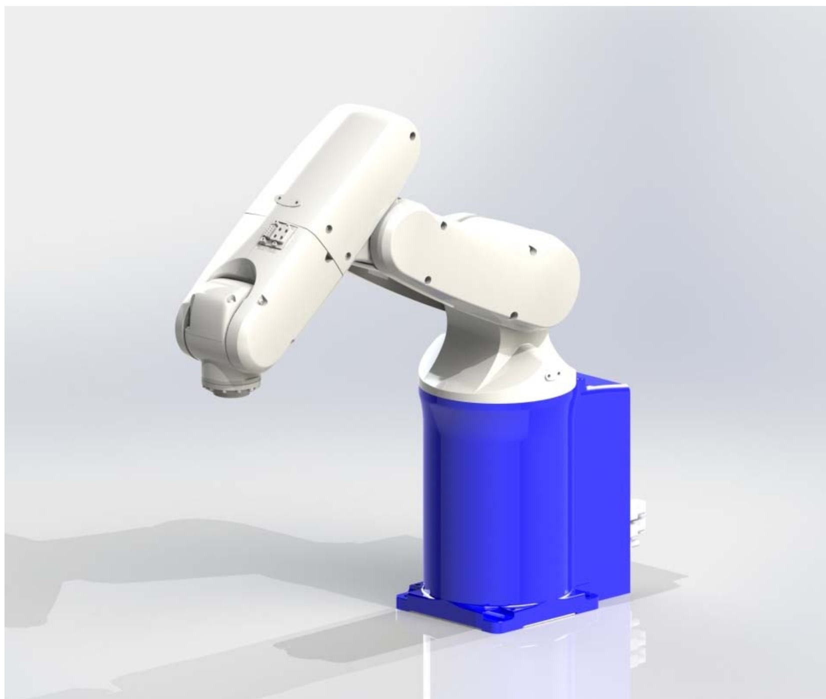
The PAVP6 Robot



Hardware Reference Manual

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Document Content

Trademarks

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Warning Labels

The following warning and caution labels are utilized throughout this manual to convey critical information required for the safe and proper operation of the hardware and software. It is extremely important that all such labels are carefully read and complied with in full to prevent personal injury and damage to the equipment.

There are four levels of special alert notation used in this manual. In descending order of importance, they are:

> **WARNING:** This indicates a potentially hazardous situation, which, if not avoided, could result in serious injury or major damage to the equipment.

> **CAUTION:** This indicates a situation, which, if not avoided, could result in minor injury or damage to the equipment.

> NOTE: This provides supplementary information, emphasizes a point or procedure, or gives a tip for easier operation

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Introduction to the Hardware

System Overview

System Description

The PAVP6 Robot is a six-axis robot which includes an embedded Guidance 1600A six-axis motion controller and a 24VDC power supply located inside the base of the robot.

The robot is designed as tabletop unit and can carry a payload of up to 2.0 kg. These robots are low cost, very reliable, and have excellent positioning repeatability. To achieve these results, the axes are powered by brushless DC motors with absolute encoders. With these characteristics, these robots are ideal for automating applications in the Life Sciences, Medical Products, Semiconductor, and Electronics industries.

A number of communications and hardware interfaces are provided with the basic robot. These include an RS-232 serial interface, an RS485 serial interface, an Ethernet interface, and a number of digital input and output lines. In addition, the robot can be purchased with several types of optional Precise peripherals. These include digital cameras, remote I/O, and a hardware manual control pendant.

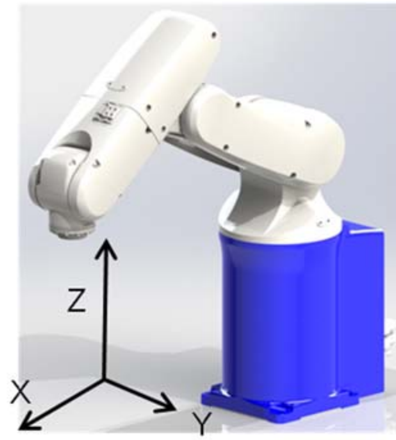
The controller is programmed by means of a PC connected through Ethernet. There are three programming modes: a Digital IO (PLC) mode, an Embedded Language mode, and a PC Control mode. When programmed in the PLC or Embedded Language mode, the PC can be removed after programming is completed and the controller will operate standalone. The PC is required for operation in the PC Control mode.

In all modes of operation, the controller includes a web based operator interface. This interface is used for configuring the system, starting and stopping execution, and monitoring its operation. The web interface can be accessed locally using a browser or remotely via the Internet. This remote interface is of great benefit in system maintenance and debugging.

The optional machine vision system, “PreciseVision”, can execute in a PC connected through Ethernet. PreciseVision requires cameras connected via Ethernet or USB, allowing any processor on the network to obtain and process information from any camera on the network, and provide the results to any networked motion controller.

System Diagram and Coordinate Systems

The major elements of the PAVP6 robot and the orientation and origin of its World Cartesian coordinate system are shown in the diagram below.



Axis	Description	Motion
1	Base Rotation	+/- 160 degrees
2	Shoulder Rotation	+/- 120 degrees
3	Elbow Rotation	19 to 160 degrees
4	Wrist Rotation	+/- 160 degrees
5	Wrist Pitch	+/- 120 degrees
6	Tool Rotation	+/- 360 degrees

The first axis of the robot, J1, rotates the shoulder about a vertical axis. When the links are opposite the connector panel, J1 is at its zero position. The zero position for the shoulder axis is vertical. The rotation of the elbow is limited; the zero position for the elbow is with the outer link aligned with the inner link. However the outer link cannot reach this position. It can move from 19 degrees downwards towards the base to 160 degrees. The wrist rotations are shown above, with zero positions in the center of the travel range.

The robot can be moved under computer control in a Joint Coordinate system, a “World” Cartesian Coordinate System fixed to the mounting surface as shown above, or a “Tool” Cartesian Coordinate System fixed to the tool flange.

All 6 axes of the robot have fail-safe brakes. If motor power is not present, the brakes can be released by depressing the “Brake Release” button on the connector panel. Care should be taken to support the robot when the brake release button is pushed, as the axes will fall due to gravity. It is not necessary for the control system to be operating for the brake release to function; the only requirement is providing AC power to the controller and turning on the controller power switch, which provides DC power for the brakes.

The robot can also be placed in a gravity-balanced mode called “Free” mode, in which the motors provide the torque necessary to support the robot and payload, and the robot can be moved by hand to desired locations to facilitate teaching.

The outer link includes a facilities panel which provides 4 air lines routed to the connector panel in the base and 9 electrical wires routed to a 9 pin Dsub connector in the base panel.

The controller and power supply for the robot is located inside the base casting, thus providing a very compact footprint for this robot as no external robot controller chassis or large cable is needed.

An LED mounted on the connector panel blinks at a rate of once per second to indicate that the controller is operational and at a rate of 4 times a second when power is being supplied to the motors.

