI n:

n = 0	Don't interrupt Port 2
n = 1	Interrupt on <enter> Port 2
n = 2	Interrupt on any character Port 2
n = -1	Clear any characters in buffer

The #COMINT label is used for the communication interrupt. For example, the DMC-41x3 can be configured to interrupt on any character received on Port 2. The #COMINT subroutine is entered when a character is received and the subroutine can decode the characters. At the end of the routine the EN command is used. EN,1 will re-enable the interrupt and return to the line of the program where the interrupt was called, EN will just return to the line of the program where it was called without re-enabling the interrupt. As with any automatic subroutine, a program must be running in thread 0 at all times for it to be enabled.

Example

A DMC-41x3 is used to jog the A and B axis. This program automatically begins upon power-up and allows the user to input values from the main serial port terminal. The speed of either axis may be changed during motion by specifying the axis letter followed by the new speed value. An S stops motion on both axes.

Instruction	Interpretation
#AUTO	Label for Auto Execute
speedA=10000	Initial A speed
speedB=10000	Initial B speed
CI 2	Set Port 2 for Character Interrupt
JG speedA, speedB	Specify jog mode speed for A and B axis
BGXY	Begin motion
#PRINT	Routine to print message to terminal
MG{P2}"TO CHANGE SPEEDS"	Print message
MG{P2}"TYPE A OR B"	
MG{P2}"TYPE S TO STOP"	
#JOGLOOP	Loop to change Jog speeds
JG speedA, speedB	Set new jog speed
JP #JOGLOOP	

EN	End of main program
#COMINT	Interrupt routine
JP #A,P2CH="A"	Check for A
JP #B,P2CH="B"	Check for B
JP #C,P2CH="S"	Check for S
ZS1;CI2;JP#JOGLOOP	Jump if not X,Y,S
#A;JS#NUM	
speedX=val	New X speed
ZS1;CI2;JP#PRINT	Jump to Print
#B;JS#NUM	
speedY=val	New Y speed
ZS1;CI2;JP#PRINT	Jump to Print
#C;ST;AMX;CI-1	Stop motion on S
MG{^8}, "THE END"	
ZS;EN,1	End-Re-enable interrupt
#NUM	Routine for entering new jog speed
MG "ENTER",P2CH(S),"AXIS SPEED" {N}	Prompt for value
#NUMLOOP; CI-1	Check for enter
#NMLP	Routine to check input from terminal
JP #NMLP,P2CD<2	Jump to error if string
JP #ERROR,P2CD=2	Read value
val=P2NM	
EN	End subroutine
#ERROR,CI-1	Error Routine
MG "INVALID-TRY AGAIN"	Error message
JP #NMLP	
EN	End

Output of Data (Numeric and String)

Numerical and string data can be output from the controller using several methods. The message command, MG, can output string and numerical data. Also, the controller can be commanded to return the values of variables and arrays, as well as other information using the interrogation commands (the interrogation commands are described in chapter 5).

Sending Messages

Messages may be sent to the bus using the message command, MG. This command sends specified text and numerical or string data from variables or arrays to the screen.

Text strings are specified in quotes and variable or array data is designated by the name of the variable or array. For example:

```
MG "The Final Value is", result
```

In addition to variables, functions and commands, responses can be used in the message command. For example:

```
MG "Analog input is", @AN[1]
MG "The Position of A is", _TPA
```

Specifying the Port for Messages:

The port can be specified with the specifier, {P1} for the main USB {P2} for auxiliary serial port, or {En} for the Ethernet port.

MG { P2 } "Hello World" Sends message to Auxiliary Port

Formatting Messages

String variables can be formatted using the specifier, {Sn} where n is the number of characters, 1 thru 6. For example:

MG STR {S3}

This statement returns 3 characters of the string variable named STR.

Numeric data may be formatted using the {Fn.m} expression following the completed MG statement. {\$n.m} formats data in HEX instead of decimal. The actual numerical value will be formatted with n characters to the left of the decimal and m characters to the right of the decimal. Leading zeros will be used to display specified format.

For example:

MG "The Final Value is", result {F5.2}

If the value of the variable result is equal to 4.1, this statement returns the following:

The Final Value is 00004.10

If the value of the variable result is equal to 999999.999, the above message statement returns the following:

The Final Value is 99999.99

The message command normally sends a carriage return and line feed following the statement. The carriage return and the line feed may be suppressed by sending {N} at the end of the statement. This is useful when a text string needs to surround a numeric value.

Example:

```
#A  
JG 50000;BGA;ASA  
MG "The Speed is", _TVA {F5.0} {N}  
MG "counts/sec"  
EN
```

When #A is executed, the above example will appear on the screen as:

The Speed is 50000 counts/sec

Using the MG Command to Configure Terminals

The MG command can be used to configure a terminal. Any ASCII character can be sent by using the format {^n} where n is any integer between 1 and 255.

Example:

MG {^07} {^255}

sends the ASCII characters represented by 7 and 255 to the bus.

Summary of Message Functions

function	description
""	Surrounds text string
{Fn.m}	Formats numeric values in decimal n digits to the left of the decimal point and m digits to the right
{P1}, {P2} or {E}	Send message to Main Serial Port, Auxiliary Serial Port or Ethernet Port

{\$n.m}	Formats numeric values in hexadecimal
{^n}	Sends ASCII character specified by integer n
{N}	Suppresses carriage return/line feed
{Sn}	Sends the first n characters of a string variable, where n is 1 thru 6.

Displaying Variables and Arrays

Variables and arrays may be sent to the screen using the format, variable= or array[x]=. For example, v1= returns the value of v1.

Example - Printing a Variable and an Array element

Instruction	Interpretation
#DISPLAY	Label
DM posA[7]	Define Array posA with 7 entries
PR 1000	Position Command
BGX	Begin
AMX	After Motion
v1=_TPA	Assign Variable v1
posA[1]=_TPA	Assign the first entry
v1=	Print v1

Interrogation Commands

The DMC-41x3 has a set of commands that directly interrogate the controller. When these command are entered, the requested data is returned in decimal format on the next line followed by a carriage return and line feed. The format of the returned data can be changed using the Position Format (PF), and Leading Zeros (LZ) command. For a complete description of interrogation commands, see [Chapter 5](#).

Using the PF Command to Format Response from Interrogation Commands

The command, PF, can change format of the values returned by theses interrogation commands:

BL ?	LE ?
DE ?	PA ?
DP ?	PR ?
EM ?	TN ?
FL ?	VE ?
IP ?	TE
TP	

The numeric values may be formatted in decimal or hexadecimal with a specified number of digits to the right and left of the decimal point using the PF command.

Position Format is specified by:

PF m.n

where m is the number of digits to the left of the decimal point (0 thru 10) and n is the number of digits to the right of the decimal point (0 thru 4) A negative sign for m specifies hexadecimal format.

Hex values are returned preceded by a \$ and in 2's complement. Hex values should be input as signed 2's complement, where negative numbers have a negative sign. The default format is PF 10.0.

If the number of decimal places specified by PF is less than the actual value, a nine appears in all the decimal places.

Example

Instruction	Interpretation
:DP21	Define position
:TPA	Tell position
0000000021	Default format
:PF4	Change format to 4 places
:TPA	Tell position
0021	New format
:PF-4	Change to hexadecimal format
:TPA	Tell Position
\$0015	Hexadecimal value
:PF2	Format 2 places
:TPA	Tell Position
99	Returns 99 if position greater than 99

Adding Leading Zeros from Response to Interrogation Commands

The leading zeros on data returned as a response to interrogation commands can be added by the use of the command, LZ. The LZ command is set to a default of 1.

LZ0	Disables the LZ function
TP	Tell Position Interrogation Command
-0000000009, 0000000005	Response (With Leading Zeros)
LZ1	Enables the LZ function
TP	Tell Position Interrogation Command
-9, 5	Response (Without Leading Zeros)

Local Formatting of Response of Interrogation Commands

The response of interrogation commands may be formatted locally. To format locally, use the command, {Fn.m} or {\$n.m} on the same line as the interrogation command. The symbol F specifies that the response should be returned in decimal format and \$ specifies hexadecimal. n is the number of digits to the left of the decimal, and m is the number of digits to the right of the decimal.

TP {F2.2}	Tell Position in decimal format 2.2
-05.00, 05.00, 00.00, 07.00	Response from Interrogation Command
TP {\$4.2}	Tell Position in hexadecimal format 4.2
FFFFB.00,\$0005.00,\$0000.00,\$0007.00	Response from Interrogation Command

Formatting Variables and Array Elements

The Variable Format (VF) command is used to format variables and array elements. The VF command is specified by:

VF m.n

where m is the number of digits to the left of the decimal point (0 thru 10) and n is the number of digits to the right of the decimal point (0 thru 4).

A negative sign for m specifies hexadecimal format. The default format for VF is VF 10.4

Hex values are returned preceded by a \$ and in 2's complement.

Instruction	Interpretation
v1=10	Assign v1

```

v1=
      :0000000010.0000          Return v1
Response - Default format
VF2.2
v1=
      :10.00                     Change format
Return v1
Response - New format
VF-2.2
v1=
      $0A.00                     Specify hex format
Return v1
Response - Hex value
VF1
v1=
      :9                         Change format
Return v1
Response - Overflow

```

Local Formatting of Variables

PF and VF commands are global format commands that affect the format of all relevant returned values and variables. Variables may also be formatted locally. To format locally, use the command, {Fn.m} or {\$n.m} following the variable name and the '=' symbol. F specifies decimal and \$ specifies hexadecimal. n is the number of digits to the left of the decimal, and m is the number of digits to the right of the decimal.

Instruction	Interpretation
v1=10	Assign v1
v1=	Return v1
:0000000010.0000	Default Format
v1={F4.2}	Specify local format
:0010.00	New format
v1={\$4.2}	Specify hex format
:\$000A.00	Hex value
v1="ALPHA"	Assign string "ALPHA" to v1
v1={S4}	Specify string format first 4 characters
:ALPH	

The local format is also used with the MG command.

Converting to User Units

Variables and arithmetic operations make it easy to input data in desired user units such as inches or RPM.

The DMC-41x3 position parameters such as PR, PA and VP have units of quadrature counts. Speed parameters such as SP, JG and VS have units of counts/sec. Acceleration parameters such as AC, DC, VA and VD have units of counts/sec². The controller interprets time in milliseconds.

All input parameters must be converted into these units. For example, an operator can be prompted to input a number in revolutions. A program could be used such that the input number is converted into counts by multiplying it by the number of counts/revolution.

Instruction	Interpretation
#RUN	Label
MG "ENTER # OF REVOLUTIONS";n1=-1	Prompt for revs
#rev;JP#rev,n1=-1	Wait until user enters new value for n1
PR n1*2000	Convert to counts
MG "ENTER SPEED IN RPM";s1=-1	Prompt for RPMs
#spd;JP#spd,s1=-1	Wait for user to enter new value for s1
SP s1*2000/60	Convert to counts/sec

MG "ENTER ACCEL IN RAD/SEC2";a1=-1	Prompt for ACCEL
#acc;JP#acc,a1=-1	Wait for user to enter new value for a1
AC a1*2000/(2*3.14)	Convert to counts/sec2
BG	Begin motion
EN	End program

Hardware I/O

Digital Outputs

The DMC-41x3 has an 8-bit uncommitted output port, the DMC-4153 through DMC-4183 has an additional 8 outputs. Each bit on the output port may be set and cleared with the software instructions SB (Set Bit) and CB (Clear Bit), or OB (define output bit).

Example- Set Bit and Clear Bit

Instruction	Interpretation
SB6	Sets bit 6 of output port
CB4	Clears bit 4 of output port

Example- Output Bit

The Output Bit (OB) instruction is useful for setting or clearing outputs depending on the value of a variable, array, input or expression. Any non-zero value results in a set bit.

Instruction	Interpretation
OB1, POS	Set Output 1 if the variable POS is non-zero. Clear Output 1 if POS equals 0.
OB 2, @IN [1]	Set Output 2 if Input 1 is high. If Input 1 is low, clear Output 2.
OB 3, @IN [1]&@IN [2]	Set Output 3 only if Input 1 and Input 2 are high.
OB 4, COUNT [1]	Set Output 4 if element 1 in the array COUNT is non-zero.

The output port can be set by specifying an 16-bit word using the instruction OP (Output Port). This instruction allows a single command to define the state of the entire 16-bit output port, where bit 0 is output 1, bit1 is output2 and so on. A 1 designates that the output is on.

Example- Output Port

Instruction	Interpretation
OP6	Sets outputs 2 and 3 of output port to high. All other bits are 0. ($2^1 + 2^2 = 6$)
OP0	Clears all bits of output port to zero
OP 255	Sets all bits of output port to one. $(2^0 + 2^1 + 2^2 + 2^3 + 2^4 + 2^5 + 2^6 + 2^7)$

The output port is useful for setting relays or controlling external switches and events during a motion sequence.

Example - Turn on output after move

Instruction	Interpretation
#OUTPUT	Label
PR 2000	Position Command

BG	Begin
AM	After move
SB1	Set Output 1
WT 1000	Wait 1000 msec
CB1	Clear Output 1
EN	End

Digital Inputs

The general digital inputs for are accessed by using the @IN[n] function or the TI command. The @IN[n] function returns the logic level of the specified input, n, where n is a number 1 through 16.

Example - Using Inputs to control program flow

Instruction	Interpretation
JP #A,@IN[1]=0	Jump to A if input 1 is low
JP #B,@IN[2]=1	Jump to B if input 2 is high
AI 7	Wait until input 7 is high
AI -6	Wait until input 6 is low

Example - Start Motion on Switch

Motor A must turn at 4000 counts/sec when the user flips a panel switch to on. When panel switch is turned to off position, motor A must stop turning.

Solution: Connect panel switch to input 1 of DMC-41x3. High on input 1 means switch is in on position.

Instruction	Interpretation
#S;JG 4000	Set speed
AI 1;BGA	Begin after input 1 goes high
AI -1;STA	Stop after input 1 goes low
AMA;JP #S	After motion, repeat
EN	

The Auxiliary Encoder Inputs

The auxiliary encoder inputs can be used for general use. For each axis, the controller has one auxiliary encoder and each auxiliary encoder consists of two inputs, channel A and channel B. The auxiliary encoder inputs are mapped to the inputs 81-96.

Each input from the auxiliary encoder is a differential line receiver and can accept voltage levels between +/- 12 volts. The inputs have been configured to accept TTL level signals. To connect TTL signals, simply connect the signal to the + input and leave the - input disconnected. For other signal levels, the - input should be connected to a voltage that is 1/2 of the full voltage range (for example, connect the - input to 5 volts if the signal is a 0 - 12 volt logic).

Example:

A DMC-4113 has one auxiliary encoder. This encoder has two inputs (channel A and channel B). Channel A input is mapped to input 81 and Channel B input is mapped to input 82. To use this input for 2 TTL signals, the first signal will be connected to AA+ and the second to AB+. AA- and AB- will be left unconnected. To access this input, use the function @IN[81] and @IN[82].

NOTE: The auxiliary encoder inputs are not available for any axis that is configured for stepper motor.

Input Interrupt Function

The DMC-41x3 provides an input interrupt function which causes the program to automatically execute the instructions following the #ININT label. This function is enabled using the II m,n,o command. The m specifies the beginning input and n specifies the final input in the range. The parameter o is an interrupt mask. If m and n are unused, o contains a number with the mask. For example, II,,5 enables inputs 1 and 3.

A low input on any of the specified inputs will cause automatic execution of the #ININT subroutine. The Return from Interrupt (RI) command is used to return from this subroutine to the place in the program where the interrupt had occurred.

Important: Use the RI command (not EN) to return from the #ININT subroutine.

Example - Input Interrupt

Instruction	Interpretation
#A	Label #A
II 1	Enable input 1 for interrupt function
JG 30000,-20000	Set speeds on A and B axes
BG AB	Begin motion on A and B axes
#B	Label #B
TP AB	Report A and B axes positions
WT 1000	Wait 1000 milliseconds
JP #B	Jump to #B
EN	End of program
#ININT	Interrupt subroutine
MG "Interrupt has occurred"	Displays the message
ST AB	Stops motion on A and B axes
#LOOP;JP #LOOP,@IN[1]=0	Loop until Interrupt cleared
JG 15000,10000	Specify new speeds
WT 300	Wait 300 milliseconds
BG AB	Begin motion on A and B axes
RI	Return from Interrupt subroutine

Jumping back to main program with #ININT

To jump back to the main program using the JP command, the RI command must be issued in a subroutine and then the ZS command must be issued prior to the JP command. See Application Note # 2418 for more information.

<http://www.galilmc.com/support/appnotes/optima/note2418.pdf>

Analog Inputs

The DMC-41x3 provides eight analog inputs. The value of these inputs in volts may be read using the @AN[n] function where n is the analog input 1 through 8. The resolution of the Analog-to-Digital conversion is 12 bits (16-bit ADC is available as an option). Analog inputs are useful for reading special sensors such as temperature, tension or pressure.

The following examples show programs which cause the motor to follow an analog signal. The first example is a point-to-point move. The second example shows a continuous move.

Example - Position Follower (Point-to-Point)

Objective - The motor must follow an analog signal. When the analog signal varies by 10V, motor must move 10000 counts.

Method: Read the analog input and command A to move to that point.

Instruction	Interpretation
#POINTS	Label
SP 7000	Speed
AC 80000;DC 80000	Acceleration
#LOOP	
VP=@AN[1]*1000	Read and analog input, compute position
PA VP	Command position
BGA	Start motion
AMA	After completion
JP #LOOP	Repeat
EN	End

Example - Position Follower (Continuous Move)

Method: Read the analog input, compute the commanded position and the position error. Command the motor to run at a speed in proportions to the position error.

Instruction	Interpretation
#CONT	Label
AC 80000;DC 80000	Acceleration rate
JG 0	Start job mode
BGX	Start motion
#LOOP	
vp=@AN[1]*1000	Compute desired position
ve=vp-_TPA	Find position error
vel=ve*20	Compute velocity
JG vel	Change velocity
JP #LOOP	Change velocity
EN	End

Example – Low Pass Digital Filter for the Analog inputs

Because the analog inputs on the Galil controller can be used to close a position loop, they have a very high bandwidth and will therefore read noise that comes in on the analog input. Often when an analog input is used in a motion control system, but not for closed loop control, the higher bandwidth is not required. In this case a simple digital filter may be applied to the analog input, and the output of the filter can be used for in the motion control application. This example shows how to apply a simple single pole low-pass digital filter to an analog input. This code is commonly run in a separate thread (XQ#filt,1 – example of executing in thread 1).

```

#filt
REM an1 = filtered output. Use this instead of @AN[1]
an1=@AN[1];'set initial value
REM k1+k2=1 this condition must be met
REM use division of m/2^n for elimination of round off
REM increase k1 = less filtering
REM increase k2 = more filtering
k1=32/64;k2=32/64
AT0;'set initial time reference
#loop
REM calculate filtered output and then way 2 samples from last
REM time reference (last AT-2,1 or AT0)
an1=(k1*@AN[1])+(k2*an1);AT-2,1
JP#loop

```

Example Applications

Wire Cutter

An operator activates a start switch. This causes a motor to advance the wire a distance of 10". When the motion stops, the controller generates an output signal which activates the cutter. Allowing 100 ms for the cutting completes the cycle.

Suppose that the motor drives the wire by a roller with a 2" diameter. Also assume that the encoder resolution is 1000 lines per revolution. Since the circumference of the roller equals 2π inches, and it corresponds to 4000 quadrature, one inch of travel equals:

$$4000/2\pi = 637 \text{ count/inch}$$

This implies that a distance of 10 inches equals 6370 counts, and a slew speed of 5 inches per second, for example, equals 3185 count/sec.

The input signal may be applied to I1, for example, and the output signal is chosen as output 1. The motor velocity profile and the related input and output signals are shown in Figure 7.1.

The program starts at a state that we define as #A. Here the controller waits for the input pulse on I1. As soon as the pulse is given, the controller starts the forward motion.

Upon completion of the forward move, the controller outputs a pulse for 20 ms and then waits an additional 80 ms before returning to #A for a new cycle.

INSTRUCTION	FUNCTION
#A	Label
AI1	Wait for input 1
PR 6370	Distance
SP 3185	Speed
BGX	Start Motion
AMX	After motion is complete
SB1	Set output bit 1
WT 20	Wait 20 ms
CB1	Clear output bit 1
WT 80	Wait 80 ms
JP #A	Repeat the process

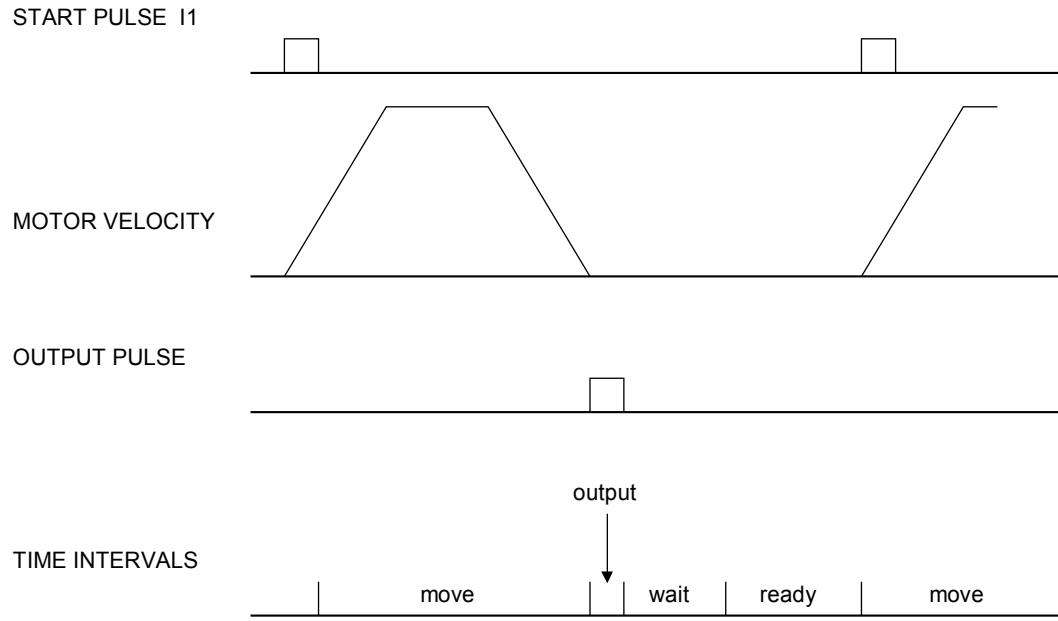


Figure 7.1: Motor Velocity and the Associated Input/Output signals

X-Y Table Controller

An X-Y-Z system must cut the pattern shown in Figure 7.2. The X-Y table moves the plate while the Z-axis raises and lowers the cutting tool.

The solid curves in Figure 7.2 indicate sections where cutting takes place. Those must be performed at a feed rate of 1 inch per second. The dashed line corresponds to non-cutting moves and should be performed at 5 inch per second. The acceleration rate is 0.1 g.

The motion starts at point A, with the Z-axis raised. An X-Y motion to point B is followed by lowering the Z-axis and performing a cut along the circle. Once the circular motion is completed, the Z-axis is raised and the motion continues to point C, etc.