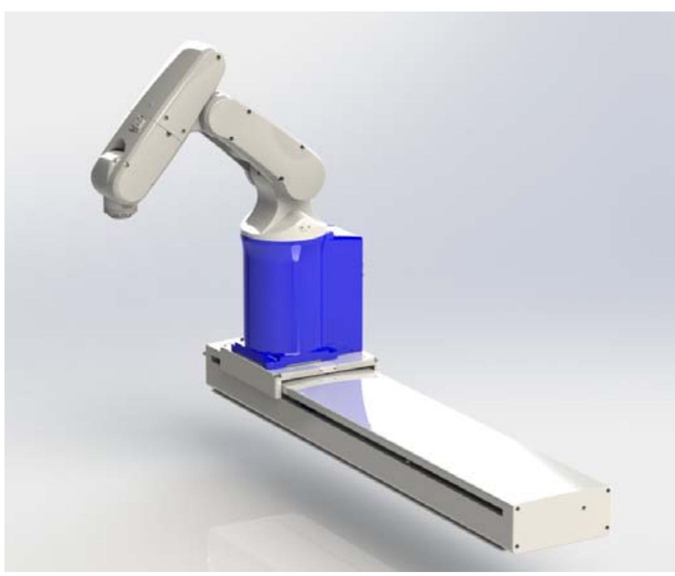
System Components

In addition to the robot, a number of other components are available from Precise which are designed to be compatible with this robot to aid in developing systems for various applications.

Optional Linear Axis Module (Future Option, not yet released)

The PAVP6 robot may be attached to an optional Linear Axis Module. The Linear Axis Module may be ordered in 1000mm, 1500mm and 2000mm travel distances. The module length is about 380mm longer than the travel distance. All cables and controls are contained inside the Linear Axis Module, which is equipped with drip proof covers and tape seals. Power entry, a power switch, Pendant, and IO connectors are extended from the base of the robot to the end cap of the Linear Axis Module. The Linear Axis Module is driven by a servo amplifier located in the carriage. This servo amp gets commands from the controls in the robot, so the Linear Axis Module must be slaved to a robot in order to work, and cannot be purchased as a standalone module at this time.

The picture below shows a PAVP6 on a 1000mm Linear Axis Module. The robot may be mounted in this orientation, in which case the linear axis moves along the Y axis in the robot's coordinate system with the linear axis extending the robot's Y axis by plus or minus 500mm. The robot may also be rotated 90 degrees so that it faces the connector end cap of the Linear Axis. In this case the Linear Axis extends the robot's X axis travel, if the appropriate SW parameter is changed. See the Software Reference section.

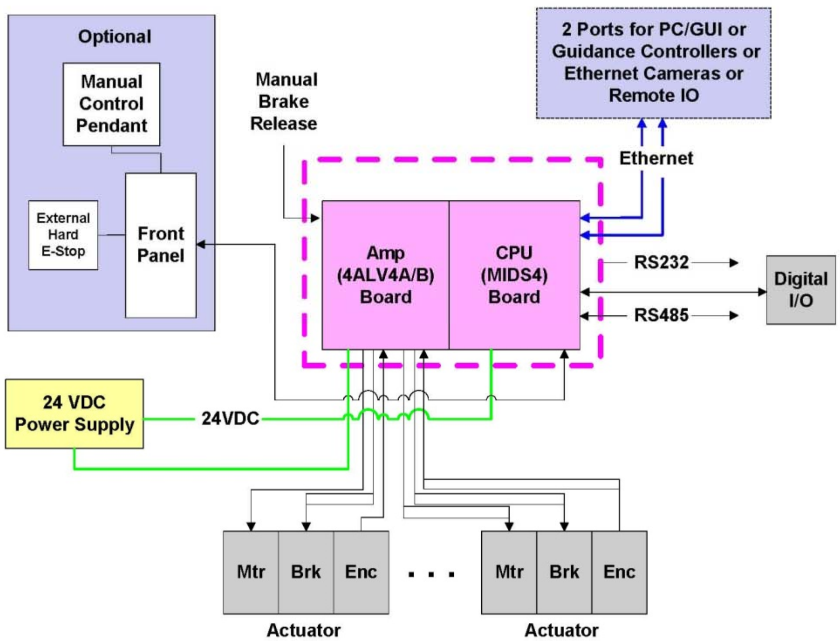


Mounting of Robot and Linear Axis Module

The Robot Base Plate contains a mounting hole pattern for 4 M8 Screws along with reference holes for locating the robot on a table or work cell surface. The Linear Axis Module contains mounting patterns for M6 and screws. See Installation section for details.

Guidance 1600A Controller

The Guidance 1600A Controller is a six-axis general purpose motion controller that contains six motor drives and two encoder inputs. It must be attached to a heat sink. The heat sink is provided by the inner robot housing. The controller includes local digital IO. It also supports RS232 and RS 485 serial communication and an optional Precise Remote IO module. It contains two Ethernet ports. The controller and power supplies are shown in the system diagram below.



For detailed information on the controller including interfacing information, please see the *"Guidance 1000A/B Controllers Manual* P/N: G1X0-DI-A0010".

Low Voltage Power Supplies

The PAVP6 Robot has an integrated 400-watt, 24VDC Power Supply that accepts a range of AC input from 90V to 264V.

DANGER: In addition to exposed high voltage pins and components, **the heat sinks on the Power Supply are not all grounded and expose high voltage levels.** AC power to the robot must be disconnected prior to accessing these units.

Energy Dump Circuit

The 24 VDC supply has a regulated output and an overvoltage protection circuit that is triggered if the voltage reaches 28 volts. Rapid deceleration of the robot motors can generate a Back EMF voltage that can pump up the motor voltage bus. In order to avoid bus pump up, an Energy Dump Circuit is connected to the 24 VDC bus. This circuit is contained in the controller and is connected to an external power resistor in the base of the robot.

Remote Front Panel, E-Stop Box and Manual Control Pendant

For users that wish to have a hardware E-Stop button, Precise offers an E-Stop Box or a portable Hardware Manual Control Pendant that includes an E-Stop button. The E-Stop box can be plugged into the Pendant connector in the connector panel in the base of the robot. The E-Stop box and Teach Pendant Estop each complete two circuits in the Pendant. If these circuits are not completed it is not possible to enable motor power to the robot. If no E-Stop box or Manual Control Pendant is connected, a plug with jumpers must be connected between these pins to enable robot motor power. The Manual Control Pendant can be plugged directly into the Pendant 9 pin Dsub connector mounted on the robot's Facilities Panel in the base of the robot.

Optional RS485 IO Module (GIO)

For users who wish to have IO available at the base of the robot, an optional IO module may be added. This module provides 12 digital inputs and 8 digital outputs in a 25 pin Dsub connector at the robot connector panel and is connected via RS485 to the robot controller.

Optional Digital IO Module (GIO)

Remote IO Module (Ethernet Version)

For applications that require a large number of Inputs and Outputs, a Precise Remote IO (RIO) module may be purchased. The RIO interfaces to any Precise robot and it's embedded Guidance Controller via 10/100 Mb Ethernet and requires 24 VDC power. Up to 4 RIO's can be connected to a controller.

The basic RIO includes: 32 isolated digital input signals, 32 isolated digital output signals and one RS-232 serial line. An enhanced version of the RIO adds 4 analog input signals, a second RS-232 port and one RS-422/485 serial port.

The Enhanced RIO module is pictured below.

> **WARNING:** The RIO contains unshielded 24 VDC signals and pins. This product is intended to be mounted in a cabinet or machine chassis that is not accessible when power is turned on.

Machine Vision Software and Cameras

The Guidance 1400 Series controllers support the PreciseVision machine vision system. This is a vision software package than can run in a PC.

Cameras must be connected via Ethernet or USB. Vendors such as DALSA already offer a variety of Ethernet machine vision cameras. In addition, other vendors offer USB cameras that are supported in PreciseVision.

Precise offers an Arm-Mounted Camera Option for certain robots. Contact Precise for details.

Machine Safety

Safety and Agency Certifications

Precise systems can include computer-controlled mechanisms that are capable of moving at high speeds and exerting considerable force. Like all robot and motion systems, and most industrial equipment, they must be treated with respect by the user and the operator.

This manual should be read by all personnel who operate or maintain Precise systems, or who work within or near the work cell.

We recommend that you read the harmonized standard EN ISO 10218-1 and 10218-2 (2011), Robots for Industrial Environments.

Standards Compliance and Agency Certifications

Precise robots are intended for use with other equipment and are considered a subassembly rather than a complete piece of equipment on their own. They meet the requirements of these standards:

ENISO 10218-1-2011 Robots for Industrial Environments, Safety Requirements
EN 610204-1 **S**afety of Machinery, Electrical Equipment of Machines
EN 61326-1(2006) Table 1 (Basic Immunity);Sec 7.0 (Emissions Class A)
EN 61000-3-2 (2006) + A1 (2009) + A2 (2009)
EN 61000-3-3 (2008)

To maintain compliance with the above standards the controller must be installed and used in accordance with the regulations of the standards, and in accordance with the instructions in this user’s guide.

In addition to the above standards, the PAVP6 robot has been designed to comply with the following agency certification requirements, and carries the CE mark.

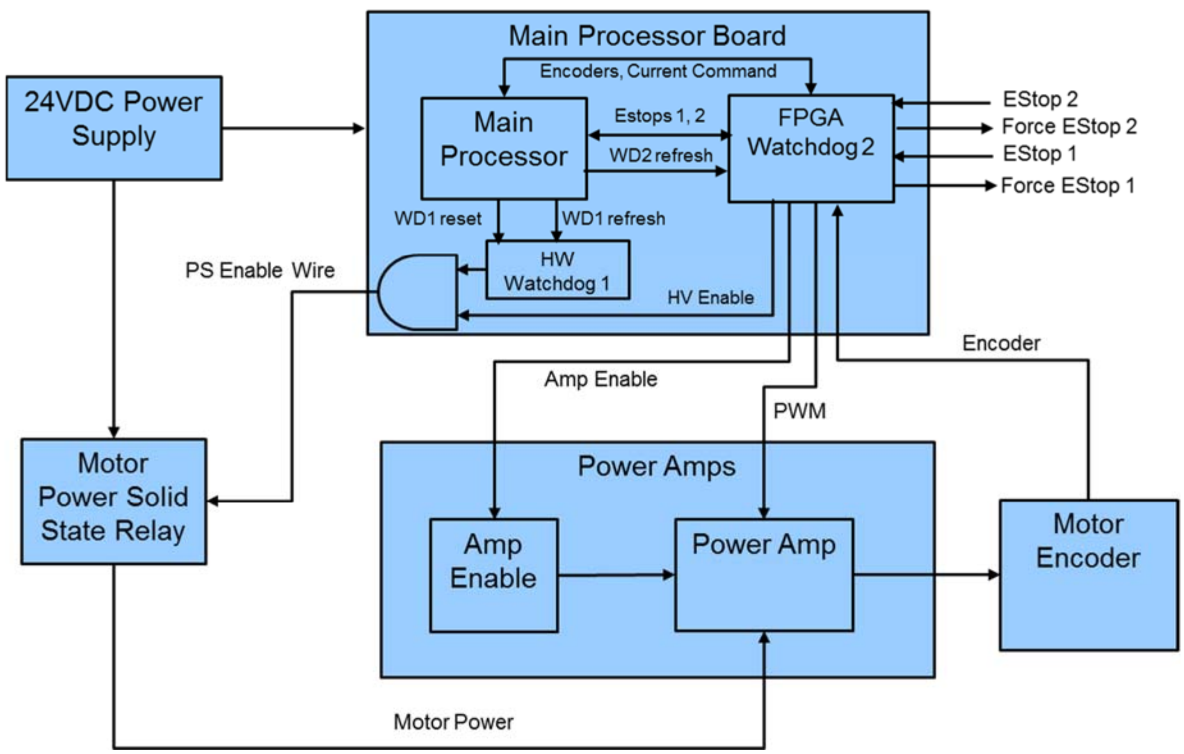
CE
CSA
FCC Class A
ANSI/RIA R15.06 Safety Standard

Moving Machine Safety and Category III

The Precise robots can operate in Manual Control Mode, in which an operator directly controls the motion of the robot, or Computer Control Mode in which the robot operation is automatic. Manual Control Mode is often used to teach locations in the robot workspace. The robot's speed is limited in Manual Control Mode to a maximum of 250mm per second for safety. While the PAVP6 can be operated in "Collaborative Mode" and in this case only apply very limited force, it is very important for operators to keep their hands, arms and especially their head out of the robot's operating volume. It is important that operators wear safety glasses when inside the robot's operating volume.

In Computer Mode, the robot can move quickly. In "Collaborative Mode" the PAVP6 can be set up to be "hand-safe" even in computer mode, and in some cases a risk assessment of the application may indicate that it can be used without operator safety screens. However, safety glasses should be worn at all times when an operator is within the robots working volume. Please refer to the EN ISO 10218-2 and ANSI/RIA R15.06 Safety Standard for Industrial Robots for information on recommended safe operating practices and enclosure design for robots of various sizes and payloads. Please also read the section in this manual under Software Reference on "Collaborative Mode".

The PAVP6 robot controller can be ordered with an option to be compliant with the requirements of ISO 13849-1-2006, Category III, Performance Level d requirements. In the block diagram below, the major hardware safety circuits for the CAT3 option for the controller are shown.



CAT 3 Option Safety Circuits for PAVP Controller

The PAVP controller checks the operation of the hardware safety circuits at startup, before enabling motor power. The safety functions are designed so that no single failure can cause unsafe operation of the robot. In addition to the hardware safety functions, there are numerous firmware and software safety checks, which are listed in the table below.

	13-Sep-17	PAVP6 CAT3								
	Safety Circuit	Start up Test 1	Redundant	Continuous Test	Diagnostic Coverage	MTTFdl, Years	Power Off On Failure	PL	Category Safety	
1	Dual Estop Circuit	Yes	Yes	No	99%	100	Yes	d	3	Startup test forces Estop, checks motor power disabled
										Dual Estop circuits turns off motor power, amp enable, and PWM to amp
										Stopping robot with hand turns off amp enable, and PWM
2	Encoder Feedback	Yes	No	Yes	90%	58	Yes	d	3	Startup test checks encoder communication, prevents mtr power if fault
										Serial update at 8Khz w checksum, comm check, accel check
										Counter embedded in position word to confirm CPU read from FPGA
3	CPU Monitor	Yes	Yes	Yes	99%	100	Yes	d	3	Startup test forces CPU WD low, checks motor power disabled
										Independent dual watchdog timers turn off PWM to amp, motor power
4	Position Envelope Error	Yes	Yes	Yes	90%	57	Yes	d	3	Startup test checks encoder communication, prevents mtr power if fault
										Serial update at 8Khz w checksum, comm check, accel check
										SW watchdog in servo loop turns off PWM to amp, motor power
										Counter embedded in position word to confirm CPU read from FPGA
5	Power amp Fault	Yes	Yes	Yes	90%	100	Yes	d	3	Startup test confirms zero current when motor power enabled
										Excess current to ground or phase to phase triggers shutdown in 10 usec
										Saturated PID current command triggers shutdown in .050 sec
										Shorted transistor just locks up brushless motor
6	Collab Force Limit	Yes	Yes	Yes	90%	SW	Yes	d	3	Tests 2, 3, 4 above test HW.
										PID current limit limits low speed collision force
										Current saturation triggers separate fault, turns off motor power and PWM
										Monitor function with WD turns off motor power and PWM to amp
7	Velocity Restrict	Yes	Yes	Yes	99%	93	Yes	d	3	Startup test, sets flag to trigger this error, then resets
										Checks velocity limit in FPGA in addition to check in CPU servo software
										1. Cat 2 and Cat 3 require startup test before enabling motor power

Voltage and Power Considerations

The Guidance 1600A controller requires one or two DC power supplies, a 24 VDC power supply for the processor and user IO, and in some cases, a separate 48VDC motor power supply. The PAVP6 uses a single 24VDC supply for both controller and motor power.