Assume that all of the 3 axes are driven by lead screws with 10 turns-per-inch pitch. Also assume encoder resolution of 1000 lines per revolution. This results in the relationship:

$$1 \text{ inch} = 40,000 \text{ counts}$$

and the speeds of

$$1 \text{ in/sec} = 40,000 \text{ count/sec}$$

$$5 \text{ in/sec} = 200,000 \text{ count/sec}$$

an acceleration rate of 0.1g equals

$$0.1g = 38.6 \text{ in/s}^2 = 1,544,000 \text{ count/s}^2$$

Note that the circular path has a radius of 2" or 80000 counts, and the motion starts at the angle of 270° and traverses 360° in the CW (negative direction). Such a path is specified with the instruction

CR 80000, 270, -360

Further assume that the Z must move 2" at a linear speed of 2" per second. The required motion is performed by the following instructions:

INSTRUCTION	FUNCTION
#A	Label
VM XY	Circular interpolation for XY
VP 160000,160000	Positions
VE	End Vector Motion
VS 200000	Vector Speed
VA 1544000	Vector Acceleration
BGS	Start Motion
AMS	When motion is complete
PR,, -80000	Move Z down
SP,, 80000	Z speed
BGZ	Start Z motion
AMZ	Wait for completion of Z motion
CR 80000,270,-360	Circle
VE	
VS 40000	Feed rate
BGS	Start circular move
AMS	Wait for completion
PR,, 80000	Move Z up
BGZ	Start Z move
AMZ	Wait for Z completion
PR -21600	Move X
SP 20000	Speed X
BGX	Start X
AMX	Wait for X completion
PR,, -80000	Lower Z
BGZ	
AMZ	
CR 80000,270,-360	Z second circle move
VE	
VS 40000	
BGS	
AMS	
PR,, 80000	Raise Z
BGZ	
AMZ	
VP -37600,-16000	Return XY to start
VE	
VS 200000	
BGS	
AMS	
EN	

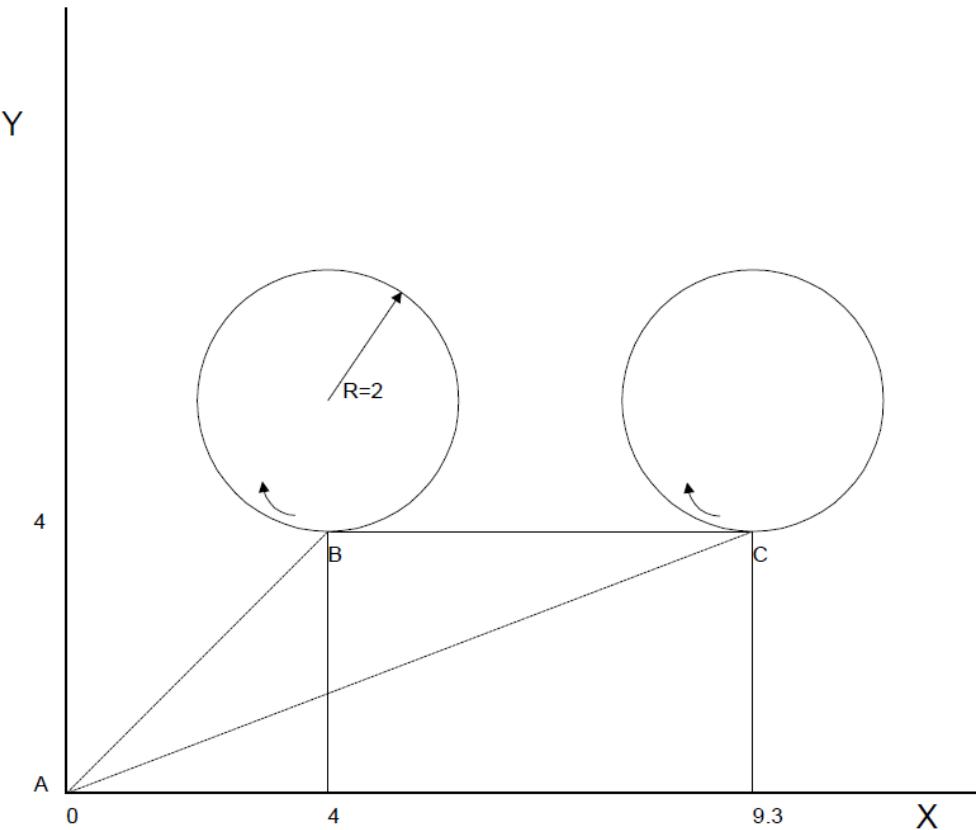


Figure 7.2: Motor Velocity and the Associated Input/Output signals

Speed Control by Joystick

The speed of a motor is controlled by a joystick. The joystick produces a signal in the range between -10V and +10V. The objective is to drive the motor at a speed proportional to the input voltage.

Assume that a full voltage of 10 Volts must produce a motor speed of 3000 rpm with an encoder resolution of 1000 lines or 4000 count/rev. This speed equals:

$$3000 \text{ rpm} = 50 \text{ rev/sec} = 200000 \text{ count/sec}$$

The program reads the input voltage periodically and assigns its value to the variable VIN. To get a speed of 200,000 ct/sec for 10 volts, we select the speed as:

$$\text{Speed} = 20000 \times \text{VIN}$$

The corresponding velocity for the motor is assigned to the VEL variable.

Instruction

```
#A  
JG0  
BGX  
#B  
VIN=@AN[1]  
VEL=VIN*20000  
JG VEL  
JP #B  
EN
```

Position Control by Joystick

This system requires the position of the motor to be proportional to the joystick angle. Furthermore, the ratio between the two positions must be programmable. For example, if the control ratio is 5:1, it implies that when the joystick voltage is 5 Volts, corresponding to 1028 counts, the required motor position must be 5120 counts. The variable V3 changes the position ratio.

INSTRUCTION	FUNCTION
#A	Label
V3=5	Initial position ratio
DPO	Define the starting position
JG0	Set motor in jog mode as zero
BGX	Start
#B	
VIN=@AN[1]	Read analog input
V2=V1*V3	Compute the desired position
V4=V2-_TPX_-TEX	Find the following error
V5=V4*20	Compute a proportional speed
JG V5	Change the speed
JP #B	Repeat the process
EN	End

Backlash Compensation by Sampled Dual-Loop

The continuous dual loop, enabled by the DV1 function is an effective way to compensate for backlash. In some cases, however, when the backlash magnitude is large, it may be difficult to stabilize the system. In those cases, it may be easier to use the sampled dual loop method described below.

This design example addresses the basic problems of backlash in motion control systems. The objective is to control the position of a linear slide precisely. The slide is to be controlled by a rotary motor, which is coupled to the slide by a lead screw. Such a lead screw has a backlash of 4 micron, and the required position accuracy is for 0.5 micron.

The basic dilemma is where to mount the sensor. If you use a rotary sensor, you get a 4 micron backlash error. On the other hand, if you use a linear encoder, the backlash in the feedback loop will cause oscillations due to instability.

An alternative approach is the dual-loop, where we use two sensors, rotary and linear. The rotary sensor assures stability (because the position loop is closed before the backlash) whereas the linear sensor provides accurate load position information. The operation principle is to drive the motor to a given rotary position near the final point.

Once there, the load position is read to find the position error and the controller commands the motor to move to a new rotary position which eliminates the position error.

Since the required accuracy is 0.5 micron, the resolution of the linear sensor should preferably be twice finer. A linear sensor with a resolution of 0.25 micron allows a position error of +/-2 counts.

The dual-loop approach requires the resolution of the rotary sensor to be equal or better than that of the linear system. Assuming that the pitch of the lead screw is 2.5mm (approximately 10 turns per inch), a rotary encoder of 2500 lines per turn or 10,000 count per revolution results in a rotary resolution of 0.25 micron. This results in equal resolution on both linear and rotary sensors.

To illustrate the control method, assume that the rotary encoder is used as a feedback for the X-axis, and that the linear sensor is read and stored in the variable LINPOS. Further assume that at the start, both the position of X and the value of LINPOS are equal to zero. Now assume that the objective is to move the linear load to the position of 1000.

The first step is to command the X motor to move to the rotary position of 1000. Once it arrives we check the position of the load. If, for example, the load position is 980 counts, it implies that a correction of 20 counts must be made. However, when the X-axis is commanded to be at the position of 1000, suppose that the actual position is only 995, implying that X has a position error of 5 counts, which will be eliminated once the motor settles. This implies that the correction needs to be only 15 counts, since 5 counts out of the 20 would be corrected by the X-axis. Accordingly, the motion correction should be:

$$\text{Correction} = \text{Load Position Error} - \text{Rotary Position Error}$$

The correction can be performed a few times until the error drops below +/-2 counts. Often, this is performed in one correction cycle.

Example:

INSTRUCTION	FUNCTION
#A	Label
DPO	Define starting positions as zero
LINPOS=0	
PR 1000	Required distance
BGX	Start motion
#B	
AMX	Wait for completion
WT 50	Wait 50 msec
LINPOS = _DEX	Read linear position
ERR=1000-LINPOS-_TEX	Find the correction
JP #C, @ABS[ERR]<2	Exit if error is small
PR ERR	Command correction
BGX	
JP #B	Repeat the process
#C	
EN	

Using the DMC-41x3 Editor to Enter Programs (Advanced)

The GalilTools software package provides an editor and utilities that allow the upload and download of DMC programs to the motion controller. In most instances the user will use Galil software or a host application to download programs to the Galil controller rather than using the ED command.

Application programs for the DMC-41x3 may also be created and edited locally using the DMC-41x3 when using a program such as hyper-terminal or telnet.

The DMC-41x3 provides a line Editor for entering and modifying programs. The Edit mode is entered with the ED instruction. (Note: The ED command can only be given when the controller is in the non-edit mode, which is signified by a colon prompt).

In the Edit Mode, each program line is automatically numbered sequentially starting with 000. If no parameter follows the ED command, the editor prompter will default to the last line of the last program in memory. If desired, the user can edit a specific line number or label by specifying a line number or label following ED.

ED	Puts Editor at end of last program
:ED 5	Puts Editor at line 5
:ED #BEGIN	Puts Editor at label #BEGIN

Line numbers appear as 000,001,002 and so on. Program commands are entered following the line numbers. Multiple commands may be given on a single line as long as the total number of characters doesn't exceed 80 characters per line.

While in the Edit Mode, the programmer has access to special instructions for saving, inserting and deleting program lines. These special instructions are listed below:

Edit Mode Commands

<RETURN>

Typing the return key causes the current line of entered instructions to be saved. The editor will automatically advance to the next line. Thus, hitting a series of <RETURN> will cause the editor to advance a series of lines. Note, changes on a program line will not be saved unless a <return> is given.

<cntrl>P

The <cntrl>P command moves the editor to the previous line.

<cntrl>I

The <cntrl>I command inserts a line above the current line. For example, if the editor is at line number 2 and <cntrl>I is applied, a new line will be inserted between lines 1 and 2. This new line will be labeled line 2. The old line number 2 is renumbered as line 3.

<cntrl>D

The <cntrl>D command deletes the line currently being edited. For example, if the editor is at line number 2 and <cntrl>D is applied, line 2 will be deleted. The previous line number 3 is now renumbered as line number 2.

<cntrl>Q

The <cntrl>Q quits the editor mode. In response, the DMC-41x3 will return a colon.

After the Edit session is over, the user may list the entered program using the LS command. If no operand follows the LS command, the entire program will be listed. The user can start listing at a specific line or label using the operand n. A command and new line number or label following the start listing operand specifies the location at which listing is to stop.

Example:

Instruction	Interpretation
:LS	List entire program
:LS 5	Begin listing at line 5
:LS 5,9	List lines 5 thru 9
:LS #A,9	List line label #A thru line 9
:LS #A, #A +5	List line label #A and additional 5 lines

Chapter 8 Hardware & Software Protection

Introduction

The DMC-41x3 provides several hardware and software features to check for error conditions and to inhibit the motor on error. These features help protect the various system components from damage.

WARNING: Machinery in motion can be dangerous! It is the responsibility of the user to design effective error handling and safety protection as part of the machine. Since the DMC-41x3 is an integral part of the machine, the engineer should design his overall system with protection against a possible component failure on the DMC-41x3. Galil shall not be liable or responsible for any incidental or consequential damages.

Hardware Protection

The DMC-41x3 includes hardware input and output protection lines for various error and mechanical limit conditions. These include:

Output Protection Lines

Amp Enable

This signal goes low when the motor off command is given, when the position error exceeds the value specified by the Error Limit (ER) command, or when off-on-error condition is enabled (OE1) and the abort command is given. Each axis amplifier has separate amplifier enable lines. This signal also goes low when the watch-dog timer is activated, or upon reset.

NOTE: The standard configuration of the AEN signal is TTL active low. Both the polarity and the amplitude can be changed. To make these changes, see section entitled Configuring the Amplifier Enable Circuit in Chapter 3..

Error Output

The error output is a TTL signal which indicates an error condition in the controller. This signal is available on the interconnect module as ERR. When the error signal is low, this indicates an error condition and the Error Light on the controller will be illuminated. For details on the reasons why the error output would be active see Error Light (Red LED) in Chapter 9.

Input Protection Lines

General Abort

A low input stops commanded motion instantly without a controlled deceleration. For any axis in which the Off-On-Error function is enabled, the amplifiers will be disabled. This could cause the motor to ‘coast’ to a stop. If the Off-On-Error function is not enabled, the motor will instantaneously stop and servo at the current position. The Off-On-Error function is further discussed in this chapter.

The Abort input by default will also halt program execution; this can be changed by changing the 5th field of the CN command. See the CN command in the command reference for more information.

Selective Abort

The controller can be configured to provide an individual abort for each axis. Activation of the selective abort signal will act the same as the Abort Input but only on the specific axis. To configure the controller for selective abort, issue the command CN,,1. This configures the inputs 5,6,7,8,13,14,15,16 to act as selective aborts for axes A,B,C,D,E,F,G,H respectively.

ELO (Electronic Lock Out)

Used in conjunction with Galil amplifiers, this input allows the user to shutdown the amplifier at a hardware level. For more detailed information on how specific Galil amplifiers behave when the ELO is triggered, see Integrated in the Appendices.

Forward Limit Switch

Low input inhibits motion in forward direction. If the motor is moving in the forward direction when the limit switch is activated, the motion will decelerate and stop. In addition, if the motor is moving in the forward direction, the controller will automatically jump to the limit switch subroutine, #LIMSWI (if such a routine has been written by the user). The CN command can be used to change the polarity of the limit switches. The OE command can also be configured so that the axis will be disabled upon the activation of a limit switch.

Reverse Limit Switch

Low input inhibits motion in reverse direction. If the motor is moving in the reverse direction when the limit switch is activated, the motion will decelerate and stop. In addition, if the motor is moving in the reverse direction, the controller will automatically jump to the limit switch subroutine, #LIMSWI (if such a routine has been written by the user). The CN command can be used to change the polarity of the limit switches. The OE command can also be configured so that the axis will be disabled upon the activation of a limit switch.

Software Protection

The DMC-41x3 provides a programmable error limit as well as encoder failure detection. It is recommended that both the position error and encoder failure detection be used when running servo motors with the DMC-41x3. Along with position error and encoder failure detection, then DMC-41x3 has the ability to have programmable software limit.

Position Error

The error limit can be set for any number between 0 and 2147483647 using the ER n command. The default value for ER is 16384.

Example:

```
ER 200,300,400,500      Set X-axis error limit for 200, Y-axis error limit to 300, Z-axis error limit to 400 counts, W-axis error limit to 500 counts
ER,1,,10                Set Y-axis error limit to 1 count, set W-axis error limit to 10 counts.
```

The units of the error limit are quadrature counts. The error is the difference between the command position and actual encoder position. If the absolute value of the error exceeds the value specified by ER, the controller will generate several signals to warn the host system of the error condition. These signals include:

Signal or Function	State if Error Occurs
# POSERR	Jumps to automatic excess position error subroutine
Error Light	Turns on
OE Function	Shuts motor off if OE1 or OE3
AEN Output Line	Switches to Motor Off state

The Jump on Condition statement is useful for branching on a given error within a program. The position error of X,Y,Z and W can be monitored during execution using the TE command.

Encoder Failure detection

The encoder failure detection on the controller operates based upon two factors that are user settable, a threshold of motor command output (OV), a time above that threshold (OT) in which there is no more than 4 counts of change on the encoder input for that axis. The encoder failure detection is activated with the OA command. When an encoder failure is detected and OA is set to 1 for that axis, the same conditions will occur as a position error.

Conditions for proper operation of Encoder Failure detection

- The axis must have a non-zero KI setting order to detect an encoder failure when the axis is not profiling.
- The IL command must be set to a value greater than the OV setting
- The TL command must be set to a value greater than the OV setting

Example:

The A axis is setup with the following settings for encoder failure detection:

```
OA 1  
OT 500  
OV 3  
OE 1  
ER 1000
```

The A axis is commanded to move 300 counts, but the B channel on the encoder has failed and no longer operates. Because the ER setting is greater than the commanded move, the error will not be detected by using the OE and ER commands, but this condition will be detected as an encoder failure. When the axis is commanded to move a 300 counts, the position error will cause the motor command voltage to be increased to a value that will be greater than the OV value, 3 volts in this case. Once the motor command output is greater than the OV threshold for more than the 500ms defined by the OT command AND there has been less than 4 counts of change on the encoder, then the controller will turn off that axis due to an encoder failure. The motor will have moved some distance during this operation, but it will be shut down before a full runaway condition occurs.

Using Encoder Failure to detect a hard stop or stalled motor

The encoder failure detection can also be used to detect when an axis is up against a hard stop. In this scenario the motor command will be commanded above the OV threshold, but because the motor is not moving the controller will detect this scenario as an encoder failure.

Programmable Position Limits

The DMC-41x3 provides programmable forward and reverse position limits. These are set by the BL and FL software commands. Once a position limit is specified, the DMC-41x3 will not accept position commands beyond the limit. Motion beyond the limit is also prevented.

Example:

```
DP0,0,0          Define Position
BL -2000,-4000,-8000 Set Reverse position limit
FL 2000,4000,8000 Set Forward position limit
JG 2000,2000,2000 Jog
BG XYZ          Begin
```

(motion stops at forward limits)

Off-On-Error

The DMC-41x3 controller has a built in function which can turn off the motors under certain error conditions. This function is known as ‘Off-On-Error’. To activate the OE function for each axis, specify 1, 2 or 3 for that axis. To disable this function, specify 0 for the axes. When this function is enabled, the specified motor will be disabled under the following 3 conditions:

1. The position error for the specified axis exceeds the limit set with the command, ER
2. A hardware limit is reached
3. The abort command is given
4. The abort input is activated with a low signal.

NOTE: If the motors are disabled while they are moving, they may ‘coast’ to a stop because they are no longer under servo control.

To re-enable the system, use the Reset (RS) or Servo Here (SH) command.

Examples:

```
OE 1,1,1,1      Enable off-on-error for X,Y,Z and W
OE 0,1,0,1      Enable off-on-error for Y and W axes and disable off-on-error for W and Z axes
OE 2,3          Enable off-on-error for limit switch for the X axis, and position error (or
                abort input) and limit switch for the Y axis
```

Automatic Error Routine

The #POSERR label causes the statements following to be automatically executed if error on any axis exceeds the error limit specified by ER, a encoder failure is detected, or the abort input is triggered. The error routine must be closed with the RE command. The RE command returns from the error subroutine to the main program.

NOTE: The Error Subroutine will be entered again unless the error condition is cleared.

Example:

```
#A;JP #A;EN          "Dummy" program
#POSERR              Start error routine on error
MG "error"           Send message
SB 1                 Fire relay
STX                  Stop motor
AMX                  After motor stops
SHX                  Servo motor here to clear error
RE                   Return to main program
```

Limit Switch Routine

The DMC-41x3 provides forward and reverse limit switches which inhibit motion in the respective direction. There is also a special label for automatic execution of a limit switch subroutine. The #LIMSWI label specifies the start of

the limit switch subroutine. This label causes the statements following to be automatically executed if any limit switch is activated and that axis motor is moving in that direction. The RE command ends the subroutine.

The state of the forward and reverse limit switches may also be tested during the jump-on-condition statement. The _LR condition specifies the reverse limit and _LF specifies the forward limit. X,Y,Z, or W following LR or LF specifies the axis. The CN command can be used to configure the polarity of the limit switches.

Limit Switch Example:

#A;JP #A;EN	Dummy Program
#LIMSWI	Limit Switch Utility
V1=_LFX	Check if forward limit
V2=_LRX	Check if reverse limit
JP#LF,V1=0	Jump to #LF if forward
JP#LR,V2=0	Jump to #LR if reverse
JP#END	Jump to end
#LF	#LF
MG "FORWARD LIMIT"	Send message
STX;AMX	Stop motion
PR-1000;BGX;AMX	Move in reverse
JP#END	End
#LR	#LR
MG "REVERSE LIMIT"	Send message
STX;AMX	Stop motion
PR1000;BGX;AMX	Move forward
#END	End
RE	Return to main program

Chapter 9 Troubleshooting

Overview

The following discussion may help you get your system to work.

Potential problems have been divided into groups as follows:

1. Installation
2. Stability and Compensation
3. Operation
4. Error Light (Red LED)

The various symptoms along with the cause and the remedy are described in the following tables.

Installation

SYMPTOM	DIAGNOSIS	CAUSE	REMEDY
Motor runs away with no connections from controller to amplifier input.	Adjusting offset causes the motor to change speed.	1. Amplifier has an internal offset. 2. Damaged amplifier.	Adjust amplifier offset. Amplifier offset may also be compensated by use of the offset configuration on the controller (see the OF command). Replace amplifier.
Motor is enabled even when MO command is given	The SH command disables the motor	1. The amplifier requires the a different Amplifier Enable setting on the Interconnect Module	Refer to Chapter 3 or contact Galil.
Unable to read main or auxiliary encoder input.	The encoder does not work when swapped with another encoder input.	1. Wrong encoder connections. 2. Encoder is damaged 3. Encoder configuration incorrect.	Check encoder wiring. For single ended encoders (CHA and CHB only) do not make any connections to the CHA- and CHB- inputs. Replace encoder Check CE command

Unable to read main or auxiliary encoder input.	The encoder works correctly when swapped with another encoder input.	1. Wrong encoder connections. 2. Encoder configuration incorrect. 3. Encoder input or controller is damaged	Check encoder wiring. For single ended encoders (MA+ and MB+ only) do not make any connections to the MA- and MB- inputs. Check CE command Contact Galil
Encoder Position Drifts	Swapping cables fixes the problem	1. Poor Connections / intermittent cable	Review all connections and connector contacts.
Encoder Position Drifts	Significant noise can be seen on MA+ and / or MB+ encoder signals	1. Noise	Shield encoder cables Avoid placing power cables near encoder cables Avoid Ground Loops Use differential encoders Use +/-12V encoders

Stability

SYMPTOM	DIAGNOSIS	CAUSE	REMEDY
Servo motor runs away when the loop is closed.	Reversed Motor Type corrects situation (MT -1)	1. Wrong feedback polarity.	Reverse Motor or Encoder Wiring (remember to set Motor Type back to default value: MT 1)
Motor oscillates.		2. Too high gain or too little damping.	Decrease KI and KP. Increase KD.

Operation

SYMPTOM	DIAGNOSIS	CAUSE	REMEDY
Controller rejects commands.	Response of controller from TC1 diagnoses error.	1. Anything	Correct problem reported by TC1
Motor Doesn't Move	Response of controller from TC1 diagnoses error.	2. Anything	Correct problem reported by SC

Error Light (Red LED)

The red error LED has multiple meanings for Galil controllers. Here is a list of reasons the error light will come on and possible solutions:

Under Voltage

If the controller is not receiving enough voltage to power up.

Under Current

If the power supply does not have enough current, the red LED will cycle on and off along with the green power LED.

Position Error

If any axis that is set up as a servo (MT command) has a position error value (TE) that exceeds the error limit (ER) - the error light will come on to signify there is an axis that has exceeded the position error limit. Use a DP*=0 to set all encoder positions to zero or a SH (Servo Here) command to eliminate position error.

Invalid Firmware

If the controller is interrupted during a firmware update or an incorrect version of firmware is installed - the error light will come on. The prompt will show up as a greater than sign “>” instead of the standard colon “:” prompt. Use GalilTools software to install the correct version of firmware to fix this problem.

Self Test

During the first few seconds of power up, it is normal for the red LED to turn on while it is performing a self test. If the self test detects a problem such as corrupted memory or damaged hardware - the error light will stay on to signal a problem with the board. To fix this problem, a Master Reset may be required. The Master Reset will set the controller back to factory default conditions so it is recommended that all motor and I/O cables be removed for safety while performing the Master Reset. Cables can be plugged back in after the correct settings have been loaded back to the controller (when necessary). To perform a Master Reset - find the jumper location labeled MR or MRST on the controller and put a jumper across the two pins. Power up with the jumper installed. The Self-Test will take slightly longer - up to 5seconds. After the error light shuts off, it is safe to power down and remove the Master Reset jumper. If performing a Master Reset does not get rid of the error light, the controller may need to be sent back to the factory to be repaired. Contact Galil for more information.

Chapter 10 Theory of Operation

Overview

The following discussion covers the operation of motion control systems. A typical motion control system consists of the elements shown in Figure 10.1.