DANGER: The 24 VDC power supply is an open frame electrical device that contains unshielded high voltage pins, components and surfaces. These products are intended to be mounted in a cabinet or machine chassis that is not accessible when AC line power is turned on.

The PAVP6 power supply has an input range of 90 to 264 VAC 50/60 Hz. Inrush current can be as high as 60 Amps at 240 VAC for short periods of time. The power supplies are protected against voltage surge to 2000 volts. Transient over voltage (< 50 µs) may not exceed 2000 V phase to ground, as per EN61800-31996. The power supply is current limited, over temperature limited, and over voltage limited.

The robot consumes less than 200 Watts during normal operation.

The Precise controller can monitor motor power through its datalogging function. Intermittent power dropouts can be detected by setting a trigger in the data logger which can record and time-stamp power fluctuations.

Mechanical and Software Limit Stops

Axes 1-5 have hard limit stops at the end of travel which are factory installed. The soft-limit stops must be set within the range of these hard stops. Axis 6 does not have a hard limit stop, but is limited to plus or minus 360 degrees of rotation by its absolute encoder. Since the robot has absolute encoders with battery backup, even if the robot is turned off, the encoders keep track of joint position. If Axis 6 is rotated manually beyond the +/- 360 degree software limit stops, it will be necessary to rotate it back to within the allowed software limits before the robot will run. The joint position can be viewed either on the optional Manual Control Pendant, or in the Virtual Manual Control Pendant in the Web Based Operator Interface. (See Guidance Controller Setup and Operation Quick Start Guide)

Stopping Time and Distance

The robot control system responds to two types of E-Stops.

A Soft E-Stop initiates a rapid deceleration of all robots currently in motion and generates an error condition for all GPL programs that are attached to a robot. This property can be used to quickly halt all robot motions in a controlled fashion when an error is detected. A soft E-stop is typically generated by an application program under conditions determined by the programmer.

This function is similar to a Hard E-Stop except that Soft E-Stop leaves High Power enabled to the amplifiers and is therefore used for less severe error conditions. Leaving power enabled is beneficial in that it prevents the robot axes from sagging and does not require high power to be manually re-enabled before program execution and robot motions are resumed. This function is also similar to a Rapid Deceleration feature except that a Rapid Deceleration only affects a single robot and no program error is generated.

If set, the **SoftEStop** property is automatically cleared by the system if High Power is disabled and re-enabled.

A Hard E-Stop is generated by one of several hardware E-Stop inputs and causes motor power to be disabled. However there is a parameter that determines a delay between the time the Hard E-Stop signal is asserted and the time the motor power supply relay is opened. This delay is nominally set at 0.4 seconds. It may be adjusted by an operator with administrator privileges. On the web based operator interface menu, go to Setup/Parameter Database/Controller/Operating Mode/ and set parameter 267 to the desired delay. If this delay is set to 0, the high power relay will be disabled within 1ms.

While all axes have mechanical brakes, braking by the mechanical brakes can be quite violent if the robot is moving quickly. Therefore, leaving the motor power enabled for 0.4 sec allows the servos to decelerate the robot. The servos will typically decelerate the robot at 0.6G, or 6000mm/sec^2. If the robot is moving at a speed of 1000mm/sec, the distance traveled will be 40mm to reach a full stop, and the time will be 0.16sec.

Releasing a Trapped Operator: Brake Release Switch

Should a hard E-Stop be triggered, the brakes will engage, and motor power will be disconnected from all motors. To release the brakes, the operator may press the brake release switch, under the inner link, as long as 24VDC is present. It is not necessary for motor power to be on for the brake release to work. The robot should be supported when the brakes are released so it does not drop.

Installation Information

Environmental Specifications

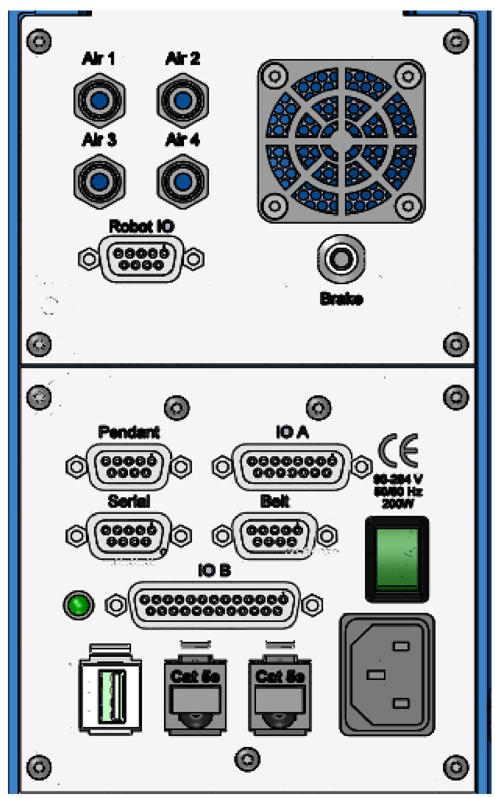
The PAVP6 robot must be installed in a clean, non-condensing environment. This robot is not intended for use in a washdown or spray environment. Please see the Environmental Specifications in Appendix B for specific environmental limits.

Facilities Connections

The Facilities Panel at the base of the robot (and optional linear axis end cap) includes:

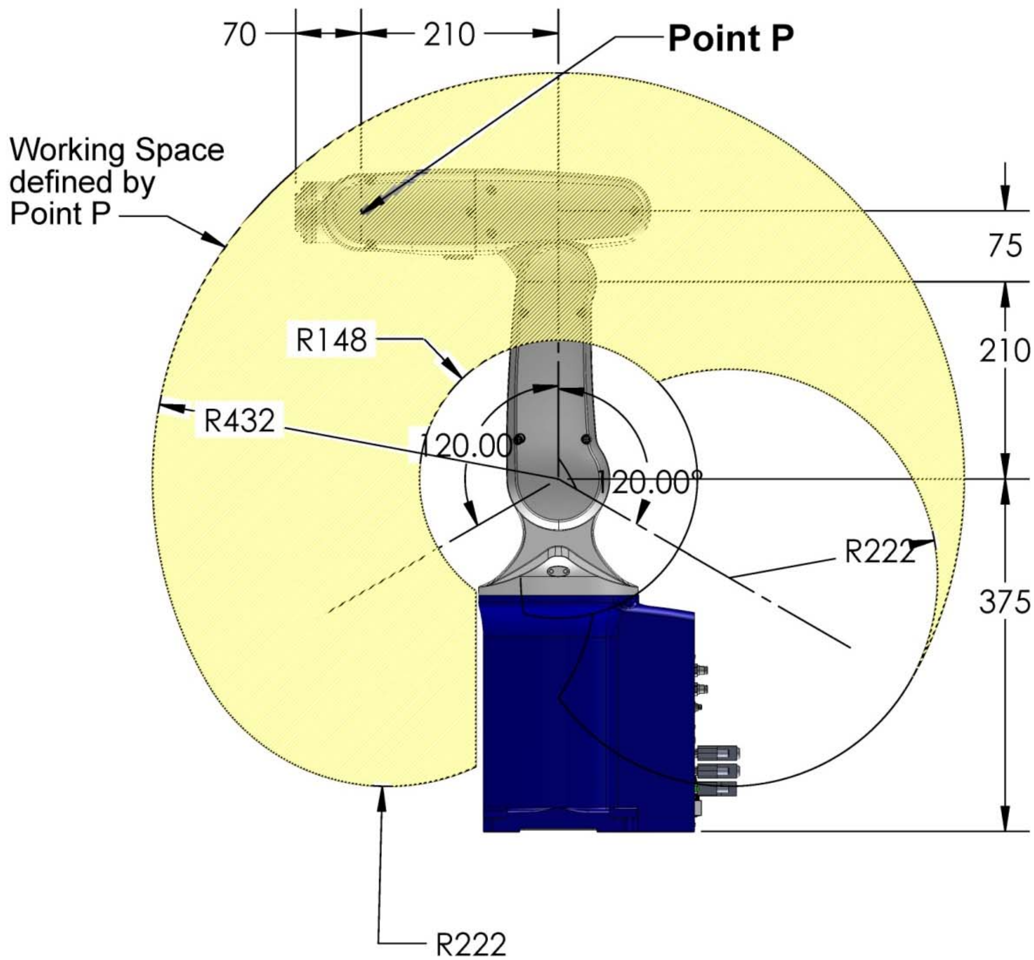
- System AC input power receptacle
- Lighted AC on/off power switch
- Connectors for controller input and output signals

Item	Description
Air 1-4	Air lines routed to wrist
Brake	Brake Release
Robot IO	9 wires to wrist
USB	(NA, Future Option)
Enet	Enet Connector
Pendant	Teach Pendant or EStop
LED	Blinks to show status
IO A	4 Inputs 4 Outputs
IO B	12 Inputs, 8 Outputs
Serial	RS485, 24V Power
Belt	Belt Encoder Input

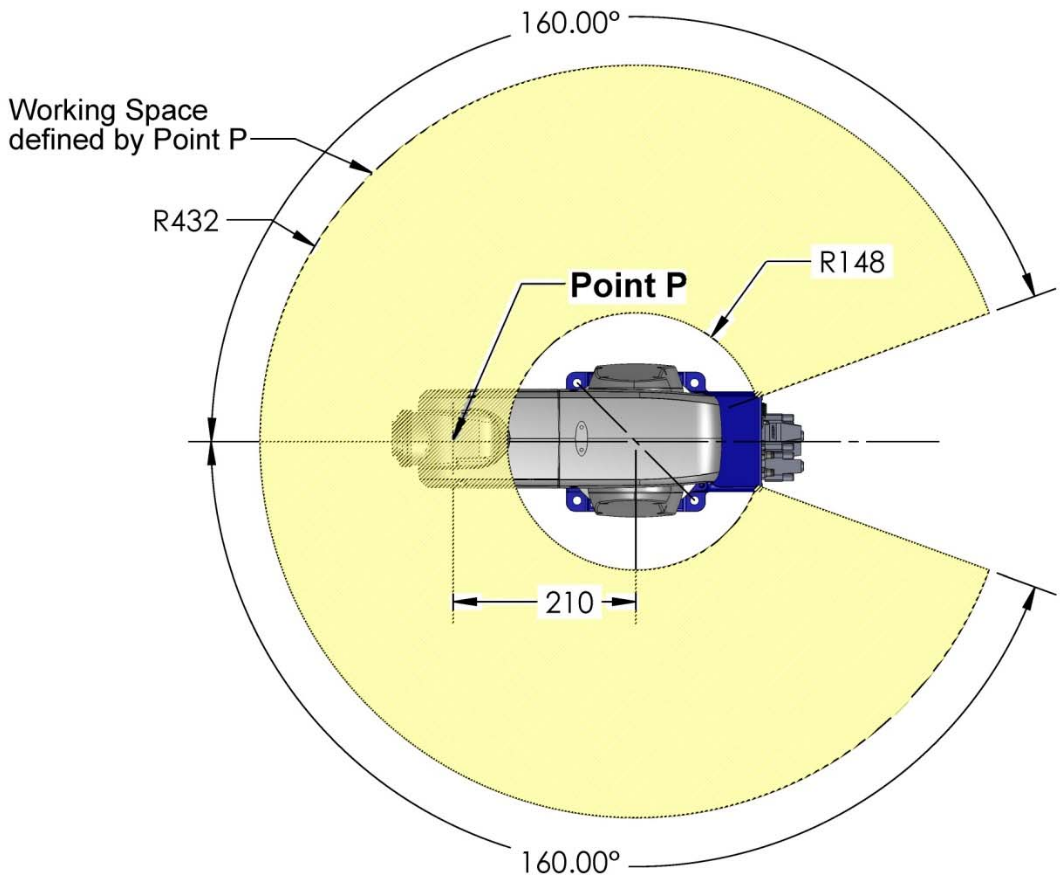


System Dimensions

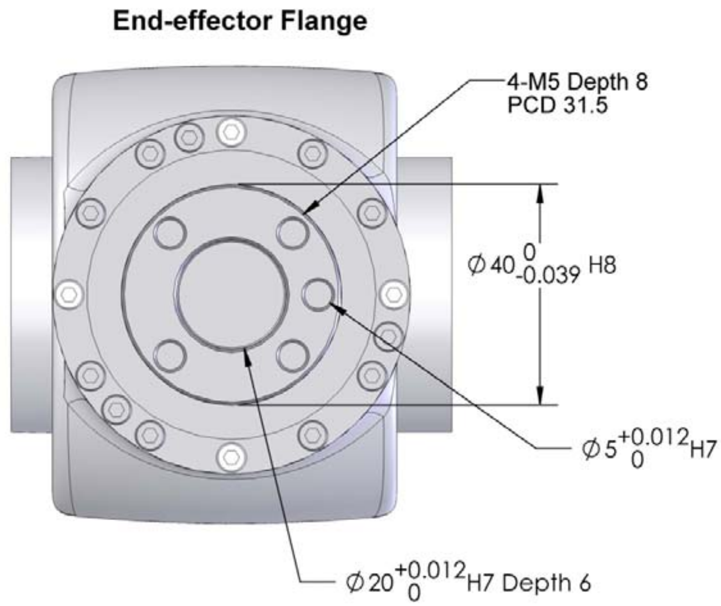
Both top and right views are shown below. All dimensions are in millimeters.