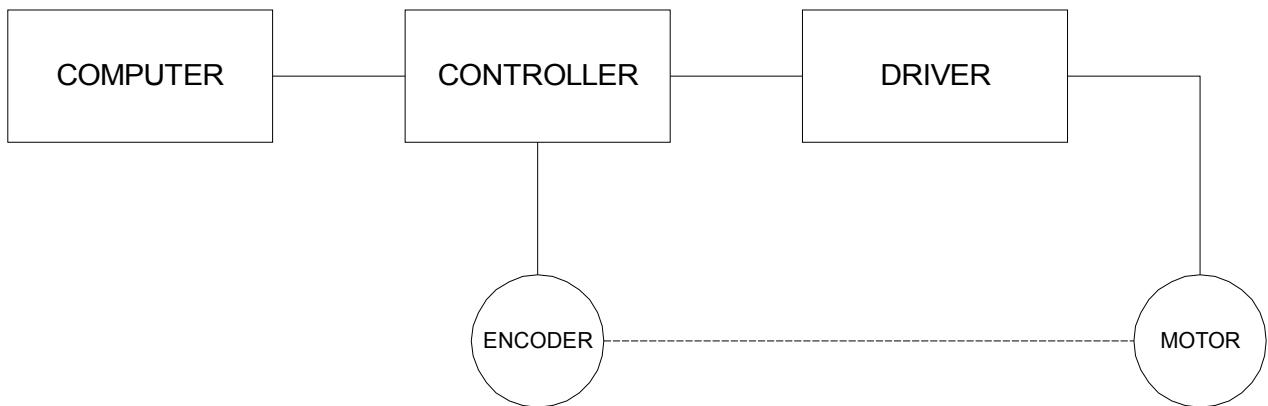


Figure 10.1: Elements of Servo Systems

The operation of such a system can be divided into three levels, as illustrated in Figure 10.2. The levels are:

1. Closing the Loop
2. Motion Profiling
3. Motion Programming

The first level, the closing of the loop, assures that the motor follows the commanded position. This is done by closing the position loop using a sensor. The operation at the basic level of closing the loop involves the subjects of modeling, analysis, and design. These subjects will be covered in the following discussions.

The motion profiling is the generation of the desired position function. This function, $R(t)$, describes where the motor should be at every sampling period. Note that the profiling and the closing of the loop are independent functions. The profiling function determines where the motor should be and the closing of the loop forces the motor to follow the commanded position.

The highest level of control is the motion program. This can be stored in the host computer or in the controller. This program describes the tasks in terms of the motors that need to be controlled, the distances and the speed.

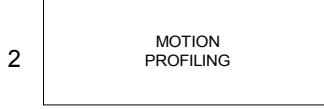


Figure 10.2: Levels of Control Functions

The three levels of control may be viewed as different levels of management. The top manager, the motion program, may specify the following instruction, for example.

```

PR 6000,4000
SP 20000,20000
AC 200000,00000
BG X
AD 2000
BG Y
EN

```

This program corresponds to the velocity profiles shown in Figure 10.3. Note that the profiled positions show where the motors must be at any instant of time.

Finally, it remains up to the servo system to verify that the motor follows the profiled position by closing the servo loop.

The following section explains the operation of the servo system. First, it is explained qualitatively, and then the explanation is repeated using analytical tools for those who are more theoretically inclined.

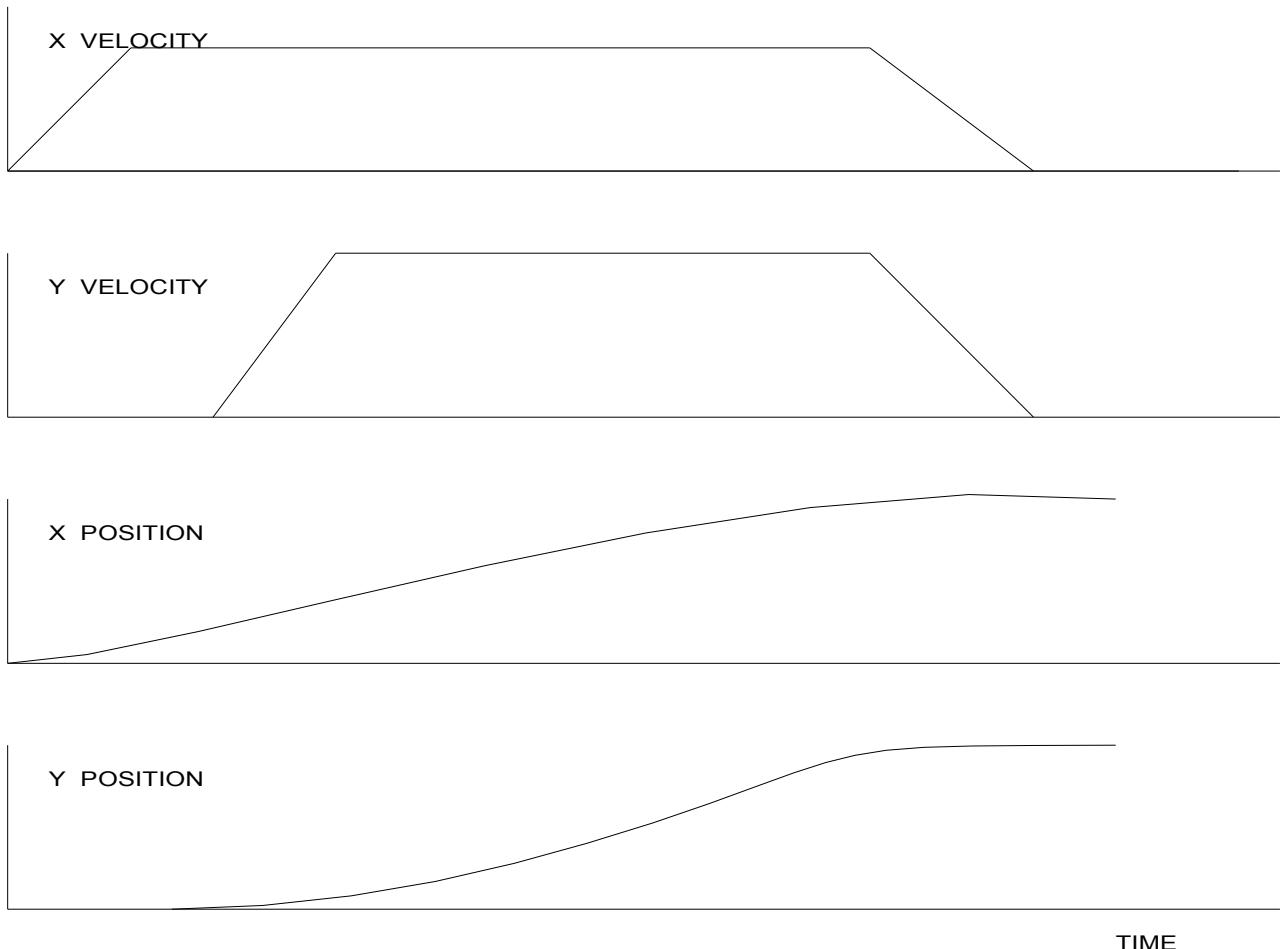


Figure 10.3: Velocity and Position Profiles

Operation of Closed-Loop Systems

To understand the operation of a servo system, we may compare it to a familiar closed-loop operation, adjusting the water temperature in the shower. One control objective is to keep the temperature at a comfortable level, say 90 degrees F. To achieve that, our skin serves as a temperature sensor and reports to the brain (controller). The brain compares the actual temperature, which is called the feedback signal, with the desired level of 90 degrees F. The difference between the two levels is called the error signal. If the feedback temperature is too low, the error is positive, and it triggers an action which raises the water temperature until the temperature error is reduced sufficiently.

The closing of the servo loop is very similar. Suppose that we want the motor position to be at 90 degrees. The motor position is measured by a position sensor, often an encoder, and the position feedback is sent to the controller. Like the brain, the controller determines the position error, which is the difference between the commanded position of 90 degrees and the position feedback. The controller then outputs a signal that is proportional to the position error. This signal produces a proportional current in the motor, which causes a motion until the error is reduced. Once the error becomes small, the resulting current will be too small to overcome the friction, causing the motor to stop.

The analogy between adjusting the water temperature and closing the position loop carries further. We have all learned the hard way, that the hot water faucet should be turned at the “right” rate. If you turn it too slowly, the temperature response will be slow, causing discomfort. Such a slow reaction is called over-damped response.

The results may be worse if we turn the faucet too fast. The overreaction results in temperature oscillations. When the response of the system oscillates, we say that the system is unstable. Clearly, unstable responses are bad when we want a constant level.

What causes the oscillations? The basic cause for the instability is a combination of delayed reaction and high gain. In the case of the temperature control, the delay is due to the water flowing in the pipes. When the human reaction is too strong, the response becomes unstable.

Servo systems also become unstable if their gain is too high. The delay in servo systems is between the application of the current and its effect on the position. Note that the current must be applied long enough to cause a significant effect on the velocity, and the velocity change must last long enough to cause a position change. This delay, when coupled with high gain, causes instability.

This motion controller includes a special filter which is designed to help the stability and accuracy. Typically, such a filter produces, in addition to the proportional gain, damping and integrator. The combination of the three functions is referred to as a PID filter.

The filter parameters are represented by the three constants KP, KI and KD, which correspond to the proportional, integral and derivative term respectively.

The damping element of the filter acts as a predictor, thereby reducing the delay associated with the motor response.

The integrator function, represented by the parameter KI, improves the system accuracy. With the KI parameter, the motor does not stop until it reaches the desired position exactly, regardless of the level of friction or opposing torque.

The integrator also reduces the system stability. Therefore, it can be used only when the loop is stable and has a high gain.

The output of the filter is applied to a digital-to-analog converter (DAC). The resulting output signal in the range between +10 and -10 Volts is then applied to the amplifier and the motor.

The motor position, whether rotary or linear is measured by a sensor. The resulting signal, called position feedback, is returned to the controller for closing the loop.

The following section describes the operation in a detailed mathematical form, including modeling, analysis and design.

System Modeling

The elements of a servo system include the motor, driver, encoder and the controller. These elements are shown in Figure 10.4. The mathematical model of the various components is given below.

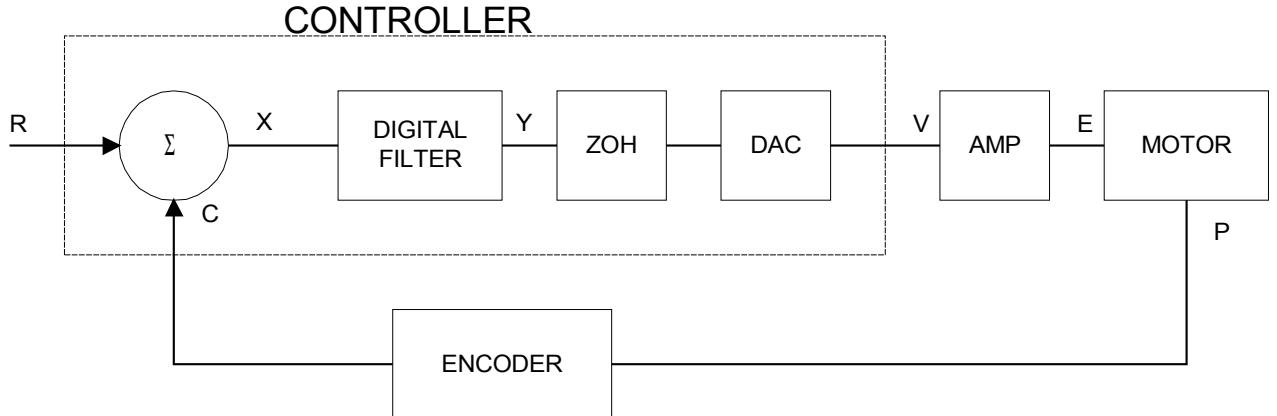


Figure 10.4: Functional Elements of a Motion Control System

Motor-Amplifier

The motor amplifier may be configured in three modes:

1. Voltage Drive
2. Current Drive
3. Velocity Loop

The operation and modeling in the three modes is as follows:

Voltage Drive

The amplifier is a voltage source with a gain of K_v [V/V]. The transfer function relating the input voltage, V , to the motor position, P , is

$$P/V = K_v / [K_t S(ST_m + 1)(ST_e + 1)]$$

where

$$T_m = RJ/K_t^2 \quad [\text{s}]$$

and

$$T_e = L/R \quad [\text{s}]$$

and the motor parameters and units are

K_t	Torque constant [Nm/A]
R	Armature Resistance Ω
J	Combined inertia of motor and load [$\text{kg} \cdot \text{m}^2$]
L	Armature Inductance [H]

When the motor parameters are given in English units, it is necessary to convert the quantities to MKS units. For example, consider a motor with the parameters:

$$K_t = 14.16 \text{ oz - in/A} = 0.1 \text{ Nm/A}$$

$$R = 2 \Omega$$

$$J = 0.0283 \text{ oz-in-s}^2 = 2 * 10^{-4} \text{ kg . m}^2$$

$$L = 0.004H$$

Then the corresponding time constants are

$$T_m = 0.04 \text{ sec}$$

and

$$T_e = 0.002 \text{ sec}$$

Assuming that the amplifier gain is $K_v = 4$, the resulting transfer function is

$$P/V = 40/[s(0.04s+1)(0.002s+1)]$$

Current Drive

The current drive generates a current I , which is proportional to the input voltage, V , with a gain of K_a . The resulting transfer function in this case is

$$P/V = K_a K_t / Js^2$$

where K_t and J are as defined previously. For example, a current amplifier with $K_a = 2 \text{ A/V}$ with the motor described by the previous example will have the transfer function:

$$P/V = 1000/s^2 [\text{rad/V}]$$

If the motor is a DC brushless motor, it is driven by an amplifier that performs the commutation. The combined transfer function of motor amplifier combination is the same as that of a similar brush motor, as described by the previous equations.

Velocity Loop

The motor driver system may include a velocity loop where the motor velocity is sensed by a tachometer and is fed back to the amplifier. Such a system is illustrated in Figure 10.5. Note that the transfer function between the input voltage V and the velocity ω is:

$$\omega/V = [K_a K_t / Js] / [1 + K_a K_t K_g / Js] = 1/[K_g(sT_1+1)]$$

where the velocity time constant, T_1 , equals

$$T_1 = J/K_a K_t K_g$$

This leads to the transfer function

$$P/V = 1/[K_g s(sT_1+1)]$$

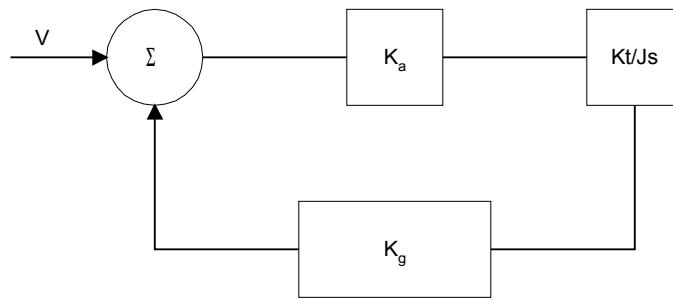
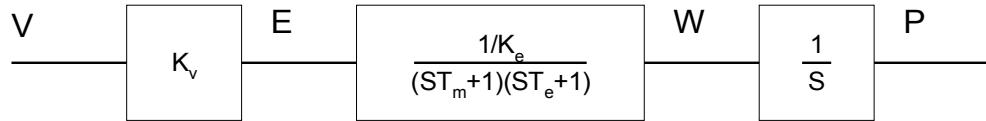


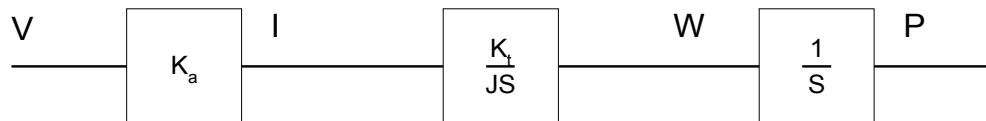
Figure 10.5: Elements of velocity loops

The resulting functions derived above are illustrated by the block diagram of Figure 10.6.

VOLTAGE SOURCE



CURRENT SOURCE



VELOCITY LOOP

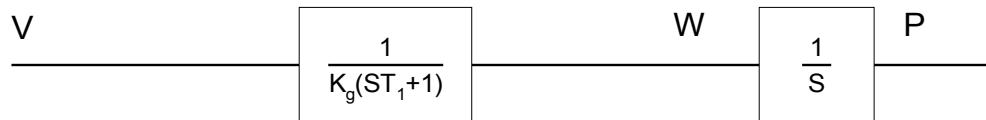


Figure 10.6: Mathematical model of the motor and amplifier in three operational modes

Encoder

The encoder generates N pulses per revolution. It outputs two signals, Channel A and B, which are in quadrature. Due to the quadrature relationship between the encoder channels, the position resolution is increased to 4N quadrature counts/rev.

The model of the encoder can be represented by a gain of

$$K_f = 4N/2\pi \quad [\text{count}/\text{rad}]$$

For example, a 1000 lines/rev encoder is modeled as

$$K_f = 638$$

DAC

The DAC or D-to-A converter converts a 16-bit number to an analog voltage. The input range of the numbers is 65536 and the output voltage range is +/-10V or 20V. Therefore, the effective gain of the DAC is

$$K = 20/65536 = 0.0003 \quad [\text{V}/\text{count}]$$

Digital Filter

The digital filter has three element in series: PID, low-pass and a notch filter. The transfer function of the filter. The transfer function of the filter elements are:

$$\text{PID} \quad D(z) = \frac{K(Z - A)}{Z} + \frac{CZ}{Z - 1}$$

$$\text{Low-pass} \quad L(z) = \frac{1 - B}{Z - B}$$

$$\text{Notch} \quad N(z) = \frac{(Z - z)(Z - \bar{z})}{(Z - p)(Z - \bar{p})}$$

The filter parameters, K, A, C and B are selected by the instructions KP, KD, KI and PL, respectively. The relationship between the filter coefficients and the instructions are:

$$K = (KP + KD)$$

$$A = KD/(KP + KD)$$

$$C = KI$$

$$B = PL$$

The PID and low-pass elements are equivalent to the continuous transfer function G(s).

$$G(s) = (P + sD + I/s) * a / (s + a)$$

where,

$$P = KP$$

$$D = T \cdot KD$$

$$I = KI/T$$

$$a = \frac{1}{T} \ln\left(\frac{1}{B}\right)$$

where T is the sampling period, and B is the pole setting

For example, if the filter parameters of the DMC-41x3 are

$$KP = 16$$

$$KD = 144$$

$$KI = 2$$

$$PL = 0.75$$

$$T = 0.001 \text{ s}$$

the digital filter coefficients are

$$K = 160$$

$$A = 0.9$$

$$C = 2$$

$$a = 250 \text{ rad/s}$$

and the equivalent continuous filter, G(s), is

$$G(s) = [16 + 0.144s + 2000/s] * 250 / (s+250)$$

The notch filter has two complex zeros, z and \bar{z} , and two complex poles, p and \bar{p} .

The effect of the notch filter is to cancel the resonance affect by placing the complex zeros on top of the resonance poles. The notch poles, P and p, are programmable and are selected to have sufficient damping. It is best to select

the notch parameters by the frequency terms. The poles and zeros have a frequency in Hz, selected by the command NF. The real part of the poles is set by NB and the real part of the zeros is set by NZ.

The most simple procedure for setting the notch filter, identify the resonance frequency and set NF to the same value. Set NB to about one half of NF and set NZ to a low value between zero and 5.

ZOH

The ZOH, or zero-order-hold, represents the effect of the sampling process, where the motor command is updated once per sampling period. The effect of the ZOH can be modeled by the transfer function

$$H(s) = 1/(1+sT/2)$$

If the sampling period is $T = 0.001$, for example, $H(s)$ becomes:

$$H(s) = 2000/(s+2000)$$

However, in most applications, $H(s)$ may be approximated as one.

This completes the modeling of the system elements. Next, we discuss the system analysis.

System Analysis

To analyze the system, we start with a block diagram model of the system elements. The analysis procedure is illustrated in terms of the following example.

Consider a position control system with the DMC-41x3 controller and the following parameters:

$K_t = 0.1$	Nm/A	Torque constant
$J = 2 * 10^{-4}$	kg.m ²	System moment of inertia
$R = 2$	Ω	Motor resistance
$K_a = 4$	Amp/Volt	Current amplifier gain
$K_P = 12.5$		Digital filter gain
$K_D = 245$		Digital filter zero
$K_I = 0$		No integrator
$N = 500$	Counts/rev	Encoder line density
$T = 1$	ms	Sample period

The transfer function of the system elements are:

Motor

$$M(s) = P/I = K_t/Js^2 = 500/s^2 \text{ [rad/A]}$$

Amp

$$K_a = 4 \text{ [Amp/V]}$$

DAC

$$K_d = 0.0003 \text{ [V/count]}$$

Encoder

$$K_f = 4N/2\pi = 318 \text{ [count/rad]}$$

ZOH

$$2000/(s+2000)$$

Digital Filter

$$K_P = 12.5, K_D = 245, T = 0.001$$

Therefore,

$$D(z) = 1030 (z-0.95)/Z$$

Accordingly, the coefficients of the continuous filter are:

$$P = 50$$

$$D = 0.98$$

The filter equation may be written in the continuous equivalent form:

$$G(s) = 50 + 0.98s = .098 (s+51)$$

The system elements are shown in Figure 10.7.

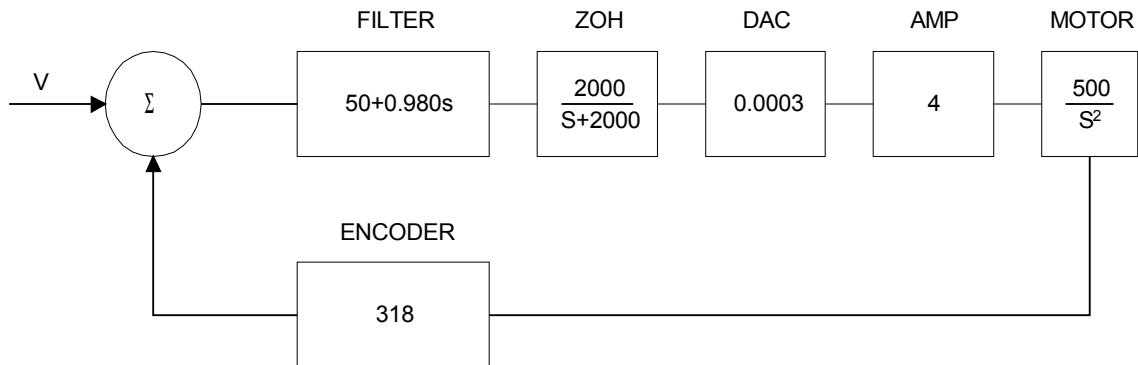


Figure 10.7: Mathematical model of the control system

The open loop transfer function, $A(s)$, is the product of all the elements in the loop.

$$A(s) = 390,000 (s+51)/[s^2(s+2000)]$$

To analyze the system stability, determine the crossover frequency, ω_c at which $A(j \omega_c)$ equals one. This can be done by the Bode plot of $A(j \omega_c)$, as shown in Figure 10.8.

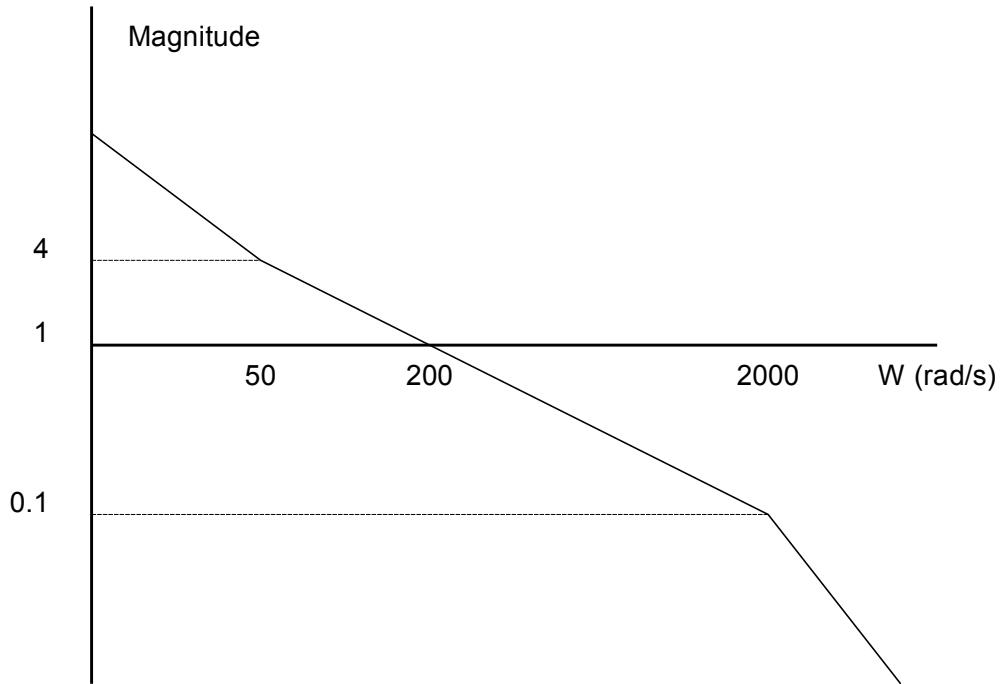


Figure 10.8: Bode plot of the open loop transfer function

For the given example, the crossover frequency was computed numerically resulting in 200 rad/s.

Next, we determine the phase of A(s) at the crossover frequency.

$$A(j200) = 390,000 (j200+51)/[(j200)^2 \cdot (j200 + 2000)]$$

$$\alpha = \text{Arg}[A(j200)] = \tan^{-1}(200/51) - 180^\circ - \tan^{-1}(200/2000)$$

$$\alpha = 76^\circ - 180^\circ - 6^\circ = -110^\circ$$

Finally, the phase margin, PM, equals

$$PM = 180^\circ + \alpha = 70^\circ$$

As long as PM is positive, the system is stable. However, for a well damped system, PM should be between 30° and 45°. The phase margin of 70° given above indicated over-damped response.

Next, we discuss the design of control systems.

System Design and Compensation

The closed-loop control system can be stabilized by a digital filter, which is preprogrammed in the DMC-41x3 controller. The filter parameters can be selected by the user for the best compensation. The following discussion presents an analytical design method.

The Analytical Method

The analytical design method is aimed at closing the loop at a crossover frequency, ω_c , with a phase margin PM. The system parameters are assumed known. The design procedure is best illustrated by a design example.

Consider a system with the following parameters:

$K_t = 0.2$	Nm/A	Torque constant
$J = 2 * 10^{-4}$	kg.m ²	System moment of inertia
$R = 2$	Ω	Motor resistance
$K_a = 2$	Amp/Volt	Current amplifier gain
$N = 1000$	Counts/rev	Encoder line density

The DAC of the DMC-41x3 outputs +/-10V for a 16-bit command of +/-32768 counts.

The design objective is to select the filter parameters in order to close a position loop with a crossover frequency of $\omega_c = 500$ rad/s and a phase margin of 45 degrees.

The first step is to develop a mathematical model of the system, as discussed in the previous section.

Motor

$$M(s) = P/I = Kt/Js^2 = 1000/s^2$$

Amp

$$K_a = 2 \quad [\text{Amp}/\text{V}]$$

DAC

$$K_d = 10/32768 = .0003$$

Encoder

$$K_f = 4N/2\pi = 636$$

ZOH

$$H(s) = 2000/(s+2000)$$

Compensation Filter

$$G(s) = P + sD$$

The next step is to combine all the system elements, with the exception of $G(s)$, into one function, $L(s)$.

$$L(s) = M(s) K_a K_d K_f H(s) = 3.17 \cdot 10^6 / [s^2(s+2000)]$$

Then the open loop transfer function, $A(s)$, is

$$A(s) = L(s) G(s)$$

Now, determine the magnitude and phase of $L(s)$ at the frequency $\omega_c = 500$.

$$L(j500) = 3.17 \cdot 10^6 / [(j500)^2 (j500+2000)]$$

This function has a magnitude of

$$|L(j500)| = 0.00625$$

and a phase

$$\text{Arg}[L(j500)] = -180^\circ - \tan^{-1}[500/2000] = -194^\circ$$

$G(s)$ is selected so that $A(s)$ has a crossover frequency of 500 rad/s and a phase margin of 45 degrees. This requires that

$$|A(j500)| = 1$$

$$\text{Arg}[A(j500)] = -135^\circ$$

However, since

$$A(s) = L(s) G(s)$$

then it follows that $G(s)$ must have magnitude of

$$|G(j500)| = |A(j500)/L(j500)| = 160$$

and a phase

$$\arg[G(j500)] = \arg[A(j500)] - \arg[L(j500)] = -135^\circ + 194^\circ = 59^\circ$$

In other words, we need to select a filter function $G(s)$ of the form

$$G(s) = P + sD$$

so that at the frequency $\omega_c = 500$, the function would have a magnitude of 160 and a phase lead of 59 degrees.

These requirements may be expressed as:

$$|G(j500)| = |P + (j500D)| = 160$$

and

$$\arg[G(j500)] = \tan^{-1}[500D/P] = 59^\circ$$

The solution of these equations leads to:

$$P = 160 \cos 59^\circ = 82.4$$

$$500D = 160 \sin 59^\circ = 137$$

Therefore,

$$D = 0.274$$

and

$$G = 82.4 + 0.274s$$

The function G is equivalent to a digital filter of the form:

$$D(z) = KP + KD(1-z^{-1})$$

where

$$P = KP$$

$$D = KD * T$$

and

$$KD = D/T$$

Assuming a sampling period of $T=1\text{ms}$, the parameters of the digital filter are:

$$KP = 82.4$$

$$KD = 274$$

The DMC-41x3 can be programmed with the instruction:

$$KP \ 82.4$$

$$KD \ 274$$

In a similar manner, other filters can be programmed. The procedure is simplified by the following table, which summarizes the relationship between the various filters.

Equivalent Filter Form - DMC-41x3

Digital	$D(z) = [K(z-A/z) + Cz/(z-1)] * (1-B)/(Z-B)$
---------	--

KP, KD, KI, PL	$K = (KP + KD)$
----------------	-----------------

	$A = KD/(KP+KD)$
--	------------------

	$C = KI$
--	----------

	$B = PL$
--	----------

Digital	$D(z) = [KP + KD(1-z^{-1}) + KI/2(1-z^{-1})] * (1-PL)/(Z-PL)$
---------	---

Continuous	$G(s) = (P + Ds + I/s) * a/(s+a)$
------------	-----------------------------------

PID, T	$P = KP$
--------	----------

	$D = T * KD$
--	--------------

	$I = KI / T$
--	--------------

	$a = 1/T \ ln(1/PL)$
--	----------------------

Appendices

Electrical Specifications

Servo Control

MCMn Amplifier Command:

+/-10 volt analog signal. Resolution 16-bit DAC or 0.0003 volts. 3 mA maximum.

MA+,MA-,MB+,MB-,MI+,MI- Encoder and Auxiliary

Output impedance – 500Ω

TTL compatible, but can accept up to +/-12 volts. Quadrature phase on CHA, CHB. Can accept single-ended (A+,B+ only) or differential (A+,A-,B+,B-). Maximum A, B edge rate: 15 MHz. Minimum IDX pulse width: 30 nsec.

Stepper Control

STPn (Step)

TTL (0-5 volts) level at 50% duty cycle. 3,000,000 pulses/sec maximum frequency

DIRn (Direction)

TTL (0-5 volts)

Input / Output

Limit Switch Inputs, Home Inputs.

2.2K ohm in series with opto-isolator. Active high or low requires at least 1.2mA to activate. Once activated, the input requires the current to go below 0.5ma. All Limit Switch and Home inputs use one common voltage (LSCOM) which can accept up to 24 volts. Voltages above 24 volts require an additional resistor.

≥ 1.5 mA = ON; ≤ 0.5 mA = OFF

AI1 thru AI8 Analog Inputs:

Standard configuration is +/-10 volts. 12-Bit Analog-to-Digital converter. 16-bit optional.

DO1 thru DO8 Outputs:

Opto-Isolated – 4mA sinking (25mA and 500mA options)

DO9 thru DO16 Outputs:

Opto-Isolated – 4mA sinking (25mA and 500mA options)

(DMC-4153 through DMC-4183 only)

DI81, DI82

Auxiliary Encoder Inputs for A (X) axis. Line Receiver Inputs - accepts differential or single ended voltages with voltage range of +/- 12 volts.

DI83, DI84

Auxiliary Encoder Inputs for B (Y) axis. Line Receiver Inputs - accepts differential or single ended voltages with voltage range of +/- 12 volts.

DI85, DI86 (DMC-4133 through DMC-4183 only)	Auxiliary Encoder Inputs for C (Z) axis. Line Receiver Inputs - accepts differential or single ended voltages with voltage range of +/- 12 volts.
DI87, DI88 (DMC-4143 through DMC-4183 only)	Auxiliary Encoder Inputs for D (W) axis. Line Receiver Inputs - accepts differential or single ended voltages with voltage range of +/- 12 volts.
DI89, DI90 (DMC-4153 through DMC-4183 only)	Auxiliary Encoder Inputs for E axis. Line Receiver Inputs - accepts differential or single ended voltages with voltage range of +/- 12 volts.
DI91, DI92 (DMC-4163 through DMC-4183 only)	Auxiliary Encoder Inputs for F axis. Line Receiver Inputs - accepts differential or single ended voltages with voltage range of +/- 12 volts.
DI93, DI94 (DMC-4173 through DMC-4183 only)	Auxiliary Encoder Inputs for G axis. Line Receiver Inputs - accepts differential or single ended voltages with voltage range of +/- 12 volts.
DI95, DI96 (DMC-4183 only)	Auxiliary Encoder Inputs for H axis. Line Receiver Inputs - accepts differential or single ended voltages with voltage range of +/- 12 volts.

Power Requirements

20-80 VDC 10W at 25 deg C

NOTE: The DMC-41x3 power should never be plugged in HOT. Always power down the power supply before installing or removing the power connector on the controller.

+5, +/-12V Power Output Specifications

Output Voltage	Tolerance	Max Current Output
+5V	+/- 5%	1.1A
+12V	+/- 5%	40mA
-12V	+/- 5%	40mA

Performance Specifications

Minimum Servo Loop Update Time/Memory:

	Normal	Fast Firmware
Minimum Servo Loop Update Time:		
DMC-4113	125 μ sec	62.5 μ sec
DMC-4123	125 μ sec	62.5 μ sec
DMC-4133	250 μ sec	125 μ sec
DMC-4143	250 μ sec	125 μ sec
DMC-4153	375 μ sec	187.5 μ sec
DMC-4163	375 μ sec	187.5 μ sec
DMC-4173	500 μ sec	250 μ sec
DMC-4183	500 μ sec	250 μ sec
Position Accuracy:	+/-1 quadrature count	
Velocity Accuracy:		
Long Term	Phase-locked, better than 0.005%	
Short Term	System dependent	
Position Range:	+/-2147483647 counts per move	
Velocity Range:	Up to 15,000,000 counts/sec servo; 3,000,000 pulses/sec-stepper	
Velocity Resolution:	2 counts/sec	
Motor Command Resolution:	16 bit or 0.0003 V	
Variable Range:	+/-2 billion	
Variable Resolution:	1 · 10-4	
Number of Variables:	510	
Array Size:	16000 elements, 30 arrays	
Program Size:	2000 lines x 80 characters	

Fast Update Rate Mode

The DMC-41x3 can operate with much faster servo update rates than the default of every millisecond. This mode is known as ‘fast mode’ and allows the controller to operate with the following update rates:

DMC-4113	62.5 μ sec
DMC-4123	62.5 μ sec
DMC-4133	125 μ sec
DMC-4143	125 μ sec
DMC-4153	187.5 μ sec
DMC-4163	187.5 μ sec
DMC-4173	250 μ sec
DMC-4183	250 μ sec

In order to run the DMC-41x3 motion controller in fast mode, the fast firmware must be uploaded. This can be done through the GalilTools communication software. The fast firmware is included with the original DMC-41x3 utilities.

In order to set the desired update rates, use the command TM.

When the controller is operating with the fast firmware, the following functions are **disabled**:

- Gearing mode
- Ecam mode
- Pole (PL)
- Analog Feedback (AF)
- Stepper Motor Operation (MT 2,-2,2.5,-2.5)
- Trippoints in thread 2-8
- Tell Velocity Interrogation Command (TV)
- Aux Encoders (TD)
- Dual Velocity (DV)
- Peak Torque Limit (TK)
- Notch Filter (NB, NF, NZ)
- PVT Mode (PV, BT)

Ordering Options for the DMC-41x3

Overview

The DMC-41x3 can be ordered in many different configurations and with different options. This section provides information regarding the different options available on the DMC-41x3 motion controller, interconnect modules and internal amplifiers. For information on pricing and how to order your controller with these options, see our DMC-41x3 part number generator on our website.

<http://www.galilmc.com/products/dmc-41x3-part-number.php>

DMC-41x3 Controller Board Options

BOX4, BOX8

The BOX4 or BOX8 option on the DMC-41x3 provides a metal enclosure for the controller. BOX4 is the box for the 1-4 axis controllers, the BOX8 is for 5-8 axis controllers. The BOXn option is required when using Galil internal amplifiers and is recommended for any application that requires CE certification.

Part number ordering example: DMC-4113-BOX4

DIN – DIN Rail Mounting

The DIN option on the DMC-41x3 motion controller provides DIN rail mounts on the base of the controller. This will allow the controller to be mounted to any standard DIN rail. Requires BOX4 or BOX8 option.

Part number ordering example: DMC-4113-BOX4-DIN

12V – Power Controller with 12VDC

The 12V option allows the controller to be powered with a regulated 12V supply. The tolerance of the 12V input must be within +/-5%.

Part number ordering example: DMC-4113-CARD(12V)

-16 bit – 16 bit Analog Inputs

The -16 bit option provides 16 bit analog inputs on the DMC-41x3 motion controller. The standard resolution of the analog inputs is 12 bits.

Part number ordering example: DMC-4113-CARD(-16bit)

4-20mA – 4-20mA analog inputs

The 4-20mA option converts all 8 analog inputs into 4-20mA analog inputs. This is accomplished by installing 475Ω precision resistors between the analog inputs and ground. When using this option the analog inputs should be configured for 0-10V analog inputs using the AQ command (AQ n,4). The equation for calculating the current is:

$$I_{ma} = 2.105 V$$

Where I_{ma} = current in mA

V = Voltage reading from DMC-41x3

Part number ordering example: DMC-4113-CARD(4-20mA)

LSNK – 25mA Sinking Outputs

The LSNK option modifies the digital outputs on the DMC-41x3 to be capable of sinking up to 25mA per output. For detailed information see the 25mA Sinking Opto-Isolated Outputs (LSNK) section in Chapter 3 Connecting Hardware.

Part number ordering example: DMC-4113-CARD-ABCD(LSNK)

LSRC – 25mA Sourcing Outputs

The LSRC option modifies the digital outputs on the DMC-41x3 to be capable of sourcing up to 25mA per output. For detailed information see the 25mA Sourcing Opto-Isolated Outputs (LSRC) section in Chapter 3 Connecting Hardware.

Part number ordering example: DMC-4113-CARD-ABCD(LSRC)

HSRC – 500mA Sourcing Outputs

The HSRC option modifies the digital outputs on the DMC-41x3 to be capable of sourcing up to 500mA per output. For detailed information see the 500mA Sourcing Opto-Isolated Outputs (HSRC) section in Chapter 3 Connecting Hardware.

Part number ordering example: DMC-4113-CARD-ABCD(HSRC)

TRES – Encoder Termination Resistors

The TRES option provides termination resistors on all of the main and auxiliary encoder inputs on the DMC-41x3 motion controller. The termination resistors are 120 Ohm, and are placed between the positive and negative differential inputs on the Main A, B, Index channels as well as the Auxiliary A and B channels as in Figure A.1.

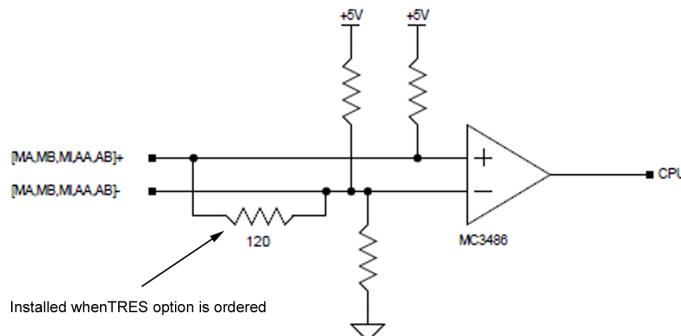


Figure A.1: Encoder Inputs with -TRES option

NOTE: Single ended encoders will not operate correctly with the termination resistors installed. If a combination of differential encoder inputs with termination resistors and single ended encoders is required on the same controller, contact Galil directly.

Part number ordering example: DMC-4113-CARD(TRES)

ISCNTL – Isolate Controller Power

The ISCNTL option isolates the power input for the controller from the power input of the amplifiers. With this option, the power is brought in through the 2 pin Molex connector on the side of the controller as shown in the [DMC-41x3 Power Connections](#) section in Chapter 2. This option is not valid when Galil amplifiers are not ordered with the DMC-41x3.

Part number ordering example: DMC-4113-BOX4(ISCNTL)-D3020

RS-422 – Auxiliary Serial Port Serial Communication

The default serial configuration for the DMC-41x3 is to have RS-232 communication on the Aux (P2) serial port. The controller can be ordered to have RS-422 for this port. RS-422 communication is a differentially driven serial communication protocol that should be used when long distance serial communication is required in an application.

RS-422-Auxiliary Port

Standard connector and cable when DMC-41x3 is ordered with RS-422 Option.

Pin	Signal
1	CTS-
2	RXD-
3	TXD-
4	RTS-
5	GND
6	CTS+
7	RXD+
8	TXD+
9	RTS+

Part number ordering example: DMC-4113-CARD(P2422)

Internal Amplifier Options

ISAMP – Isolation of power between each AMP amplifier

The ISAMP option separates the power pass-through between the Axes 1-4 amplifier and the Axes 5-8 amplifier. This allows the 2 internal amplifiers to be powered at separate voltages.

If the ISCNTL option is NOT ordered on the DMC-41x3, the amplifier with the higher bus voltage will automatically power the controller. The amplifier with the higher voltage, and the voltage level does not have to be specified during time of purchase as long as the voltage falls within the range of 20-80VDC.

This option is only valid on the 5-8 Axes amplifier board.

Part number ordering example: DMC-4183-BOX8-D3040-D3040-ISAMP

SR90 – SR-49000 Shunt Regulator Option

The SR-49000 is a shunt regulator for the DMC-41x3 controller and internal amplifiers. This option is highly recommended for any application where there is a large inertial load, or a gravitational load. The SR-49000 is installed inside the box of the DMC-41x3 controller.

The Shunt Regulator activates when the voltage supplied to the amplifier rises above 90V. When activated, the power from the power supply is dissipated through a 5Ω 20W power resistor.

The SR-49000 can be ordered to activate at different voltages. 33V, 66V and 90V are all standard ordering options and can be ordered as -SR33, -SR66 and -SR90 respectively.

Part number ordering example: DMC-4143-BOX8-D3040-SR90

100mA – 100mA Maximum Current output for AMP-43140

The 100mA option configures the AMP-43140 (-D3140) for 10mA/V gain with a maximum current output of 100mA.

This option is only valid with the AMP-43140.

Part number ordering example: DMC-4143-BOX4-D3140(100mA)

SSR – Solid State Relay Option for AMP-43140

The SSR option configures the AMP-43140 (-D3140) with Solid State Relays on the motor power leads that are engaged and disengaged when the amplifier is enabled and disabled. See the -SSR Option in the AMP-43140 section of the Appendix for more information.

This option is only valid with the AMP-43140.

Part number ordering example: DMC-4143-BOX4-D3140(SSR)

Power Connectors for the DMC-41x3

Overview

The DMC-41x3 uses Molex Mini-Fit, Jr.TM Receptacle Housing connectors for connecting DC Power to the Amplifiers, Controller, and Motors. This section gives the specifications of these connectors. For information specific to your Galil amplifier or driver, refer to the specific amplifier/driver in the Integrated Components section.

Molex Part Numbers

There are 3 different Molex connectors used with the DMC-41x3. The type of connectors on any given controller will be determined by the Amplifiers/Drivers that were ordered. Below are tables indicating the type of Molex Connectors used and the specific part numbers used on each Amplifier or Driver. For more information on the connectors, go to <http://www.molex.com/>

On Board Connector	Common Mating Connectors*	Crimp Part Number	Type
MOLEX# 39-31-0060	MOLEX# 39-01-2065	MOLEX# 44476-3112	6 Position
MOLEX# 39-31-0040	MOLEX# 39-01-2045	MOLEX# 44476-3112	4 Position
MOLEX# 39-31-0020	MOLEX# 39-01-2025	MOLEX# 44476-3112	2 Position

*The mating connectors listed are not the only mating connectors available from Molex. See 366H<http://www.molex.com/> for the full list of available mating connectors.

Galil Amplifier / Driver	On Board Connector	Type
None	MOLEX# 39-31-0020	2 Position
AMP-43040	Power	MOLEX# 39-31-0060
	Motor	MOLEX# 39-31-0040
AMP-43140	Power	MOLEX# 39-31-0040
	Motor	MOLEX# 39-31-0020
SDM-44040	Power	MOLEX# 39-31-0060
	Motor	MOLEX# 39-31-0040
SMD-44140	Power	MOLEX# 39-31-0060
	Motor	MOLEX# 39-31-0040

Connectors for DMC-41x3 (Pin-outs)

J5 - I/O (A-D) 44 pin HD D-Sub Connector (Female)

Pin#	Label	Description	Pin#	Label	Description	Pin#	Label	Description
1	ERR	Error Output	16	RST	Reset Input	31	GND	Digital Ground
2	DI1	Digital Input 1/ A latch	17	INCOM0	Input Common (DI 1-8)	32	DI2	Digital Input 2 / B latch
3	DI4	Digital Input 4 / D latch	18	DI3	Digital Input 3 / C latch	33	DI5	Digital Input 5
4	DI7	Digital Input 7	19	DI6	Digital Input 6	34	DI8	Digital Input 8
5	ELO	Electronic Lock Out	20	ABRT	Abort Input	35	GND	Digital Ground
6	LSCOM0	Limit Switch Com (A-D)	21	N/C	No Connect	36	FLSA	Forward Limit Switch A
7	HOMA	Home Switch A	22	RLSA	Reverse Limit Switch A	37	FLSB	Forward Limit Switch B
8	HOMB	Home Switch B	23	RLSB	Reverse Limit Switch B	38	FLSC	Forward Limit Switch C
9	HOMC	Home Switch C	24	RLSC	Reverse Limit Switch C	39	FLSD	Forward Limit Switch D
10	HOMD	Home Switch D	25	RLSD	Reverse Limit Switch D	40	GND	Digital Ground
11	OP0A	Output GND/PWR	26	N/C	No Connect	41	DO1	Digital Output 1
12	DO3	Digital Output 3	27	DO2	Digital Output 2	42	DO4	Digital Output 4
13	DO6	Digital Output 6	28	DO5	Digital Output 5	43	DO7	Digital Output 7
14	OP0B	Output PWR/GND	29	DO8	Digital Output 8	44	CMP	Output Compare (A-D)
15	+5V	+5V	30	+5V	+5V			

J8 - I/O (E-H) 44 pin HD D-Sub Connector (Female)

4183

For DMC-4153 thru DMC-4183 controllers only.