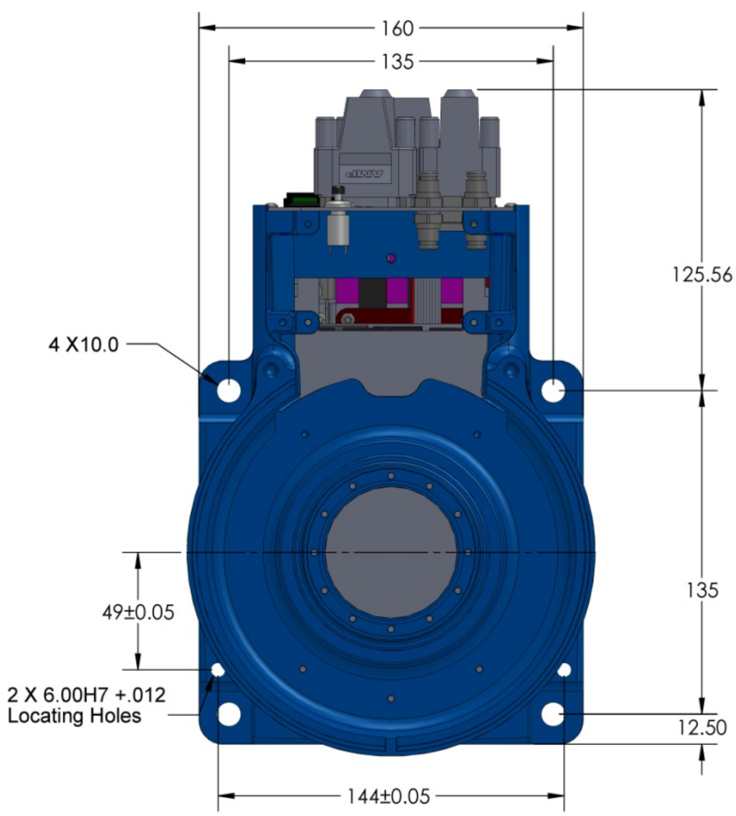


PAVP6 Working Volume Elevation



PAVP6 Working Volume Plan View

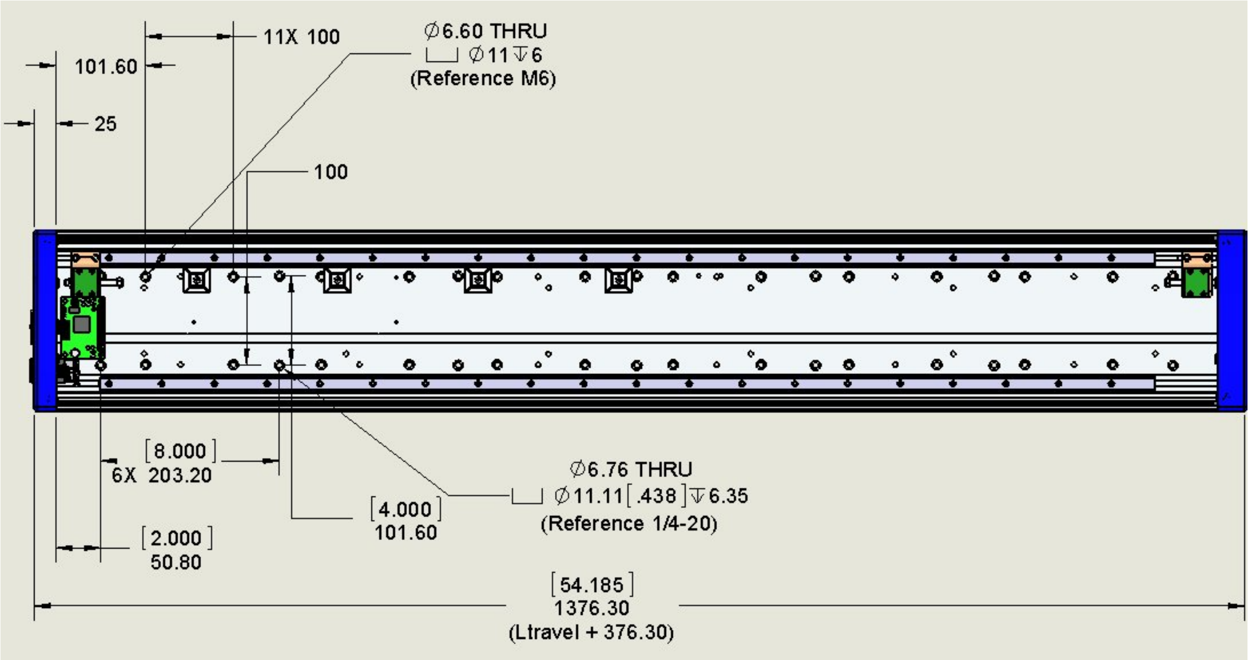


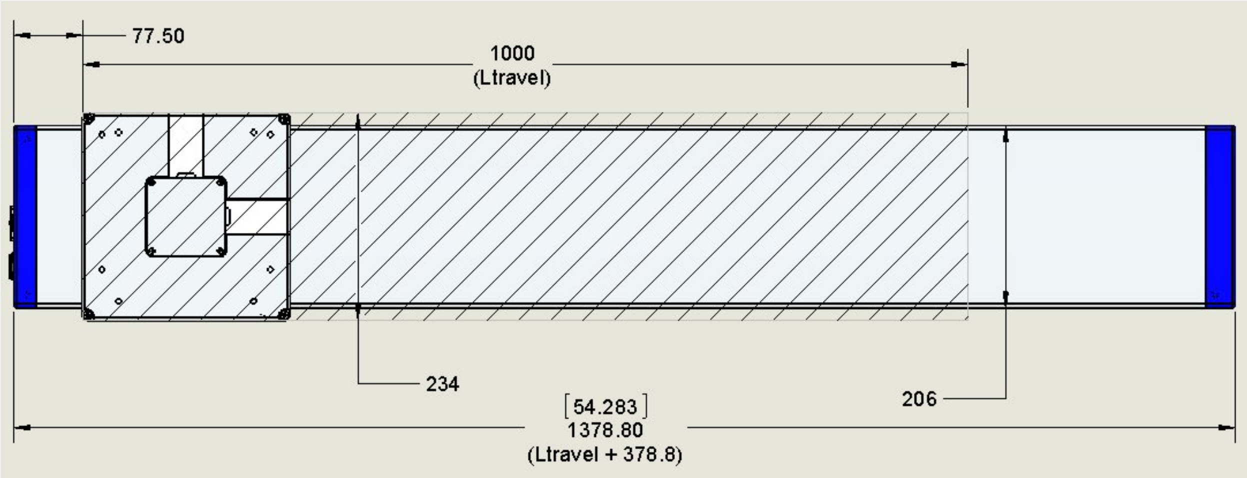


Mounting Details

Linear Axis Mounting Dimensions

If it is desired to use the Precise Linear Axis with the PAVP6, contact application engineering. Special cables and an external 48VDC power supply must be added. This option is not yet released as a standard option. The linear axis has both an M6 and ¼-20 hole pattern inside the extrusion. You must loosen the connector end cap slightly and remove the top cover to access these holes patterns. When replacing the top cover, be sure the tape seals are inside the slot in the top cover and not crushed.





Mounting Instructions

The PAVP6 must be attached to a rigid surface that can withstand lateral forces of 1000 Newtons without moving or vibrating. The robot base has an integrated M10 bolting pattern to accommodate 4 M8 SHCS mounting screws and washers located as shown above. Two M6 locating holes are provided and an M6 dowel and M6 diamond pin are provided with the robot to locate it in these reference holes.

Tool Mounting

The PAVP6 is typically supplied without a gripper. In some cases a pneumatic gripper may be supplied by Precise or by the end user. Four air lines are routed from the facilities panel to the wrist.

To facilitate electrical interfacing to user tooling, 9 user wires are available in the outer link in a Dsub miniature connector. These wires are routed to the Robot IO connector on the facilities panel. The user can then connect these wires to the IO A or IO B connectors.