Pin#	Label	Description	Pin#	Label	Description	Pin#	Label	Description
1	ERR	Error Output	16	RST*	Reset Input	31	GND	Digital Ground
2	DI9	Digital Input 9 / E latch	17	INCOM1	Input Common (DI 9-16)	32	DI10	Digital Input 10 / F latch
3	DI12	Digital Input 12/H latch	18	DI11	Digital Input 11 / G latch	33	DI13	Digital Input 13
4	DI15	Digital Input 15	19	DI14	Digital Input 14	34	DI16	Digital Input 16
5	ELO*	Electronic Lock Out	20	ABRT*	Abort Input	35	GND	Digital Ground
6	LSCOM1	Limit Switch Com (E-H)	21	N/C	No Connect	36	FLSE	Forward Limit Switch E
7	HOME	Home Switch E	22	RLSE	Reverse Limit Switch E	37	FLSF	Forward Limit Switch F
8	HOMF	Home Switch F	23	RLSF	Reverse Limit Switch F	38	FLSG	Forward Limit Switch G
9	HOMG	Home Switch G	24	RLSG	Reverse Limit Switch G	39	FLSH	Forward Limit Switch H
10	HOMH	Home Switch H	25	RLSH	Reverse Limit Switch H	40	GND	Digital Ground
11	OP1A	Output GND/PWR	26	N/C	No Connect	41	DO9	Digital Output 9
12	DO11	Digital Output 11	27	DO10	Digital Output 10	42	DO12	Digital Output 12
13	DO14	Digital Output 14	28	DO13	Digital Output 13	43	DO15	Digital Output 15
14	OP1B	Output PWR/GND	29	DO16	Digital Output 16	44	CMP	Output Compare (E-H)
15	+5V	+5V	30	+5V	+5V			

* ABRT, RST and ELO use INCOM0

Jn1 - Encoder 26 pin HD D-Sub Connector (Female)

Pin #	Label	Description	Pin #	Label	Description
1	HALC	Hall C	14	FLS	Forward Limit Switch Input
2	AEN	Amplifier Enable	15	AB+	B+ Aux Encoder Input
3	DIR	Direction	16	MI-	I- Index Pulse Input
4	HOM	Home	17	MB+	B+ Main Encoder Input
5	LSCOMn	Limit Switch Common*	18	GND	Digital Ground
6	AA-	A- Aux Encoder Input	19	MCMD	Motor Command
7	MI+	I+ Index Pulse Input	20	ENBL+	Amp Enable Power
8	MA-	A- Main Encoder Input	21	HALA	Hall A
9	+5V	+5V	22	RLS	Reverse Limit Switch Input
10	GND	Digital Ground	23	AB-	B- Aux Encoder Input
11	ENBL-	Amp Enable Return	24	AA+	A+ Aux Encoder Input
12	HALB	Hall B	25	MB-	B- Main Encoder Input
13	STP	PWM/Step	26	MA+	A+ Main Encoder Input

- * LSCOMn on JA1, JB1, JC1 and JD1 is common to LSCOM0 on J5
- LSCOMn on JE1, JF1, JG1 and JH1 is common to LSCOM1 on J8

J4 - Analog 15 pin D-sub Connector (Male)

Pin #	Label	Description
1	AGND	Analog Ground
2	AI1	Analog Input 1
3	AI3	Analog Input 3
4	AI5	Analog Input 5
5	AI7	Analog Input 7
6	AGND	Analog Ground
7	-12V	-12V
8	+5V	+5V
9	AGND	Analog Ground
10	AI2	Analog Input 2
11	AI4	Analog Input 4
12	AI6	Analog Input 6
13	AI8	Analog Input 8
14	N/C	No Connect
15	+12V	+12V

JPn1 - Amplifier Enable Jumper Description for DMC-41x3

Jumper	Label	Function (If jumpered)
Q and P	1	Sink/Source Selection
	2	Sink/Source Selection
	3	Sink/Source Selection
	4	HAEN/LAEN Selection
	5	5V/12V/External Power Selection
	6	5V/12V/External Power Selection

NOTE: See Configuring the Amplifier Enable Circuit in Chapter 3 for detailed information.

J1 – Ethernet (RJ45)

Pin #	Signal
1	TXP
2	TXN
3	RXP
4	NC
5	NC
6	RXN
7	NC
8	NC

The Ethernet connection is Auto MDIX, 100bT/10bT.

J2 – USB

The USB port on the DMC-41x3 is a Female Type B USB port. The standard cable when communicating to a PC will be a Male Type A – Male Type B USB cable.

J3 – RS-232 Auxiliary Port (Female)

Standard connector and cable, 9Pin

Pin #	Signal
1	NC
2	TXD
3	RXD
4	NC
5	GND
6	NC
7	RTS
8	CTS
9	NC (5V with APWR Jumper)

J3 - RS-422-Auxiliary Port (Non-Standard Option)

Standard connector and cable when DMC-41x3 is ordered with RS-422 Option. For detailed information on the RS-422 option see RS-422 – Auxiliary Serial Port Serial Communication in the Appendices.

Pin #	Signal
1	CTS-
2	RXD-
3	TXD-
4	RTS-
5	GND
6	CTS+
7	RXD+
8	TXD+
9	RTS+

JP1 - Jumper Description for DMC-41x3

Label	Function (If jumpered)
ARXD	
ACTS	
APWR	Connects 5V to pin 9 on the Aux serial port connector (J3)
OPT	Reserved
MO	When controller is powered on or reset, Amplifier Enable lines will be in a Motor Off state. A SH will be required to re-enable the motors.
19.2K	Baud Rate setting – see table below
UPGD	Used to upgrade controller firmware when resident firmware is corrupt.
MRST	Master Reset enable. Returns controller to factory default settings and erases EEPROM. Requires power-on or RESET to be activated.

Baud Rate Jumper Settings

19.2	BAUD RATE
ON	19200
OFF	115200 (Recommended)

Signal Descriptions for DMC-41x3

Outputs

Motor Command	+/- 10 Volt range signal for driving amplifier. In servo mode, motor command output is updated at the controller sample rate. In the motor off mode, this output is held at the OF command level.
Amplifier Enable	Signal to disable and enable an amplifier. Amp Enable goes low on Abort and OE1.
PWM / Step	PWM/STEP OUT is used for directly driving power bridges for DC servo motors or for driving step motor amplifiers. For servo motors: If you are using a conventional amplifier that accepts a +/- 10 Volt analog signal, this pin is not used and should be left open. The PWM output is available in two formats: Inverter and Sign Magnitude. In the Inverter mode, the PWM (31 kHz) signal is .2% duty cycle for full negative voltage, 50% for 0 Voltage and 99.8% for full positive voltage (31 kHz Switching Frequency). In the Sign Magnitude Mode (MT1.5), the PWM (62 kHz) signal is 0% for 0 Voltage, 99.6% for full voltage and the sign of the Motor Command is available at the sign output (62 kHz Switching Frequency).
PWM / Step	For stepper motors: The STEP OUT pin produces a series of pulses for input to a step motor driver. The pulses may either be low or high. The pulse width is 50%.
Sign / Direction	Used with PWM signal to give the sign of the motor command for servo amplifiers or direction for step motors.
Error	The signal goes low when the position error on any axis exceeds the value specified by the error limit command, ER.
Output 1-Output 8 Output 9-Output 16 (DMC-4153 thru 4183)	The optically isolated outputs are uncommitted and may be designated by the user to trigger external events. The output lines are toggled by Set Bit, SB, and Clear Bit, CB, instructions. The OP instruction is used to define the state of all the bits of the Output port.

Inputs

Encoder, MA+, MB+	Position feedback from incremental encoder with two channels in quadrature, CHA and CHB. The encoder may be analog or TTL. Any resolution encoder may be used as long as the maximum frequency does not exceed 15,000,000 quadrature states/sec. The controller performs quadrature decoding of the encoder signals resulting in a resolution of quadrature counts (4 x encoder cycles). Note: Encoders that produce outputs in the format of pulses and direction may also be used by inputting the pulses into CHA and direction into Channel B and using the CE command to configure this mode.
Encoder Index, MI+	Once-Per-Revolution encoder pulse. Used in Homing sequence or Find Index command to define home on an encoder index.

Encoder, MA-, MB-, MI-	Differential inputs from encoder. May be input along with CHA, CHB for noise immunity of encoder signals. The CHA- and CHB- inputs are optional.
Auxiliary Encoder, AA+, AB+, Aux A-, Aux B-	Inputs for additional encoder. Used when an encoder on both the motor and the load is required. Not available on axes configured for step motors.
Abort	A low input stops commanded motion instantly without a controlled deceleration. Also aborts motion program.
Reset	A low input resets the state of the processor to its power-on condition. The previously saved state of the controller, along with parameter values, and saved sequences are restored.
Electronic Lock Out	Input that when triggered will shut down the amplifiers at a hardware level. Useful for safety applications where amplifiers must be shut down at a hardware level.
Forward Limit Switch	When active, inhibits motion in forward direction. Also causes execution of limit switch subroutine, #LIMSWI. The polarity of the limit switch may be set with the CN command.
Reverse Limit Switch	When active, inhibits motion in reverse direction. Also causes execution of limit switch subroutine, #LIMSWI. The polarity of the limit switch may be set with the CN command.
Home Switch	Input for Homing (HM) and Find Edge (FE) instructions. Upon BG following HM or FE, the motor accelerates to slew speed. A transition on this input will cause the motor to decelerate to a stop. The polarity of the Home Switch may be set with the CN command.
Input 1 - Input 8 isolated Input 9 - Input 16 isolated	Uncommitted inputs. May be defined by the user to trigger events. Inputs are checked with the Conditional Jump instruction and After Input instruction or Input Interrupt. Input 1 is latch X, Input 2 is latch Y, Input 3 is latch Z and Input 4 is latch W if the high speed position latch function is enabled.
Latch	High speed position latch to capture axis position on occurrence of latch signal. AL command arms latch. Input 1 is latch X, Input 2 is latch Y, Input 3 is latch Z and Input 4 is latch W. Input 9 is latch E, input 10 is latch F, input 11 is latch G, input 12 is latch H.

Coordinated Motion - Mathematical Analysis

The terms of coordinated motion are best explained in terms of the vector motion. The vector velocity, V_s , which is also known as the feed rate, is the vector sum of the velocities along the X and Y axes, V_x and V_y .

$$V_s = \sqrt{V_x^2 + V_y^2}$$

The vector distance is the integral of V_s , or the total distance traveled along the path. To illustrate this further, suppose that a string was placed along the path in the X-Y plane. The length of that string represents the distance traveled by the vector motion.

The vector velocity is specified independently of the path to allow continuous motion. The path is specified as a collection of segments. For the purpose of specifying the path, define a special X-Y coordinate system whose origin is the starting point of the sequence. Each linear segment is specified by the X-Y coordinate of the final point expressed in units of resolution, and each circular arc is defined by the arc radius, the starting angle, and the angular width of the arc. The zero angle corresponds to the positive direction of the X-axis and the CCW direction of rotation is positive. Angles are expressed in degrees, and the resolution is 1/256th of a degree. For example, the path shown in Figure A.2 is specified by the instructions:

```
VP 0,10000  
CR 10000, 180, -90  
VP 20000, 20000
```

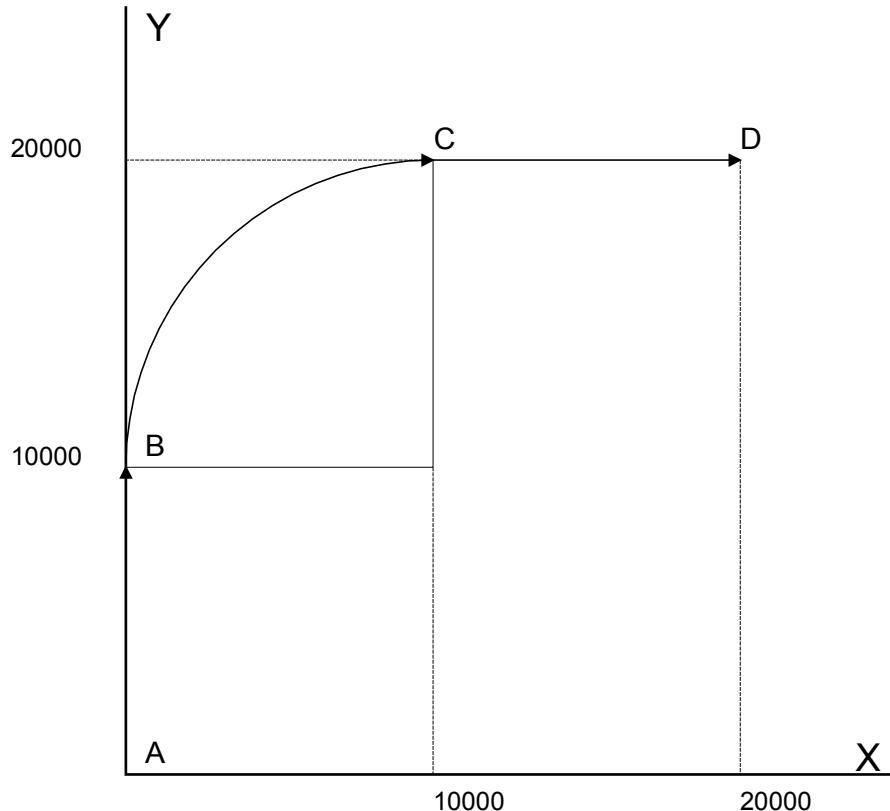


Figure A.2: X-Y Motion Path

The first line describes the straight line vector segment between points A and B. The next segment is a circular arc, which starts at an angle of 180° and traverses -90° . Finally, the third line describes the linear segment between points C and D. Note that the total length of the motion consists of the segments:

A-B	Linear	10000 units
B-C	Circular	$\frac{R \Delta\theta 2\pi}{360} = 15708$
C-D	Linear	10000
Total		35708 counts

In general, the length of each linear segment is

$$L_k = \sqrt{Xk^2 + Yk^2}$$

Where Xk and Yk are the changes in X and Y positions along the linear segment. The length of the circular arc is

$$L_k = R_k |\Delta\theta_k| 2\pi / 360$$

The total travel distance is given by

$$D = \sum_{k=1}^n L_k$$

The velocity profile may be specified independently in terms of the vector velocity and acceleration.

For example, the velocity profile corresponding to the path of Figure A.2 may be specified in terms of the vector speed and acceleration.

$$\begin{aligned} VS &= 100000 \\ VA &= 2000000 \end{aligned}$$

The resulting vector velocity is shown in Figure A.3.

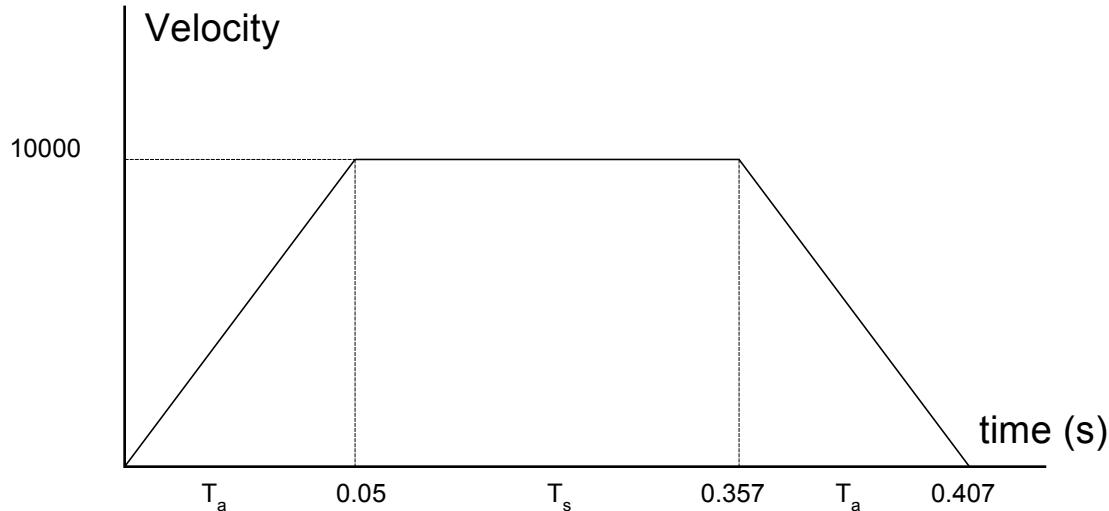


Figure A.3: Vector Velocity Profile

The acceleration time, T_a , is given by

$$T_a = \frac{VS}{VA} = \frac{100000}{2000000} = 0.05s$$

The slew time, T_s , is given by

$$T_s = \frac{D}{VS} - T_a = \frac{35708}{100000} - 0.05 = 0.307s$$

The total motion time, T_t , is given by:

$$T_t = \frac{D}{VS} + T_a = 0.407s$$

The velocities along the X and Y axes are such that the direction of motion follows the specified path, yet the vector velocity fits the vector speed and acceleration requirements.

For example, the velocities along the X and Y axes for the path shown in Figure A.2 are given in Figure A.4.

Figure A.4 shows the vector velocity. It also indicates the position point along the path starting at A and ending at D. Between the points A and B, the motion is along the Y axis. Therefore,

$$V_y = V_s$$

and

$$V_x = 0$$

Between the points B and C, the velocities vary gradually and finally, between the points C and D, the motion is in the X direction.

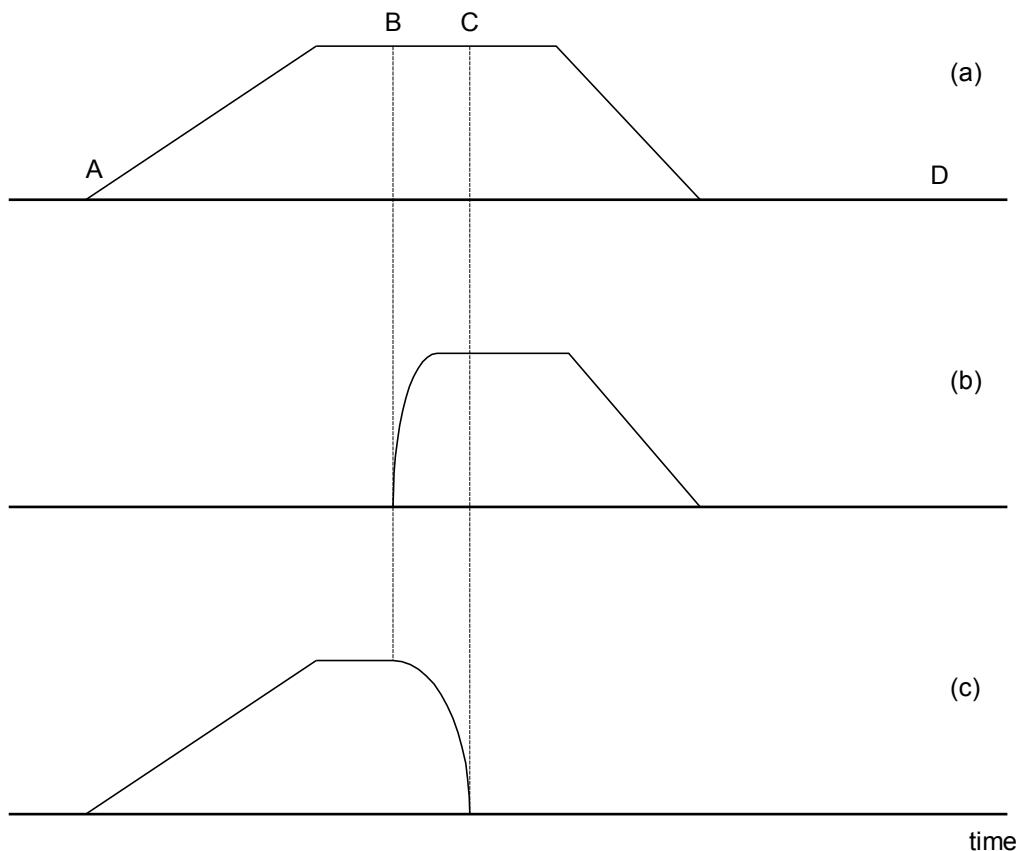


Figure A.4: Vector and Axes Velocities

Example- Communicating with OPTO-22 SNAP-B3000-ENET

Controller is connected to OPTO-22 via handle F. The OPTO-22's IP address is 131.29.50.30. The Rack has the following configuration:

Digital Inputs	Module 1
Digital Outputs	Module 2
Analog Outputs (+/-10V)	Module 3
Analog Inputs (+/-10V)	Module 4

Instruction	Interpretation
#CONFIG	Label
IHF=131,29,50,30<502>2	Establish connection
WT10	Wait 10 milliseconds
JP #CFGERR, _IHF2=0	Jump to subroutine
JS #CFGDOUT	Configure digital outputs
JS #CFGAYOUT	Configure analog outputs
JS #CFGAIN	Configure analog inputs
MBF = 6,6,1025,1	Save configuration to OPTO-22
EN	End
#CFGDOUT	Label
MODULE=2	Set variable
CFGVALUE=\$180	Set variable
NUMOFIO=4	Set variable
JP #CFGJOIN	Jump to subroutine
#CFGAYOUT	Label
MODULE=3	Set variable
CFGVALUE=\$A7	Set variable
NUMOFIO=2	Set variable
JP #CFGJOIN	Jump to subroutine
#CFGAIN	Label
MODULE=5	Set variable
CFGVALUE=12	Set variable
NUMOFIO=2	Set variable
JP#CFGJOIN	Jump to subroutine
#CFGJOIN	Label
DM A[8]	Dimension array
I=0	Set variable
#CFGLOOP	Loop subroutine
A[I]=0	Set array element
I=I+1	Increment
A[I]=CFGVALUE	Set array element
I=I+1	Increment
JP #CFGLOOP, I<(2*NUMOFIO)	Conditional statement

```

MBF=6,16,632+
(MODULE*8),NUMOFIO*2,A[]          Configure I/O using Modbus function code 16 where
                                    the starting register is 632+(MODULE*8), number
                                    of registers is NUMOFIO*2 and A[] contains the
                                    data.

EN                                end

#CFERR                           Label
MG"UNABLE TO ESTABLISH           Message
CONNECTION"
EN                                End

```

Using the equation:

I/O number = (HandleNum*1000) + ((Module-1)*4) + (BitNum-1)

MG @IN[6001] display level of input at handle 6, module 1, bit 2

SB 6006 set bit of output at handle 6, module 2, bit 3

or to one

OB 6006,1

AO 608,3.6 set analog output at handle 6, module 53, bit 1 to 3.6 volts

MG @AN[6017] display voltage value of analog input at handle 6, module 5, bit 2

DMC-41x3/DMC-40x0/DMC-21x3 Comparison

Specification	DMC-40x0	DMC-41x3	DMC-21x3
Servo bandwidth	Up to 32kHz update rate	Up to 16kHz update rate	Up to 8kHz update rate
Processing power	~10X faster than DMC-20x0	~2.5X faster than DMC-21x3	
Program Storage	2000lines x 80 Characters	2000lines x 80 Characters	1000 lines x 80 characters
Array Storage	16000 array elements in 30 arrays	16000 array elements in 30 arrays	8000 array elements in 30 arrays
Variable Storage	510 Variables	510 Variables	254 Variables
Number of Labels	510 Labels	510 Labels	254 Labels
Encoder Frequency	22 MHz	15 MHz	12 MHz
Stepper Frequency	6 MHz	3 MHz	3 MHz
Ethernet Connection	100/10bT	100/10bT	10bT
Box option availability	Box options available for all configurations of integrated drives	Box options available for all configurations of integrated drives	Box option limited to specific configurations of controller and drives
Contour Buffer	511 elements	511 elements	1 element
New commands/features	^L^K, PW, %, OV, OT, OA, ALTX, TR1,1, HV, LD, M axis, _EY, ZA, OE2, TM scaling, _NO, LC1000, MT1.5, PV, BT, BW, #POSERR, #LIMSWI, #MCTIME, and #ININT run without a thread	^L^K, PW, %, OV, OT, OA, ALTX, TR1,1, HV, LD, M axis, _EY, ZA, OE2, TM scaling, _NO, LC1000, MT1.5, PV, BT, BW, #POSERR, #LIMSWI, #MCTIME, and #ININT run without a thread,	
Removed Commands	VT, WC	VT, WC, IN, CO	

List of Other Publications

"Step by Step Design of Motion Control Systems"

by Dr. Jacob Tal

"Motion Control Applications"

by Dr. Jacob Tal

"Motion Control by Microprocessors"

by Dr. Jacob Tal

Training Seminars

Galil, a leader in motion control with over 500,000 controllers working worldwide, has a proud reputation for anticipating and setting the trends in motion control. Galil understands your need to keep abreast with these trends in order to remain resourceful and competitive. Through a series of seminars and workshops held over the past 20 years, Galil has actively shared their market insights in a no-nonsense way for a world of engineers on the move. In fact, over 10,000 engineers have attended Galil seminars. The tradition continues with three different seminars, each designed for your particular skill set-from beginner to the most advanced.

MOTION CONTROL MADE EASY

WHO SHOULD ATTEND

Those who need a basic introduction or refresher on how to successfully implement servo motion control systems.

TIME: 4 hours (8:30 am-12:30 pm)

ADVANCED MOTION CONTROL

WHO SHOULD ATTEND

Those who consider themselves a "servo specialist" and require an in-depth knowledge of motion control systems to ensure outstanding controller performance. Also, prior completion of "Motion Control Made Easy" or equivalent is required. Analysis and design tools as well as several design examples will be provided.

TIME: 8 hours (8:00 am-5:00 pm)

PRODUCT WORKSHOP

WHO SHOULD ATTEND

Current users of Galil motion controllers. Conducted at Galil's headquarters in Rocklin, CA, students will gain detailed understanding about connecting systems elements, system tuning and motion programming. This is a "hands-on" seminar and students can test their application on actual hardware and review it with Galil specialists.

Attendees must have a current application and recently purchased a Galil controller to attend this course.

TIME: Two days (8:30-4:30pm)

<http://www.galilmc.com/learning/training-at-galil.php>

Contacting Us

Galil Motion Control

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Web: 370H<http://www.galilmc.com/>

WARRANTY

All controllers manufactured by Galil Motion Control are warranted against defects in materials and workmanship for a period of 18 months after shipment. Motors, and Power supplies are warranted for 1 year. Extended warranties are available.

In the event of any defects in materials or workmanship, Galil Motion Control will, at its sole option, repair or replace the defective product covered by this warranty without charge. To obtain warranty service, the defective product must be returned within 30 days of the expiration of the applicable warranty period to Galil Motion Control, properly packaged and with transportation and insurance prepaid. We will reship at our expense only to destinations in the United States and for products within warranty.

Call Galil to receive a Return Materials Authorization (RMA) number prior to returning product to Galil.

Any defect in materials or workmanship determined by Galil Motion Control to be attributable to customer alteration, modification, negligence or misuse is not covered by this warranty.

EXCEPT AS SET FORTH ABOVE, GALIL MOTION CONTROL WILL MAKE NO WARRANTIES EITHER EXPRESSED OR IMPLIED, WITH RESPECT TO SUCH PRODUCTS, AND SHALL NOT BE LIABLE OR RESPONSIBLE FOR ANY INCIDENTAL OR CONSEQUENTIAL DAMAGES.

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Integrated Components

Overview

When ordered, the following components will reside inside the box of the DMC-41x3 motion controller. The amplifiers and stepper drivers provide power to the motors in the system, and the interconnect modules and communication boards provide the connections for the signals and communications.

A1 – AMP-430x0 (-D3040,-D3020) 2- and 4-axis 500W Servo Drives

The AMP-43040 (four-axis) and AMP-43020 (two-axis) are multi-axis brush/brushless amplifiers that are capable of handling 500 watts of continuous power per axis. The AMP-43040/43020 Brushless drive modules are connected to a DMC-41x3. The standard amplifier accepts DC supply voltages from 18-80 VDC.

A2 – AMP-43140 (-D3140) 4-axis 20W Linear Servo Drives

The AMP-43140 contains four linear drives for operating small brush-type servo motors. The AMP-43140 requires a \pm 12–30 DC Volt input. Output power is 20 W per amplifier or 60 W total. The gain of each transconductance linear amplifier is 0.1 A/V at 1 A maximum current. The typical current loop bandwidth is 4 kHz.

A3 – AMP-43240 (-D3240)

The AMP-43240 is a multi-axis brush/brushless amplifiers that is capable of handling 750 watts of continuous power per axis. The AMP-43240 Brushless drive module is connected to a DMC-40x0. The standard amplifier accepts DC supply voltages from 18-80 VDC.

A4 – AMP-43540 (-D3540)

The AMP-43540 contains four PWM drives for sinusoidally commutating brushless motors. It is capable of up to 8 Amps of continuous current and 15Amps of peak current and requires a single DC supply voltage in the range of 18-80 VDC.

A5 – AMP-43640 (-D3640)

The AMP-43640 contains four linear drives for sinusoidally commutating brushless motors. The AMP-43640 requires a single 18–30VDC input. Output power delivered is typically 20 W per amplifier or 80 W total.

A6 – SDM-44040 (-D4040) 4-axis Stepper Drives

The SDM-44040 is a stepper driver module capable of driving up to four bipolar two-phase stepper motors. The current is selectable with options of 0.5, 0.75, 1.0, and 1.4 Amps/Phase. The step resolution is selectable with options of full, half, 1/4 and 1/16.

A7 – SDM-44140 (-D4140) 4-axis Microstep Drives

The SDM-44140 microstepper module drives four bipolar two-phase stepper motors with 1/64 microstep resolution (the SDM-44140 drives two). The current is selectable with options of 0.5, 1.0, 2.0, & 3.0 Amps per axis.

A1 – AMP-430x0 (-D3040,-D3020)

Description

The AMP-43040 resides inside the DMC-41x3 enclosure and contains four transconductance, PWM amplifiers for driving brushless or brush-type servo motors. Each amplifier drives motors operating at up to 7 Amps continuous, 10 Amps peak, 20–80 VDC. The gain settings of the amplifier are user-programmable at 0.4 Amp/Volt, 0.7 Amp/Volt and 1 Amp/Volt. The switching frequency is 60 kHz. The drive for each axis is software configurable to operate in either a chopper or inverter mode. The chopper mode is intended for operating low inductance motors. The amplifier offers protection for over-voltage, under-voltage, over-current, short-circuit and over-temperature. Two AMP-43040s are required for 5- thru 8-axis controllers. A shunt regulator option is available. A two-axis version, the AMP-43020 is also available. If higher voltages are required, please contact Galil.

If the application has a potential for regenerative energy it is recommended to order the controller with the ISCNTL – Isolate Controller Power option and the SR90 – SR-49000 Shunt Regulator Option.

The BOX option is required when the AMP-430x0 is ordered with the DMC-41x3.

Note: Do not “hot swap” the motor power or supply voltage power input connections. If the amp is enabled when the motor connector is connected or disconnected, damage to the amplifier can occur. Galil recommends powering the controller and amplifier down before changing the connector, and breaking the AC side of the power supply connection in order to power down the amplifier. The ELO input may be used to cut power to the motors in an Emergency Stop or Abort situation.



Figure A1.1: DMC-4143-D3040-BOX4 (DMC-4143 with AMP-43040)

Electrical Specifications

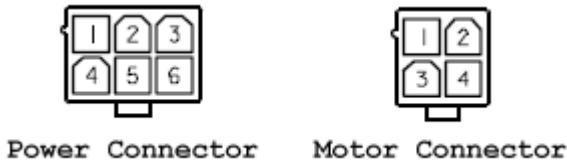
The amplifier is a brush/brushless trans-conductance PWM amplifier. The amplifier operates in torque mode, and will output a motor current proportional to the command signal input.

Supply Voltage:	18-80 VDC
Continuous Current:	7 Amps
Peak Current	10 Amps
Nominal Amplifier Gain	0.7 Amps/Volt
Switching Frequency	60 kHz (up to 140 kHz available-contact Galil)
Minimum Load Inductance: not found)	0.5 mH (Inverter mode) 0.2 mH (Error: Reference source
Brushless Motor Commutation angle	120° (60° option available)

Mating Connectors

	On Board Connector	Terminal Pins
POWER	6-pin Molex Mini-Fit, Jr. TM MOLEX# 39-31-0060	MOLEX#44476-3112
A,B,C,D: 4-pin Motor Power Connectors	4-pin Molex Mini-Fit, Jr. TM MOLEX# 39-31-0040	MOLEX#44476-3112

For mating connectors see <http://www.molex.com/>



Power Connector Motor Connector

Power Connector	
Pin Number	Connection
1,2,3	DC Power Supply Ground
4,5,6	+VS (DC Power)
Motor Connector	
1	Phase C (N/C for Brushed Motors)
2	Phase B
3	No Connect
4	Phase A

Operation

Brushless Motor Setup

NOTE: If you purchased a Galil motor with the amplifier, it is ready for use. No additional setup is necessary.

To begin the setup of the brushless motor and amplifier, it is first necessary to have communications with the motion controller. It is also necessary to have the motor hardware connected and the amplifier powered to begin the setup phase. After the encoders and motor leads are connected, the controller and amplifier need to be configured correctly in software. Take all appropriate safety precautions. For example, set a small error limit ($ER^*=1000$), a low torque limit ($TL^*=3$), and set off on Error to 1 for all axes ($OE^*=1$).

The AMP-430x0 requires that the hall commutation for a brushless motor be manually configured. Details on how to determine the correct commutation for a brushless motor, see Application Note # 5489.

<http://www.galilmc.com/support/appnotes/miscellaneous/note5489.pdf>

Brush Amplifier Operation

The AMP-43040 and AMP-43020 also allow for brush operation. To configure an axis for brush-type operation, connect the 2 motor leads to Phase A and Phase B connections for the axis. Connect the encoders, homes, and limits as required. Set the controller into brush-axis operation by issuing $BR\ n,n,n,n$. By setting $n=1$, the controller will operate in brushed mode on that axis. For example, $BR\ 0,1,0,0$ sets the Y-axis as brush-type, all others as brushless. If an axis is set to brush-type, the amplifier has no need for the Hall inputs. These inputs can subsequently be used as general-use inputs, queried with the QH command.

Setting Amplifier Gain and Current Loop Bandwidth

AG command:

Select the amplifier gain that is appropriate for the motor. The gain settings for the amplifier are identical for the brush and brushless operation. The amplifier gain command (AG) can be set to 0, 1, or 2 corresponding to 0.4, 0.7, and 1.0 A/V. In addition to the gain, peak and continuous torque limits can be set through TK and TL respectively. The TK and TL values are entered in volts on an axis by axis basis. The peak limit will set the maximum voltage that will be output from the controller to the amplifier. The continuous current will set what the maximum average current is over a one second interval. Figure A1.2 is indicative of the operation of the continuous and peak operation. In this figure, the continuous limit was configured for 2 volts, and the peak limit was configured for 10 volts.

AU and AW commands:

With the AMP-43040 and 43020, the user is also given the ability to choose between normal and high current bandwidth (AU). In addition, the user can calculate what the bandwidth of the current loop is for their specific combination (AW). To select normal current loop gain for the X axis and high current loop gain for the Y axis, issue $AU\ 0,1$. The command AW is used to calculate the bandwidth of the amplifier using the basic amplifier parameters. To calculate the bandwidth for the X axis, issue $AWX=v,l,n$ where v represents the DC voltage input to the card, l represents the inductance of the motor in millihenries, and n represents 0 or 1 for the AU setting.

NOTE: For most applications, unless the motor has more than 5 mH of inductance with a 24V supply, or 10 mH of inductance with a 48 volts supply, the normal current loop bandwidth option should be chosen. AW will return the current loop bandwidth in Hertz.

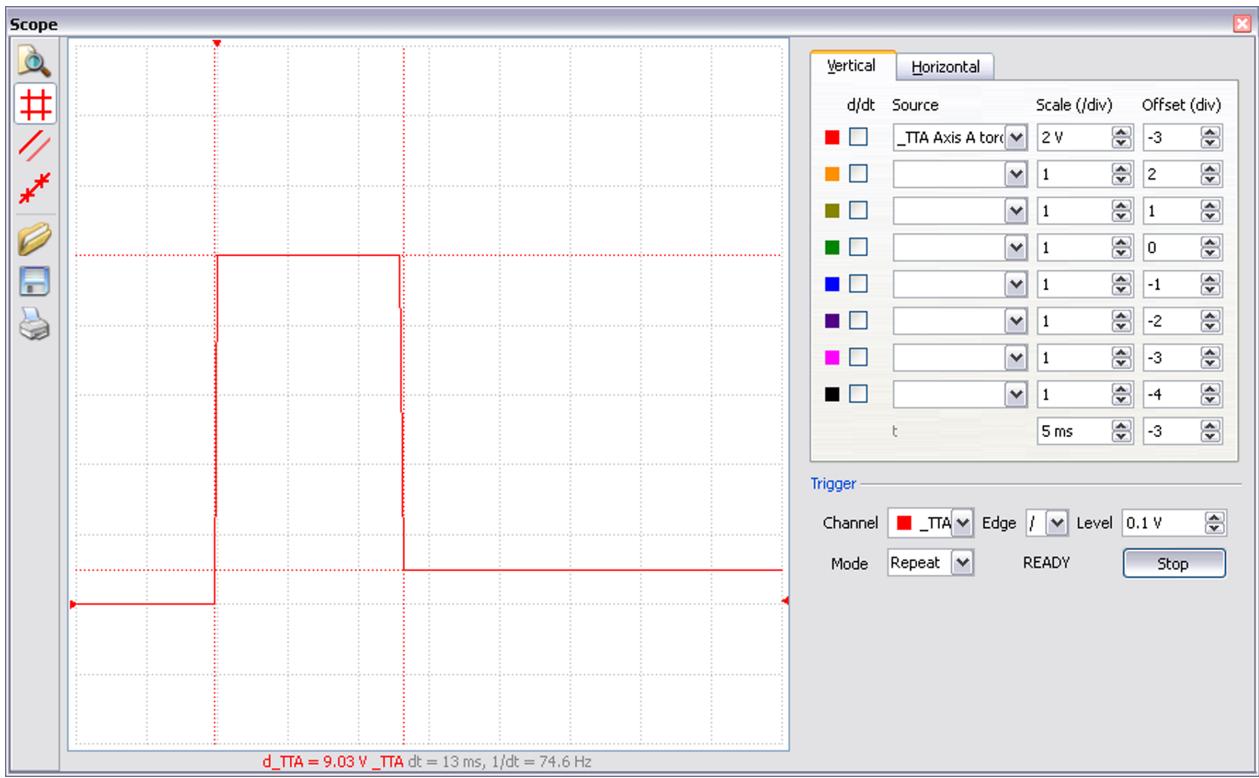


Figure A1.2: Peak Current Operation

Chopper Mode

The AMP-430x0 can be put into what is called a “Chopper” mode. The chopper mode is in contrast to the normal inverter mode in which the amplifier sends PWM power to the motor of +/-VS. In chopper mode, the amplifier sends a 0 to +VS PWM to the motor when moving in the forward direction, and a 0 to –VS PWM to the motor when moving in the negative direction.

This mode is set with the AU command. A setting of 0.5 is Chopper mode with normal current bandwidth. A setting of 1.5 is Chopper mode with high current bandwidth.

This mode is useful when using low inductance motors because it reduces the losses due to switching voltages across the motor windings. It is recommended to use chopper mode when using motors with 200-500 μ H inductance.

Using External Amplifiers

Use connectors on top of controller to access necessary signals to run external amplifiers. In order to use the full torque limit, make sure the AG setting for the axes using external amplifiers are set to 0 or 1. Set the BR command to 1 for any axis that will be setup to run external amplifiers (this will disable the hall error protection). For more information on connecting external amplifiers, see Connecting to External Amplifiers in Chapter 2.

ELO Input

If the ELO input on the controller is triggered, the amplifier will be shut down at a hardware level, the motors will be essentially in a Motor Off (MO) state. TA3 will return a 3 and the #AMPERR routine will run when the ELO input is triggered. To recover from an ELO, an MO then SH must be issued, or the controller must be reset.

It is recommended that OE1 be used for all axes when the ELO is used in an application.

Error Monitoring and Protection

The amplifier is protected against over-voltage, under-voltage, over-temperature, and over-current for brush and brushless operation. The controller will also monitor for illegal Hall states (000 or 111 with 120° phasing). The controller will monitor the error conditions and respond as programmed in the application. The errors are monitored via the TA command. TA n may be used to monitor the errors with n = 0, 1, 2, or 3. The command will return an eight bit number representing specific conditions. TA0 will return errors with regard to under voltage, over voltage, over current, and over temperature. TA1 will return hall errors on the appropriate axes, TA2 will monitor if the amplifier current exceeds the continuous setting, and TA3 will return if the ELO input has been triggered.

The user also has the option to include the special label #AMPERR in their program to handle soft or hard errors. As long as a program is executing in thread zero and the #AMPERR label is included, when an error is detected the program will jump to the label and execute the user defined routine. Note that the TA command is a monitoring function only, and does not generate an error condition. The over voltage condition will not permanently shut down the amplifier or trigger the #AMPERR routine. The amplifier will be momentarily disabled; when the condition goes away, the amplifier will continue normal operation assuming it did not cause the position error to exceed the error limit.

Hall Error Protection

During normal operation, the controller should not have any Hall errors. Hall errors can be caused by a faulty Hall-effect sensor or a noisy environment. If at any time the Halls are in an invalid state, the appropriate bit of TA1 will be set. The state of the Hall inputs can also be monitored through the QH command. Hall errors will cause the amplifier to be disabled if OE 1 is set, and will cause the controller to enter the #AMPERR subroutine if it is included in a running program.

Under-Voltage Protection

If the supply to the amplifier drops below 18 VDC, the amplifier will be disabled. The amplifier will return to normal operation once the supply is raised above the 18V threshold; bit 3 of the error status (TA0) will tell the user whether the supply is in the acceptable range.

NOTE: If there is an #AMPERR routine and the controller is powered before the amplifier, then the #AMPERR routine will automatically be triggered.

Over-Voltage Protection

If the voltage supply to the amplifier rises above 94 VDC, then the amplifier will automatically disable. The amplifier will re-enable when the supply drops below 90 V. This error is monitored with bit 1 of the TA0 command.

Over-Current Protection

The amplifier also has circuitry to protect against over-current. If the total current from a set of 2 axes (ie A and B or C and D) exceeds 20 A, the amplifier will be disabled. The amplifier will not be re-enabled until there is no longer an over-current draw and then either SH command has been sent or the controller is reset. Since the AMP-43040 is a trans-conductance amplifier, the amplifier will never go into this mode during normal operation. The amplifier will be shut down regardless of the setting of OE, or the presence of the #AMPERR routine. Bit 0 of TA0 will be set.

NOTE: If this fault occurs, it is indicative of a problem at the system level. An over-current fault is usually due to a short across the motor leads or a short from a motor lead to ground.

Over-Temperature Protection

The amplifier is also equipped with over-temperature protection.

If the average heat sink temperature rises above 80°C, then the amplifier will be disabled. Bit 2 of TA0 will be set when the over-temperature occurs on the A-D axis amplifier, and Bit 6 of TA0 will be set when the over-temperature occurs on the E-H axis amplifier. The over-temperature condition will trigger the #AMPERR routine if included in the program on the controller.

A2 – AMP-43140 (-D3140)

Description

The AMP-43140 resides inside the DMC-41x3 enclosure and contains four linear drives for operating small, brush-type servo motors. The AMP-43140 requires a \pm 12-30 VDC input. Output power is 20 W per amplifier or 60 W total. The gain of each transconductance linear amplifier is 0.1 A/V at 1 A maximum current. The typical current loop bandwidth is 4 kHz.

The AMP-43140 can be ordered to have a 100mA maximum current output where the gain of the amplifier is 10mA/V. Order as ‘-D3140(100mA)’.

The BOX option is required when the AMP-43140 is ordered with the DMC-41x3.

NOTE: Do not “hot swap” the motor power or supply voltage power input connections. If the amp is enabled when the motor connector is connected or disconnected, damage to the amplifier can occur. Galil recommends powering the controller and amplifier down before changing the connector, and breaking the AC side of the power supply connection in order to power down the amplifier. The ELO input may be used to cut power to the motors in an Emergency Stop or Abort situation.

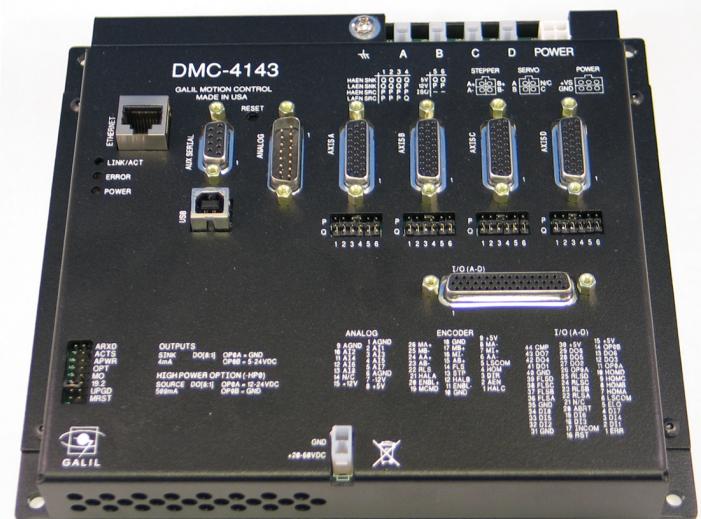


Figure A2.1: DMC-4143-D3140-BOX4 (DMC-4143 with AMP-43140)

Electrical Specifications

The amplifier is a brush type trans-conductance linear amplifier. The amplifier operates in torque mode, and will output a motor current proportional to the command signal input.

DC Supply Voltage:	+/-12-30 VDC (bipolar)
Max Current (per axis)	1.0 Amps (100mA option)
Amplifier gain:	0.1 A/V (10mA/V option)
Power output (per channel):	20 W
Total max. power output:	60 W

Mating Connectors

	On Board Connector	Terminal Pins
POWER	4-pin Molex Mini-Fit, Jr. TM MOLEX# 39-01-2045	MOLEX#44476-3112
A,B,C,D: 4-pin Motor Power Connectors	2-pin Molex Mini-Fit, Jr. TM MOLEX# 39-01-2025	MOLEX#44476-3112

For mating connectors see <http://www.molex.com/>



Power Connector Motor Connector

Power Connector	
Pin Number	Connection
1,2	Power Supply Ground
3	-VS (-DC Power)
4	+VS (DC Power)
Motor Connector	
1	Motor Lead A-
2	Motor Lead A+

Operation

ELO Input

If the ELO input on the controller is triggered, then the amplifier will be shut down at a hardware level, the motors will be essentially in a Motor Off (MO) state. TA3 will return a 3 and the #AMPERR routine will run when the ELO input is triggered. To recover from an ELO, an MO then SH must be issued, or the controller must be reset.

It is recommended that OE1 be used for all axes when the ELO is used in an application.

-SSR Option

The AMP-43140 linear amplifier require a bipolar power supply. It is possible that the plus and minus (V+ and V-) rise to nominal voltage at different rates during power up and any difference between voltage levels will be seen as an offset in the amplifier. This offset may cause a slight jump during power up prior to the controller establishing closed-loop control. When ordered with the -SSR option a solid state relay is added to the amplifier. This relay disconnects the amplifier power from the motor power leads when the controller is placed in the motor-off state. If the MO jumper is installed, or the MO command is burned into memory, the addition of the -SSR option will eliminate any jump due to the power supply.

Using External Amplifiers

Use connectors on top of controller to access necessary signals to run external amplifiers. For more information on connecting external amplifiers, see Connecting to External Amplifiers in Chapter 2.

A3 – AMP-43240 (-D3240)

Description

The AMP-43240 resides inside the DMC-41x3 enclosure and contains four transconductance, PWM amplifiers for driving brushless or brush-type servo motors. Each amplifier drives motors operating at up to 10 Amps continuous, 20 Amps peak, 20–80 VDC. The gain settings of the amplifier are user-programmable at 0.5 Amp/Volt, 1.0 Amp/Volt and 2.0 Amp/Volt. The switching frequency is 24 kHz. The drive operates in a Chopper Mode. The amplifier offers protection for over-voltage, under-voltage, over-current, short-circuit and over-temperature. Two AMP-43240s can be used in 5- thru 8-axis controllers. A shunt regulator option is available. If higher voltages are required, please contact Galil.

If the application has a potential for regenerative energy it is recommended to order the controller with the ISCNTL – Isolate Controller Power option and the SR90 – SR-49000 Shunt Regulator Option.

The BOX option is required when the AMP-43240 is ordered with the DMC-41x3.

Note: Do not “hot swap” the motor power or supply voltage power input connections. If the amp is enabled when the motor connector is connected or disconnected, damage to the amplifier can occur. Galil recommends powering the controller and amplifier down before changing the connector, and breaking the AC side of the power supply connection in order to power down the amplifier. The ELO input may be used to cut power to the motors in an Emergency Stop or Abort situation.