Accessing the Robot Controller

Although most of the controller interface signals are exposed on the Facilities Panel at the base, there are times when it may be necessary to access either the robot's controller or its power supplies. To access the robot controller, the cover on the bottom of the robot must be removed by removing 8 M3 X 6 FHCS retaining the bottom cover.

In particular changing the IO B signals from their sourcing or sinking default configuration requires removing the bottom cover to access the GIO option board.

Please see the *Guidance Input and Output (GIO) Module Manual*, *Guidance 1000A/B Controller, Hardware Introduction and Reference Manual* for detailed information on hardware configuration and interfacing the controller using the various input and output ports such as those for digital I/O. Also, please refer to the *Guidance System Setup and Operation Quick Start Guide* for information on configuring the PC and instructions on operating the robot. These manuals are available in PDF format and are also contained in the *Precise Documentation Library*.

Power Requirements

The PAVP6 robot contains an auto-ranging power supply that operates between 90 and 264 VAC, 50 or 60Hz. The robot is equipped with an IEC electrical socket that accepts country specific electrical cords. Power requirements vary with the robot duty cycle, but do not exceed 200 watts RMS.

Emergency Stop

It is necessary to wire an Emergency Stop Button to the controller. This button may be wired in series with other emergency stop contacts. The E-stop signals are available in the Pendant 9-pin DSub connector that is mounted on the Facilities Panel. Please see the Hardware Reference section of this manual for detailed information on the E-Stop signals. A jumper plug which connects the Estop signals is provided with the robot for user convenience.

Hardware Reference

System Schematics

System Diagram and Power Supplies

The robot has a 24VDC power supply located in the base. The power supply is fused internally with slow-blow 8A 5X20mm fuses.

The robot controller and all motors are powered by the 24VDC supply. The 24VDC supply is protected against over voltage bus pump up by an energy dump circuit, which connects a 25 Watt dump resistor across the power supply output when the voltage reaches 28 volts, and disconnects the dump resistor when the voltage drops to 26 volts. This protects the power supply during high speed motor deceleration when the motor generates Back EMF voltage that adds to the power supply voltage.

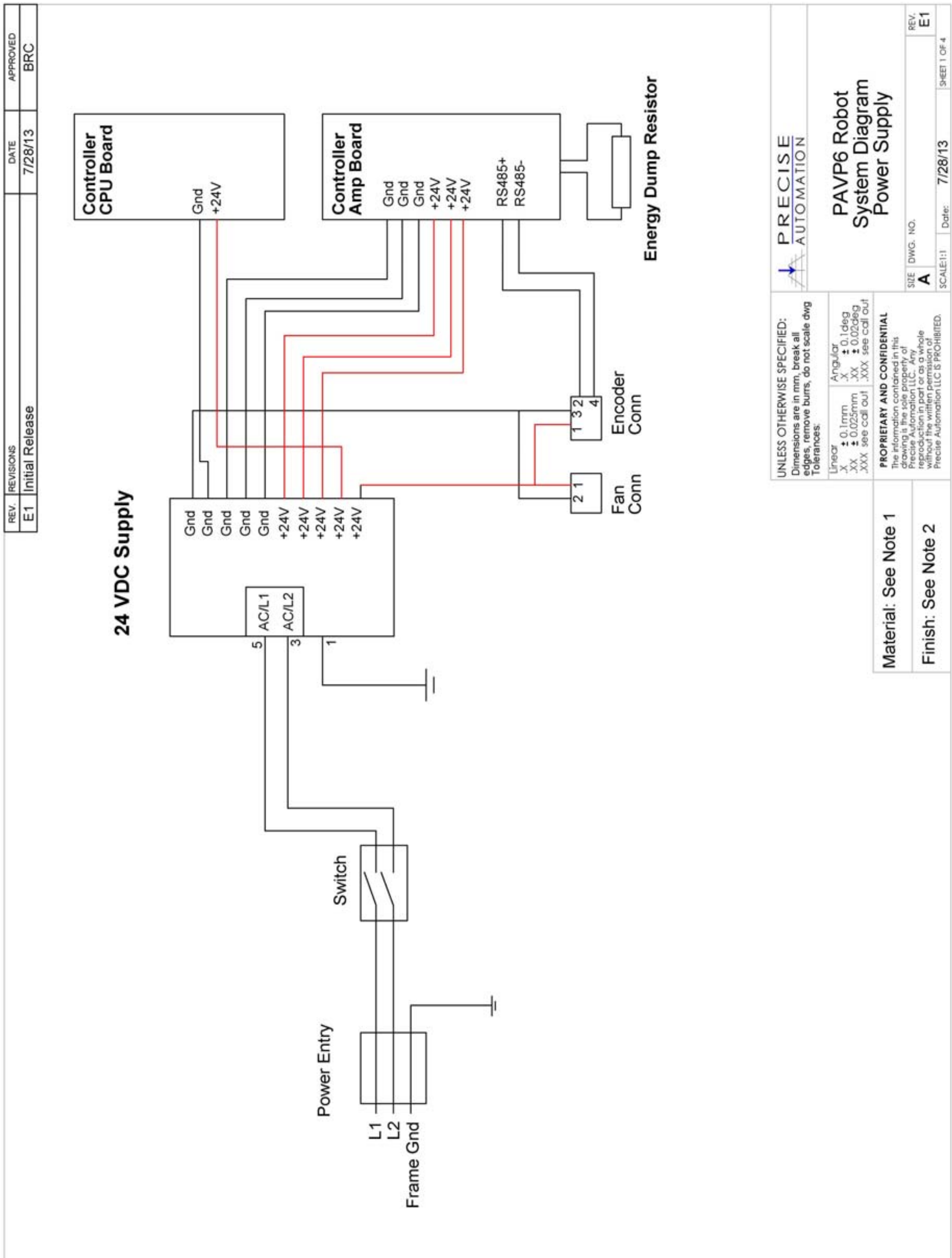
Four digital input and four digital output signals from the main robot controller are connected to the IO A 15 pin Dsub connector on the facilities panel. The ESTOP circuit is connected from the controller to the Pendant connector. The Pendant connector also contains an RS232 serial port. An optional IO board (GIO) provides 12 additional inputs and 8 additional outputs and is connected to the IO B 25 pin Dsub connector on the facilities panel.

An extra encoder input is provided for interfacing a conveyor encoder or other optional encoder to the robot. This is nominally configured as a differential input incremental encoder.

The serial port Dsub contains a proprietary RS485 port for adding extra slave amplifiers or GIO outside the robot. It also contains a user RS232 port.

The brake release button provides a ground return from the brakes to ground bypassing the transistor that performs this function under computer power so that the brake can be released manually without motor power being enabled.

At the time of product introduction the main network connector is 100Mb Ethernet. Faster Ethernet and USB ports may be available in the future.