Figure A3.1: DMC-4143-D3240-BOX4 (DMC-4143 with AMP-43240)

Electrical Specifications

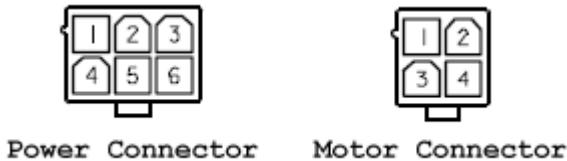
The amplifier is a brush/brushless trans-conductance PWM amplifier. The amplifier operates in torque mode, and will output a motor current proportional to the command signal input.

Supply Voltage:	18-80 VDC
Continuous Current:	10 Amps
Peak Current	20 Amps
Nominal Amplifier Gain	1.0 Amps/Volt
Switching Frequency	24 kHz
Minimum Load Inductance:	--
Brushless Motor Commutation angle	120° (60° option available)

Mating Connectors

	On Board Connector	Terminal Pins
POWER	6-pin Molex Mini-Fit, Jr. TM MOLEX# 39-31-0060	MOLEX#44476-3112
A,B,C,D: 4-pin Motor Power Connectors	4-pin Molex Mini-Fit, Jr. TM MOLEX# 39-31-0040	MOLEX#44476-3112

For mating connectors see <http://www.molex.com/>



Power Connector Motor Connector

Power Connector	
Pin Number	Connection
1,2,3	DC Power Supply Ground
4,5,6	+VS (DC Power)
Motor Connector	
1	Phase C (N/C for Bushed Motors)
2	Phase B
3	No Connect
4	Phase A

Operation

Brushless Motor Setup

NOTE: If you purchased a Galil motor with the amplifier, it is ready for use. No additional setup is necessary.

To begin the setup of the brushless motor and amplifier, it is first necessary to have communications with the motion controller. It is also necessary to have the motor hardware connected and the amplifier powered to begin the setup phase. After the encoders and motor leads are connected, the controller and amplifier need to be configured correctly in software. Take all appropriate safety precautions. For example, set a small error limit ($ER^*=1000$), a low torque limit ($TL^*=3$), and set off on Error to 1 for all axes ($OE^*=1$).

The AMP-43240 requires that the hall commutation for a brushless motor be manually configured. Details on how to determine the correct commutation for a brushless motor, see Application Note # 5489.

<http://www.galilmc.com/support/appnotes/miscellaneous/note5489.pdf>

Brush Amplifier Operation

The AMP-43240 allows for brush operation. To configure an axis for brush-type operation, connect the 2 motor leads to Phase A and Phase B connections for the axis. Connect the encoders, homes, and limits as required. Set the controller into brush-axis operation by issuing $BR\ n,n,n,n$. By setting $n=1$, the controller will operate in brushed mode on that axis. For example, $BR\ 0,1,0,0$ sets the Y-axis as brush-type, all others as brushless. If an axis is set to brush-type, the amplifier has no need for the Hall inputs. These inputs can subsequently be used as general-use inputs, queried with the QH command.

Setting Amplifier Gain and Current Loop Bandwidth

AG command:

Select the amplifier gain that is appropriate for the motor. The gain settings for the amplifier are identical for the brush and brushless operation. The amplifier gain command (AG) can be set to 0, 1, or 2 corresponding to 0.5, 1.0, and 2.0 A/V. In addition to the gain, peak and continuous torque limits can be set through TK and TL respectively. The TK and TL values are entered in volts on an axis by axis basis. The peak limit will set the maximum voltage that will be output from the controller to the amplifier. The continuous current will set what the maximum average current is over a one second interval. Figure A3.2 is indicative of the operation of the continuous and peak operation. In this figure, the continuous limit was configured for 2 volts, and the peak limit was configured for 10 volts.

AU and AW commands:

With the AMP-43240, the user is also given the ability to choose between normal and high current bandwidth (AU). In addition, the user can calculate what the bandwidth of the current loop is for their specific combination (AW). To select normal current loop gain for the X axis and high current loop gain for the Y axis, issue AU 0,1. The command AW is used to calculate the bandwidth of the amplifier using the basic amplifier parameters. To calculate the bandwidth for the X axis, issue $AWX=v,l,n$ where v represents the DC voltage input to the card, l represents the inductance of the motor in millihenries, and n represents 0 or 1 for the AU setting.

NOTE:For most applications, unless the motor has more than 5 mH of inductance with a 24V supply, or 10 mH of inductance with a 48 volts supply, the normal current loop bandwidth option should be chosen. AW will return the current loop bandwidth in Hertz.

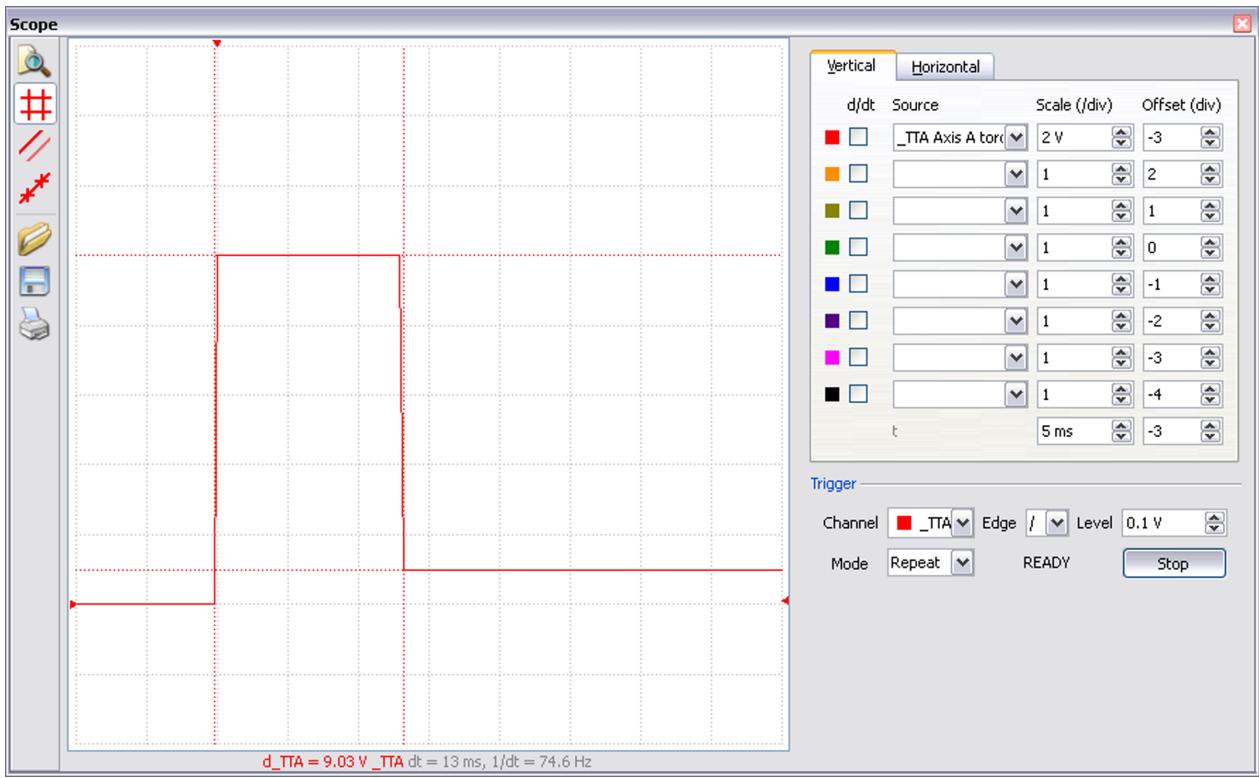


Figure A3.2: Peak Current Operation

Chopper Mode

The AMP-43240 runs in what is called a “Chopper” mode. The chopper mode is in contrast to the normal inverter mode (AMP-43040) in which the amplifier sends PWM power to the motor of $+\text{VS}$. In chopper mode, the amplifier sends a 0 to $+\text{VS}$ PWM to the motor when moving in the forward direction, and a 0 to $-\text{VS}$ PWM to the motor when moving in the negative direction.

Using External Amplifiers

Use connectors on top of controller to access necessary signals to run external amplifiers. In order to use the full torque limit, make sure the AG setting for the axes using external amplifiers are set to 0 or 1. Set the BR command to 1 for any axis that will be setup to run external amplifiers (this will disable the hall error protection). For more information on connecting external amplifiers, see Connecting to External Amplifiers in Chapter 2.

ELO Input

If the ELO input on the controller is triggered, the amplifier will be shut down at a hardware level, the motors will be essentially in a Motor Off (MO) state. TA3 will return a 3 and the #AMPERR routine will run when the ELO input is triggered. To recover from an ELO, an MO then SH must be issued, or the controller must be reset.

It is recommended that OE1 be used for all axes when the ELO is used in an application.

Error Monitoring and Protection

The amplifier is protected against over-voltage, under-voltage, over-temperature, and over-current for brush and brushless operation. The controller will also monitor for illegal Hall states (000 or 111 with 120° phasing). The controller will monitor the error conditions and respond as programmed in the application. The errors are monitored via the TA command. TA n may be used to monitor the errors with n = 0, 1, 2, or 3. The command will return an eight bit number representing specific conditions. TA0 will return errors with regard to under voltage, over voltage, over current, and over temperature. TA1 will return hall errors on the appropriate axes, TA2 will monitor if the amplifier current exceeds the continuous setting, and TA3 will return if the ELO input has been triggered.

The user also has the option to include the special label #AMPERR in their program to amplifier errors. As long as a program is executing in thread zero and the #AMPERR label is included, when an error is detected the program will jump to the label and execute the user defined routine. Note that the TA command is a monitoring function only, and does not generate an error condition.

See the TA command for detailed information on bit status during error conditions.

Hall Error Protection

During normal operation, the controller should not have any Hall errors. Hall errors can be caused by a faulty Hall-effect sensor or a noisy environment. If at any time the Halls are in an invalid state, the appropriate bit of TA1 will be set. The state of the Hall inputs can also be monitored through the QH command. Hall errors will cause the amplifier to be disabled if OE 1 is set, and will cause the controller to enter the #AMPERR subroutine if it is included in a running program.

Under-Voltage Protection

If the supply to the amplifier drops below 18 VDC, the amplifier will be disabled. The amplifier will return to normal operation once the supply is raised above the 18V threshold.

NOTE: If there is an #AMPERR routine and the controller is powered before the amplifier, then the #AMPERR routine will automatically be triggered.

Over-Voltage Protection

If the voltage supply to the amplifier rises above 94 VDC, then the amplifier will automatically disable. The amplifier will re-enable when the supply drops below 90 V.

The over voltage condition will not permanently shut down the amplifier or trigger the #AMPERR routine. The amplifier will be momentarily disabled; when the condition goes away, the amplifier will continue normal operation assuming it did not cause the position error to exceed the error limit.

Over-Current Protection

The amplifier also has circuitry to protect against over-current. If the total current from a set of 2 axes (ie A and B or C and D) exceeds 40 A, the amplifier will be disabled. The amplifier will not be re-enabled until there is no longer an over-current draw and then either SH command has been sent or the controller is reset. Since the AMP-43240 is a transconductance amplifier, the amplifier will never go into this mode during normal operation. The amplifier will be shut down regardless of the setting of OE, or the presence of the #AMPERR routine.

NOTE: If this fault occurs, it is indicative of a problem at the system level. An over-current fault is usually due to a short across the motor leads or a short from a motor lead to ground.

Over-Temperature Protection

The amplifier is also equipped with over-temperature protection.

If the average heat sink temperature rises above 80°C, then the amplifier will be disabled. The over-temperature condition will trigger the #AMPERR routine if included in the program on the controller.

The amplifier will not be re-enabled until the temperature drops below 80°C and then either an SH command is sent to the controller, or the controller is reset (RS command or power cycle).

A4 – AMP-43540 (-D3540)

Description

The AMP-43540 resides inside the DMC-41x3 enclosure and contains four sinusoidally commutated, PWM amplifiers for driving brushless servo motors. Each amplifier drives motors operating at up to 8 Amps continuous, 15 Amps peak, 20–80 VDC. The gain settings of the amplifier are user-programmable at 0.4 Amp/Volt, 0.8 Amp/Volt and 1.6 Amp/Volt. The switching frequency is 33 kHz. The amplifier offers protection for over-voltage, under-voltage, over-current, short-circuit and over-temperature. Two AMP-43540s can be used for 5- thru 8-axis controllers. A shunt regulator option is available. If higher voltages are required, please contact Galil.

If the application has a potential for regenerative energy it is recommended to order the controller with the ISCNTL – Isolate Controller Power option and the SR90 – SR-49000 Shunt Regulator Option.

The BOX option is required when the AMP-43540 is ordered with the DMC-41x3.

Note: Do not “hot swap” the motor power or supply voltage power input connections. If the amp is enabled when the motor connector is connected or disconnected, damage to the amplifier can occur. Galil recommends powering the controller and amplifier down before changing the connector, and breaking the AC side of the power supply connection in order to power down the amplifier. The ELO input may be used to cut power to the motors in an Emergency Stop or Abort situation.



Figure A4.1: DMC-4143-D3540-BOX4 (DMC-4143 with AMP-43540)

Electrical Specifications

The amplifier is a brush/brushless transconductance PWM amplifier. The amplifier operates in torque mode, and will output a motor current proportional to the command signal input.

Supply Voltage:	18-80 VDC
Continuous Current:	8 Amps
Peak Current	15 Amps
Nominal Amplifier Gain	0.8 Amps/Volt
Switching Frequency	33 kHz
Minimum Inductance	$V_{\text{supply}} = 24\text{VDC} - 0.75 \text{ mH}$
	$V_{\text{supply}} = 48\text{VDC} - 1.2 \text{ mH}$
Brushless Motor Commutation angle	120°

Mating Connectors

	On Board Connector	Terminal Pins
POWER	6-pin Molex Mini-Fit, Jr. TM MOLEX# 39-31-0060	MOLEX#44476-3112
A,B,C,D: 4-pin Motor Power Connectors	4-pin Molex Mini-Fit, Jr. TM MOLEX# 39-31-0040	MOLEX#44476-3112

For mating connectors see <http://www.molex.com/>



Power Connector Motor Connector

Power Connector	
Pin Number	Connection
1,2,3	DC Power Supply Ground
4,5,6	+VS (DC Power)
Motor Connector	
1	Phase C
2	Phase B (N/C for Bushed Motors)
3	No Connect
4	Phase A

Operation

Setting up the Brushless Mode and finding proper commutation

1. Issue the BA command to specify which axis you want to use the sinusoidal amplifier will run with a sine drive. An internal sign drive for that axis is required.
2. Calculate the number of encoder counts per magnetic cycle. For example, in a rotary motor that has 2 pole pairs and 10,000 counts per revolution, the number of encoder counts per magnetic cycle would be $10,000/2 = 5000$. Assign this value to BM
3. Issue either the BZ or BX command. Either the BX or BZ command must be executed on every reset or power-up of the controller.
 - BZ Command:
Issue the BZ command to lock the motor into a phase. Note that this will cause up to $\frac{1}{2}$ a magnetic cycle of motion. Be sure to use a high enough value with BZ to ensure the motor is locked into phase thoroughly.
 - BX Command:
Issue the BX command. The BX command utilizes a minimal movement algorithm in order to determine the correct commutation of the motor. As of April 2011 this command was still in the Beta testing phase.
4. **CAUTION:** This step commands uncontrolled motion, rotary motors should not be connected to mechanics. This step is required only once to ensure proper wiring.
- If the BX command was used in Step 3:
Set KP, KI and KD to zero and issue a small offset (OF command). Verify that the motor runs away (If you have limited travel you should set PID's to non-zero and use the JG command).
If the motor locks into a position then you need to change the encoder polarity. Set CE to 2 for that axis OR swap MA+/MA- on the encoder leads (swapping encoder leads is recommended), repeat step 3.
- If the BZ command was used in Step 3:
We now must confirm we have the proper wiring for our motor power leads. Set KP, KI, KD to zero. Issue a small offset (OF command) and record the velocity with the TV command. It is possible that you will not see any motion for given combinations of motor power leads. Now issue the same offset but negative and record TV again. Power down the controller and swap motor power leads. Repeat steps 1-3 for each of the 6 motor power lead combinations. The combination that yields velocities that are similar in magnitude is the correct choice. In the event that two combinations both yield similar magnitudes for positive and negative offsets select the one with the higher overall magnitude.

Trial#	Phase A	Phase B	Phase C	+ Velocity	- Velocity
1	Power lead 1	Power lead 2	Power lead 3		
2	Power lead 1	Power lead 3	Power lead 2		
3	Power lead 2	Power lead 3	Power lead 1		
4	Power lead 2	Power lead 1	Power lead 3		
5	Power lead 3	Power lead 1	Power lead 2		
6	Power lead 3	Power lead 2	Power lead 1		

Setting Amplifier Gain and Current Loop Gain

The AG command will set the amplifier gain (Amps/Volt), and the AU command will set the current loop gain for the AMP-43540. The current loop gain will need to be set based upon the bus voltage and inductance of the motor and is critical in providing the best possible performance of the system.

AG command:

The AMP-43540 has 3 amplifier gain settings. The gain is set with the AG command as shown in Table A4.1 for AG n=m:

AG setting	Gain Value
m = 0	0.4 A/V
m = 1	0.8 A/V
m = 2	1.6 A/V

Table A4.1: Amplifier Gain Settings for AMP-43540

The axis must be in a motor off (MO) state prior to execution of the AG command. With an amplifier gain of 2 (1.6A/V) the maximum motor command output is limited to 5V (TL of 5).

AU command:

Proper configuration of the AU command is essential to optimum operation of the AMP-43540. This command sets the gain for the current loop on the amplifier. The goal is to set the gain as high as possible without causing the current loop to go unstable. In most cases AU 0 should not be used. Table A4.2 indicates the recommended AU_n=m settings for 24 and 48 VDC power supplies.

To set the AU command, put the axis in a motor off (MO) state, set the preferred AG setting, and then set the AU setting. To verify that the current loop is stable, set the PID's to 0 (KP, KD and KI) and then enable the axis (SH). An unstable current loop will result in oscillations of the motor or a high frequency “buzz” from the motor.

Vsupply VDC	Inductance L (mH)	m =
24	-	0
24	L < 1	1
24	1 < L < 2.3	2
24	2.3 < L < 4.2	3
24	4.2 < L	4
48	-	0
48	L < 2.4	1
48	2.4 < L < 4.2	2
48	4.2 < L < 7	3
48	7 < L	4

Table A4.2: Amplifier Current Loop Gain Settings

Setting Peak and Continuous Current (TL and TK)

To set TL and TK for a particular motor, find the continuous current and peak current ratings for that motor and divide that number by the amplifier gain. For example, a particular motor has a continuous current rating of 2.0 A and peak current rating of 5.0 A. With an AG setting of 1, the amplifier gain of the AMP-43540 is 0.8A/V

$$TL \text{ setting} = (2.0\text{A}) / (0.8\text{A/V}) = 2.5\text{V (TL n=2.5)}$$

$$TK \text{ setting} = (5.0\text{A}) / (0.8\text{A/V}) = 7.5\text{V (TK n=6.25)}$$

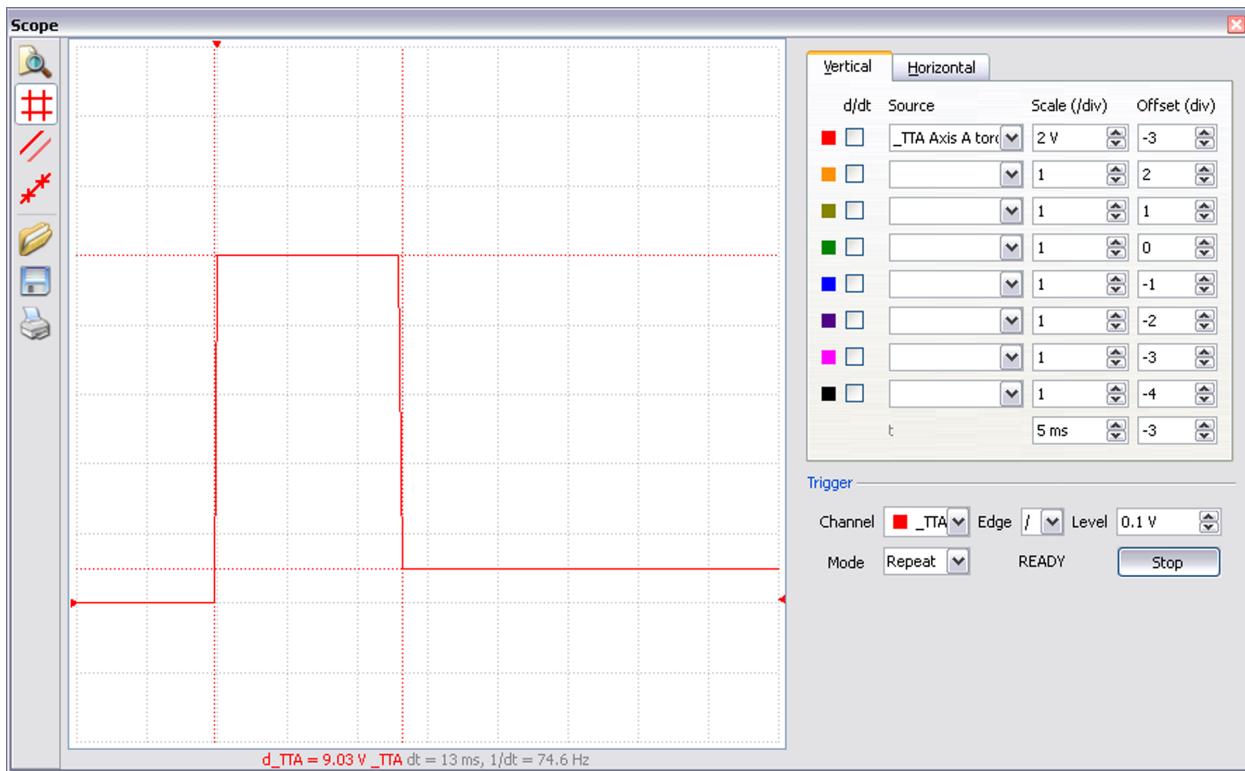


Figure A4.2: Peak Current Operation

Setting up Brushed Motors

The AMP-43540 must be configured for brushed motor operation at the factory. Contact Galil prior placing the order. Once the amplifier is configured for a brushed axis the controller needs to be set for brushed mode by using the BR command, this is done by setting the BR command to 1 for a particular axis.

Using External Amplifiers

The BR command must be set to a -1 for any axis where an AMP-43540 is installed but the use of an external axis is required. This setting will disable the requirement to have the BA, BM and BX or BZ commands executed prior to being able to issue the SH command for that axis. BR-1 is required for both external servo and stepper drivers.

Use the connectors on top of the controller to access necessary signals to run external amplifiers. For more information on connecting external amplifiers, see Connecting to External Amplifiers in Chapter 2.

ELO Input

If the ELO input on the controller is triggered, the amplifier will be shut down at a hardware level, the motors will be essentially in a Motor Off (MO) state. TA3 will return a 3 and the #AMPERR routine will run when the ELO input is triggered. To recover from an ELO, an MO then SH must be issued, or the controller must be reset.

It is recommended that OE1 be used for all axes when the ELO is used in an application.

Error Monitoring and Protection

The amplifier is protected against over-voltage, under-voltage, over-temperature, and over-current for brush and brushless operation. The controller will monitor the error conditions and respond as programmed in the application. The errors are monitored via the TA command. TA n may be used to monitor the errors with n = 0, 2, or 3. The command will return an eight bit number representing specific conditions. TA0 will return errors with regard to under voltage, over voltage, over current, and over temperature. TA2 will monitor if the amplifier current exceeds the continuous setting, and TA3 will return if the ELO input has been triggered.

The user also has the option to include the special label #AMPERR in their program to handle amplifier errors. As long as a program is executing in thread zero and the #AMPERR label is included, when an error is detected the program will jump to the label and execute the user defined routine. Note that the TA command is a monitoring function only, and does not generate an error condition.

See the TA command for detailed information on bit status during error conditions.

Under-Voltage Protection

If the supply to the amplifier drops below 18 VDC, the amplifier will be disabled. The amplifier will return to normal operation once the supply is raised above the 18V threshold.

NOTE: If there is an #AMPERR routine and the controller is powered before the amplifier, then the #AMPERR routine will automatically be triggered.

Over-Voltage Protection

If the voltage supply to the amplifier rises above 94 VDC, then the amplifier will automatically disable. The amplifier will re-enable when the supply drops below 90 V.

The over voltage condition will not permanently shut down the amplifier or trigger the #AMPERR routine. The amplifier will be momentarily disabled; when the condition goes away, the amplifier will continue normal operation assuming it did not cause the position error to exceed the error limit.

Over-Current Protection

The amplifier also has circuitry to protect against over-current. If the total current from a set of 2 axes (ie A and B or C and D) exceeds 20 A, the amplifier will be disabled. The amplifier will not be re-enabled until there is no longer an over-current draw and then either SH command has been sent or the controller is reset. Since the AMP-43540 is a trans-conductance amplifier, the amplifier will never go into this mode during normal operation. The amplifier will be shut down regardless of the setting of OE, or the presence of the #AMPERR routine.

NOTE: If this fault occurs, it is indicative of a problem at the system level. An over-current fault is usually due to a short across the motor leads or a short from a motor lead to ground.

Over-Temperature Protection

The amplifier is also equipped with over-temperature protection.

If the average heat sink temperature rises above 80°C, then the amplifier will be disabled. The over-temperature condition will trigger the #AMPERR routine if included in the program on the controller.

The amplifier will not be re-enabled until the temperature drops below 80°C and then either an SH command is sent to the controller, or the controller is reset (RS command or power cycle).

A5 – AMP-43640 (-D3640)

Introduction

The AMP-43640 contains four linear drives for sinusoidally commutating brushless motors. The AMP-43640 requires a single 15–30VDC input. Output power delivered is typically 20 W per amplifier or 80 W total. The gain of each transconductance linear amplifier is 0.2 A/V. Typically a 24VDC supply will deliver 1A continuous and 2A peak while a 30VDC will be able to provide 1.0 A continuous and 2.0 A peak. The current loop bandwidth is approximately 4 kHz. By default the amplifier will use 12 bit DAC's however there is an option for 16 bit DAC's to increase the current resolution for systems with high feedback gain.

The BOX option is required when the AMP-43640 is ordered with the DMC-41x3.

Note: Do not “hot swap” the motor power or supply voltage power input connections. If the amp is enabled when the motor connector is connected or disconnected, damage to the amplifier can occur. Galil recommends powering the controller and amplifier down before changing the connector, and breaking the AC side of the power supply connection in order to power down the amplifier. The ELO input may be used to cut power to the motors in an Emergency Stop or Abort situation.



Figure A5.1: DMC-4143-D3640-BOX4 (DMC-4143 with AMP-43640)

Electrical Specifications

The amplifier is a brushless type trans-conductance linear amplifier for sinusoidal commutation. The amplifier outputs a motor current proportional to the command signal input.

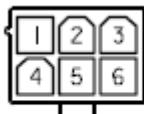
DC Supply Voltage:	15-30 VDC
	In order to run the AMP-43640 in the range of 15-20 VDC, the ISCNTL – Isolate Controller Power option must be ordered
Continuous Current	1.0 Amps
Peak Current (per axis)	2.0 Amps
Amplifier gain:	0.2 A/V
Power output (per channel):	20 W (see section below)
Total max. power output:	80 W (assuming proper thermal mounting and heat dissipation)

The amplifier has built in thermal protection which will cause the amplifier to be disabled until the temperature of the transistors falls below the threshold.

Mating Connectors

	On Board Connector	Terminal Pins
POWER	6-pin Molex Mini-Fit, Jr. TM MOLEX# 39-31-0060	MOLEX#44476-3112
A,B,C,D: 4-pin Motor Power Connectors	4-pin Molex Mini-Fit, Jr. TM MOLEX# 39-31-0040	MOLEX#44476-3112

For mating connectors see <http://www.molex.com/>



Power Connector



Motor Connector

Power Connector	
Pin Number	Connection
1,2,3	DC Power Supply Ground
4,5,6	+VS (DC Power)
Motor Connector	
1	Phase C
2	Phase B
3	No Connect
4	Phase A

Power

Unlike a switching amplifier a linear amplifier does not have a straightforward relationship between the power delivered to the motor and the power lost in the amplifier. Therefore, determining the available power to the motor is dependent on the supply voltage, the characteristics of the load motor, and the required velocity and current.

All of the power delivered by the power supply is either used in the motor or lost in the amplifier.

$$\text{Power of Power Supply } P_{ps} = P_m + P_A$$

The power to the motor is both the power used to provide motion and the power lost to heat.

$$\text{Power of the motor } P_m = \text{Work} + \text{Power Lost in Motor} \quad P_m = K_e * \text{Velocity} * i + i^2 R_m$$

$$\text{Power of amplifier } P_A = (V_s - i * R_m - K_e * \text{Velocity}) * i$$

In addition there is a minimum power dissipated by the amplifier when powered regardless of load. The minimum power that the amplifier will consume is roughly

$$P_{A,\min} \approx \text{drop across op amp power stages} + \text{drop across sense resistor} + \text{op amp supply}$$

$$P_{A,\min} \approx 4 * i + i^2 * .5 + N$$

Where N = 1.5W for 24V and N = 3W for 48V

For example: assume a 24VDC supply and a motor with $R_m = 4\text{ohms}$ and $K_e = 5V / RPM$ and desired output currents of 1 and .5 amps.

First calculate the minimum power used in the amplifier.

$$P_{A,\min}(1\text{amp}) \approx 4 * i + i^2 * .5 + 1.5 = 6W$$

$$P_{A,\min}(.5\text{amp}) \approx 4 * .5 + .5^2 * .5 + 3 = 5.125W$$

The power used by the motor will vary by its velocity even though the power lost in the motor is a constant for each value of current. The more power sent to the motor, the less power will be dissipated by the amplifier as heat.

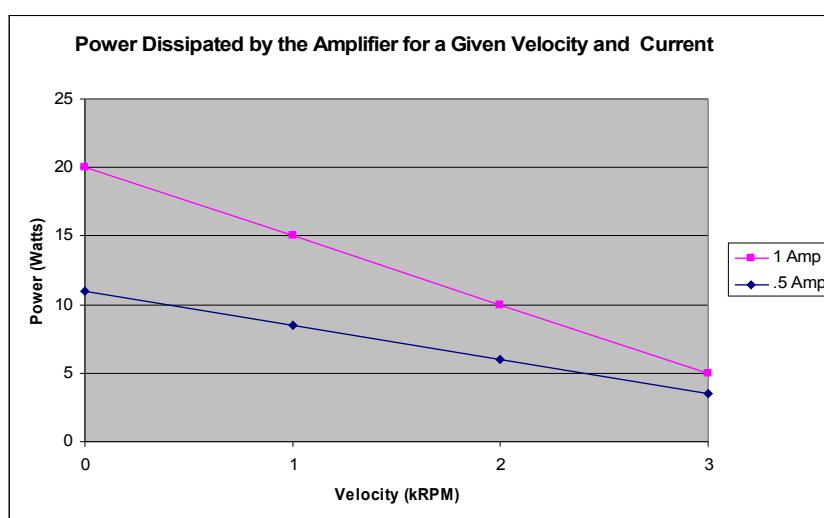


Figure A5.2: Power Dissipation for Velocity and Current

Operation

Finding Proper Commutation

Using the D3640 requires version 1.1d revision firmware or higher; be sure this is installed on your controller (contact Galil). The 4 commands used for set up are the BA, BM, BX and BZ commands. Please see the command reference for details.

1. Issue the BA command to specify which axis you want to use the sinusoidal amplifier on
2. Calculate the number of encoder counts per magnetic cycle. For example, in a rotary motor that has 2 pole pairs and 10,000 counts per revolution, the number of encoder counts per magnetic cycle would be $10,000/2 = 5000$. Assign this value to BM
3. Issue either the BZ or BX command. Either the BX or BZ command must be executed on every reset or power-up of the controller.
- BZ Command:
Issue the BZ command to lock the motor into a phase. Note that this will cause up to $\frac{1}{2}$ a magnetic cycle of motion. Be sure to use a high enough value with BZ to ensure the motor is locked into phase properly.
- BX Command:
Issue the BX command. The BX command utilizes a minimal movement algorithm in order to determine the correct commutation of the motor. As of April 2011 this command was still in the Beta testing phase.
4. **CAUTION:** This step commands uncontrolled motion, rotary motors should not be connected to mechanics.
- If the BX command was used in Step 3:
Set KP, KI and KD to zero and issue a small offset (OF command). Verify that the motor runs away (If you have limited travel you should set PID's to non-zero and use the JG command).
If the motor locks into a position then you need to change the encoder polarity. Set CE to 2 for that axis OR swap MA+/MA- on the encoder leads (swapping encoder leads is recommended), repeat step 3.
- If the BZ command was used in Step 3:
We now must confirm we have the proper wiring for our motor power leads. Set KP, KI, KD to zero. Issue a small offset (OF command) and record the velocity with the TV command. It is possible that you will not see any motion for given combinations of motor power leads. Now issue the same offset but negative and record TV again. Power down the controller and swap motor power leads. Repeat steps 1-3 for each of the 6 motor power lead combinations. The combination that yields velocities that are similar in magnitude is the correct choice. In the event that two combinations both yield similar magnitudes for positive and negative offsets select the one with the higher overall magnitude.

Trial#	Phase A	Phase B	Phase C	+ Velocity	- Velocity
1	Power lead 1	Power lead 2	Power lead 3		
2	Power lead 1	Power lead 3	Power lead 2		
3	Power lead 2	Power lead 3	Power lead 1		
4	Power lead 2	Power lead 1	Power lead 3		
5	Power lead 3	Power lead 1	Power lead 2		
6	Power lead 3	Power lead 2	Power lead 1		

Setting Peak and Continuous Current (TL and TK)

The peak and continuous torque limits can be set through TK and TL respectively. The TK and TL values are entered in volts on an axis by axis basis. The peak limit will set the maximum voltage that will be output from the controller to the amplifier. The continuous current will set what the maximum average current is over a one second interval. Figure A5.1 is indicative of the operation of the continuous and peak operation. In this figure, the continuous limit was configured for 2 volts, and the peak limit was configured for 10 volts.

The TL command is limited to 5V for the AMP-43640. This limits the continuous current output of the amplifier to 1A. The TK command can be set to 9.998V, which provides a peak current output of 2A.

To set TL and TK for a particular motor, find the continuous current and peak current ratings for that motor and divide that number by the amplifier gain. For example, a particular motor has a continuous current rating of 0.5A and peak current rating of 1.5A. The gain of the AMP-43640 is 0.2A/V

$$TL \text{ setting} = (0.5\text{A}) / (0.2\text{A/V}) = 2.5\text{V (TL n=2.5)}$$

$$TK \text{ setting} = (1.5\text{A}) / (0.2\text{A/V}) = 7.5\text{V (TK n=7.5)}$$

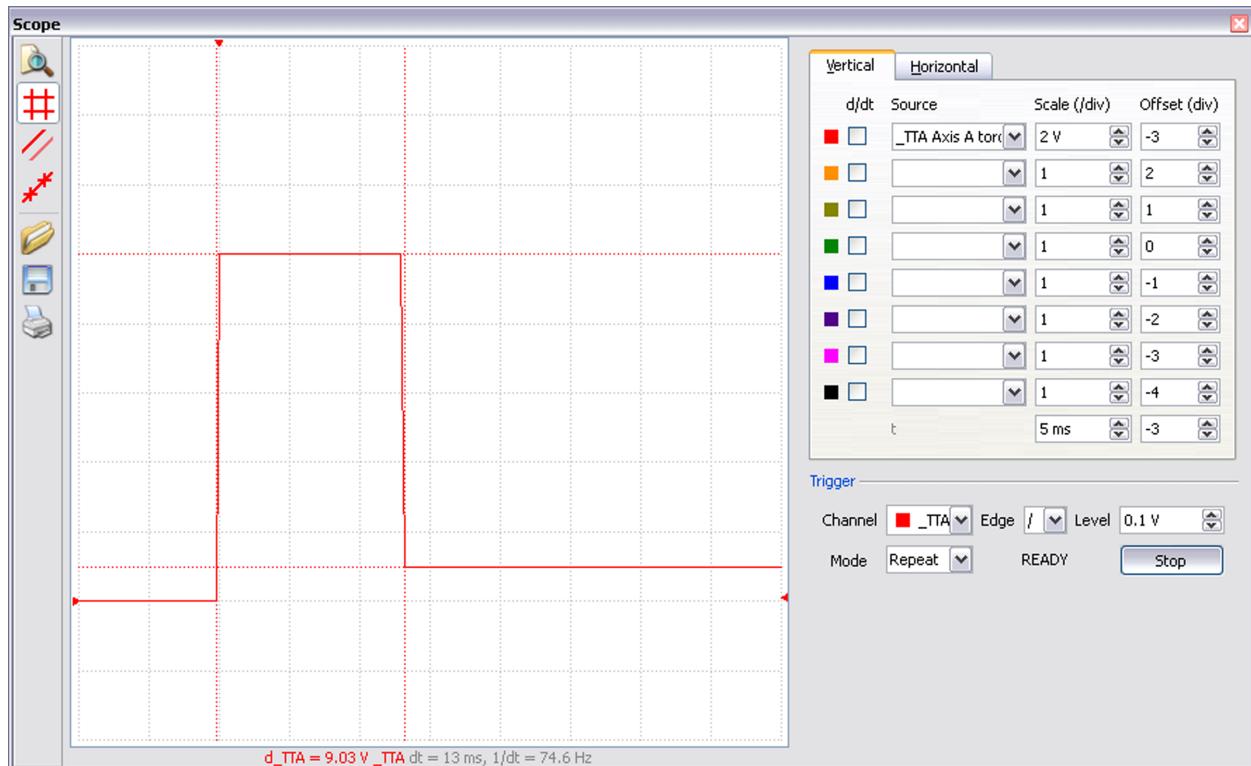


Figure A5.3: Peak Current Operation

ELO Input

If the ELO input on the controller is triggered, the amplifier will be shut down at a hardware level, the motors will be essentially in a Motor Off (MO) state. TA3 will return a 3 and the #AMPERR routine will run when the ELO input is triggered. To recover from an ELO, an MO then SH must be issued, or the controller must be reset.

It is recommended that OE1 be used for all axes when the ELO is used in an application.

Using External Amplifiers

The BR command must be set to a -1 for any axis where an AMP-43640 is installed but the use of an external axis is required. This setting will disable the requirement to have the BA, BM and BX or BZ commands executed prior to being able to issue the SH command for that axis. BR-1 is required for both external servo and stepper drivers.

Use the connectors on top of the controller to access necessary signals to run external amplifiers. For more information on connecting external amplifiers, see Connecting to External Amplifiers in Chapter 2.

A6 – SDM-44040 (-D4040)

Description

The SDM-44040 resides inside the DMC-41x3 enclosure and contains four drives for operating two-phase bipolar step motors. The SDM-44040 requires a single 12-30 VDC input. The unit is user-configurable for 1.4 A, 1.0 A, 0.75 A, or 0.5 A per phase and for full-step, half-step, 1/4 step or 1/16 step.

The BOX option is required when the SDM-44040 is order with the DMC-41x3.

NOTE: Do not “hot swap” the motor power or supply voltage power input connections. If the amp is enabled when the motor connector is connected or disconnected, damage to the amplifier can occur. Galil recommends powering the controller and amplifier down before changing the connector, and breaking the AC side of the power supply connection in order to power down the amplifier. The ELO input may be used to cut power to the motors in an Emergency Stop or Abort situation.



Figure A6.1: DMC-4143-D4040-BOX4 (DMC-4143 with SDM-44040)

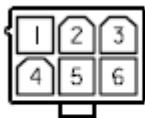
Electrical Specifications

DC Supply Voltage:	12-30 VDC
Max Current (per axis)	1.4 Amps/Phase Amps (Selectable with AG command)
Maximum Step Frequency:	6 MHz
Motor Type:	Bipolar 2 Phase

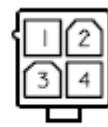
Mating Connectors

	On Board Connector	Terminal Pins
POWER	6-pin Molex Mini-Fit, Jr. TM MOLEX# 39-31-0060	MOLEX#44476-3112
A,B,C,D: 4-pin Motor Power Connectors	4-pin Molex Mini-Fit, Jr. TM MOLEX# 39-31-0040	MOLEX#44476-3112

For mating connectors see <http://www.molex.com/>



Power Connector



Motor Connector

Power Connector	
Pin Number	Connection
1,2,3	DC Power Supply Ground
4,5,6	+VS (DC Power)
Motor Connector	
1	B-
2	A-
3	B+
4	A+

Operation

The SDM-44040 should be setup for Active High step pulses (MT-2 or MT-2.5).

The AG command sets the current on each axis, the LC command configures each axis's behavior when holding position and the YA command sets the step driver resolution. These commands are detailed below, see also the command reference for more information:

Current Level Setup (AG Command)

AG configures how much current the SDM-44040 delivers to each motor. Four options are available: 0.5A, 0.75A, 1.0A, and 1.4 Amps

Drive Current Selection per Axis: AG n,n,n,n,n,n,n,n

n = 0	0.5 A
n = 1	0.75 A (default)
n = 2	1.0 A
n = 3	1.4 A

Low Current Setting (LC Command)

LC configures each motor's behavior when holding position (when RP is constant) and multiple configurations:

LC command set to 0 “Full Current Mode” - causes motor to use 100% of peak current (AG) while at a “resting” state (profiler is not commanding motion). This is the default setting.

LC command set to 1 “Low Current Mode” - causes motor to use 25% of peak current while at a “resting” state. This is the recommended configuration to minimize heat generation and power consumption.

LC command set to an integer between 2 and 32767 specifying the number of samples to wait between the end of the move and when the amp enable line toggles

Percentage of full (AG) current used while holding position with LC n,n,n,n,n,n,n,n

n = 0	100%
n = 1	25%

The LC command must be entered after the motor type has been selected for stepper motor operation (i.e. MT-2,-2,-2,-2). LC is axis-specific, thus LC1 will cause only the X-axis to operate in “Low Current” mode.

Step Drive Resolution Setting (YA command)

When using the SDM-44040, the step drive resolution can be set with the YA command

Step Drive Resolution per Axis: YA n,n,n,n,n,n,n,n

n = 1	Full
n = 2	Half
n = 4	1/4
n = 16	1/16

Protection Circuitry

The SDM-44040 has short circuit protection as well as over-temperature and under-voltage detection.

The short circuit protection will protect against phase to phase shorts, a shorted load and a short to ground or chassis. The over current shutdown will occur when any one phase exceeds an output greater than 2Amps.

The over-temperature shutdown will occur when the driver temperature exceeds 165 deg C.

In the event of any of these faults, bit 0 of TA0 will be set (bit 5 for axes E-H) and the SDM-44040 will be disabled. All 4 axes on the amplifier must be in MO state in order for the error status to be cleared.

ELO Input

If the ELO input on the controller is triggered, then the amplifier will be shut down at a hardware level, the motors will be essentially in a Motor Off (MO) state. TA3 will return a 3 and the #AMPERR routine will run when the ELO input is triggered. To recover from an ELO, an MO then SH must be issued, or the controller must be reset.

It is recommended that OE1 be used for all axes when the ELO is used in an application.

A7 – SDM-44140 (-D4140)

Description

The SDM-44140 resides inside the DMC-41x3 enclosure and contains four microstepping drives for operating two-phase bipolar stepper motors. The drives produce 64 microsteps per full step or 256 steps per full cycle which results in 12,800 steps/rev for a standard 200-step motor. The maximum step rate generated by the controller is 6,000,000 microsteps/second. The SDM-44140 drives motors operating at up to 3 Amps at 12 to 60 VDC (available voltage at motor is 10% less). There are four softwareselectable current settings: 0.5 A, 1 A, 2 A and 3 A. Plus, a selectable lowcurrent mode reduces the current by 75% when the motor is not in motion. No external heatsink is required.

The BOX option is required when the SDM-44140 is order with the DMC-41x3.

NOTE: Do not “hot swap” the motor power or supply voltage power input connections. If the amp is enabled when the motor connector is connected or disconnected, damage to the amplifier can occur. Galil recommends powering the controller and amplifier down before changing the connector, and breaking the AC side of the power supply connection in order to power down the amplifier. The ELO input may be used to cut power to the motors in an Emergency Stop or Abort situation.



Figure A7.1: DMC-4143-D4140 (DMC-4143 with SDM-44140)

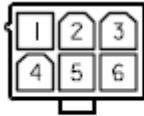
Electrical Specifications

DC Supply Voltage:	12-60 VDC
Max Current (per axis)	3.0 Amps (Selectable with AG command)
Max Step Frequency:	6 MHz
Motor Type:	Bipolar 2 Phase
Switching Frequency:	60 kHz
Minimum Load Inductance:	0.5 mH

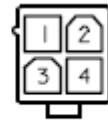
Mating Connectors

	On Board Connector	Terminal Pins
POWER	6-pin Molex Mini-Fit, Jr. TM MOLEX# 39-31-0060	MOLEX#44476-3112
A,B,C,D: 4-pin Motor Power Connectors	4-pin MATE-N-LOK MOLEX# 39-31-0040	MOLEX#44476-3112

For mating connectors see <http://www.molex.com/>



Power Connector



Motor Connector

Power Connector	
Pin Number	Connection
1,2,3	DC Power Supply Ground
4,5,6	+VS (DC Power)
Motor Connector	
1	B-
2	A-
3	B+
4	A+

Operation

The SDM-44140 should be setup for Active High step pulses (MT-2 or MT-2.5).

The AG command sets the current on each axis and the LC command configures each axis's behavior when holding position. These commands are detailed below:

Current Level Setup (AG Command)

AG configures how much current the SDM-44140 delivers to each motor. Four options are available: 0.5A, 1.0A, 2.0A, and 3.0Amps

NOTE: when using the 3.0A setting, mounting the unit to a metal or heat dissipating surface is recommended.

Drive Current Selection per Axis: AG n,n,n,n,n,n,n

n = 0	0.5 A
n = 1	1 A (default)
n = 2	2 A
n = 3	3.0 A

Low Current Setting (LC Command)

LC configures each motor's behavior when holding position (when RP is constant) and multiple configurations:

LC command set to 0 "Full Current Mode" - causes motor to use 100% of peak current (AG) while at a "resting" state (profiler is not commanding motion). This is the default setting.

LC command set to 1 "Low Current Mode" - causes motor to use 25% of peak current while at a "resting" state. This is the recommended configuration to minimize heat generation and power consumption.

LC command set to an integer between 2 and 32767 specifying the number of samples to wait between the end of the move and when the amp enable line toggles

Percentage of full (AG) current used while holding position with LC n,n,n,n,n,n,n

n = 0	100%
n = 1	25%

The LC command must be entered after the motor type has been selected for stepper motor operation (i.e. MT-2,-2,-2,-2). LC is axis-specific, thus LC1 will cause only the X-axis to operate in "Low Current" mode.

Over-Current Protection

The stepper driver also has circuitry to protect against over-current. If the total current from a set of 2 axes (ie A and B or C and D) exceeds 10 A, the SDM-44140 will be disabled. The amplifier will not be re-enabled until there is no longer an over-current draw and then either SH command has been sent or the controller is reset. The amplifier will never go into this mode during normal operation. The amplifier will be shut down regardless of the setting of OE, or the presence of the #AMPERR routine. Bit 0 of TA0 will be set.

NOTE: If this fault occurs, it is indicative of a problem at the system level. An over-current fault is usually due to a short across the motor leads or a short from a motor lead to ground.

Under-Voltage Protection

If the supply to the amplifier drops below 12 VDC, the amplifier will be disabled. The amplifier will return to normal operation once the supply is raised above the 12V threshold; bit 3 of the error status (TA0) will tell the user whether the supply is in the acceptable range.

Note: If there is an #AMPERR routine and the controller is powered before the amplifier, then the #AMPERR routine will automatically be triggered.

ELO Input

If the ELO input on the controller is triggered, then the amplifier will be shut down at a hardware level, the motors will be essentially in a Motor Off (MO) state. TA3 will return a 3 and the #AMPERR routine will run when the ELO input is triggered. To recover from an ELO, an MO then SH must be issued, or the controller must be reset.

It is recommended that OE1 be used for all axes when the ELO is used in an application.