REV.
REVISIONS
DATE
APPROVED
E1
Initial Release
7/28/13
BRC
Controller CPU Board
Gnd
+24V
Controller Amp Board
Gnd
Gnd
Gnd
+24V
+24V
+24V
RS485+
RS485-
Energy Dump Resistor
24 VDC Supply
Gnd
Gnd
Gnd
Gnd
Gnd
+24V
+24V
+24V
+24V
+24V
AC/L1
AC/L2
5
3
1
1 3 2 4
Encoder Conn
2 1
Fan Conn
Switch
Power Entry
L1
L2
Frame Gnd
UNLESS OTHERWISE SPECIFIED:
Dimensions are in mm, break all edges, remove burrs, do not scale dwg
Tolerances:
Linear .X ± 0.1mm .XX ± 0.025mm .XXX see call out
Angular .X ± 0.1deg .XX ± 0.02deg .XXX see call out
PROPRIETARY AND CONFIDENTIAL
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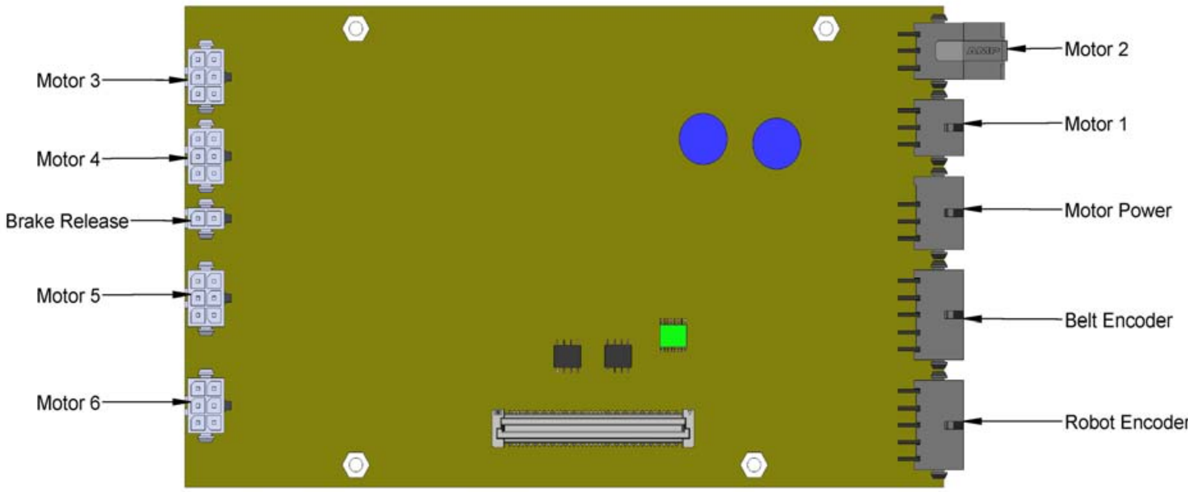
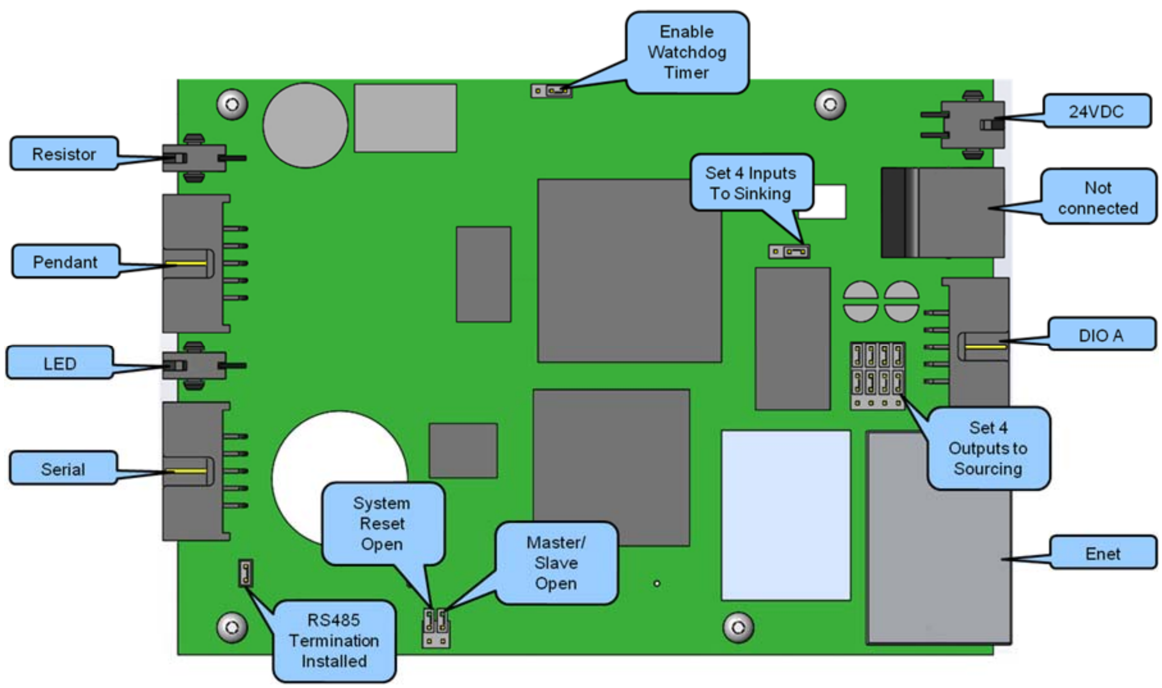
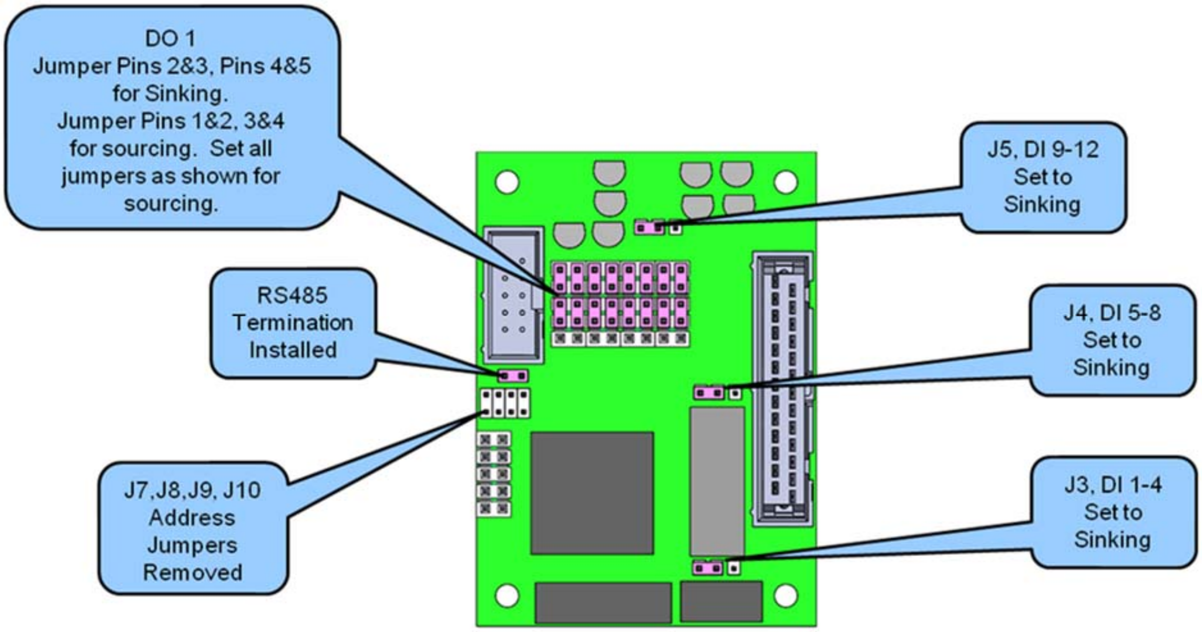
PRECISE AUTOMATION
PAVP6 Robot
System Diagram
Power Supply
SIZE A
DWG. NO.
REV. E1
SCALE:1:1
Date: 7/28/13
SHEET 1 OF 4
Material: See Note 1
Finish: See Note 2



Controller Power Amplifier Connectors

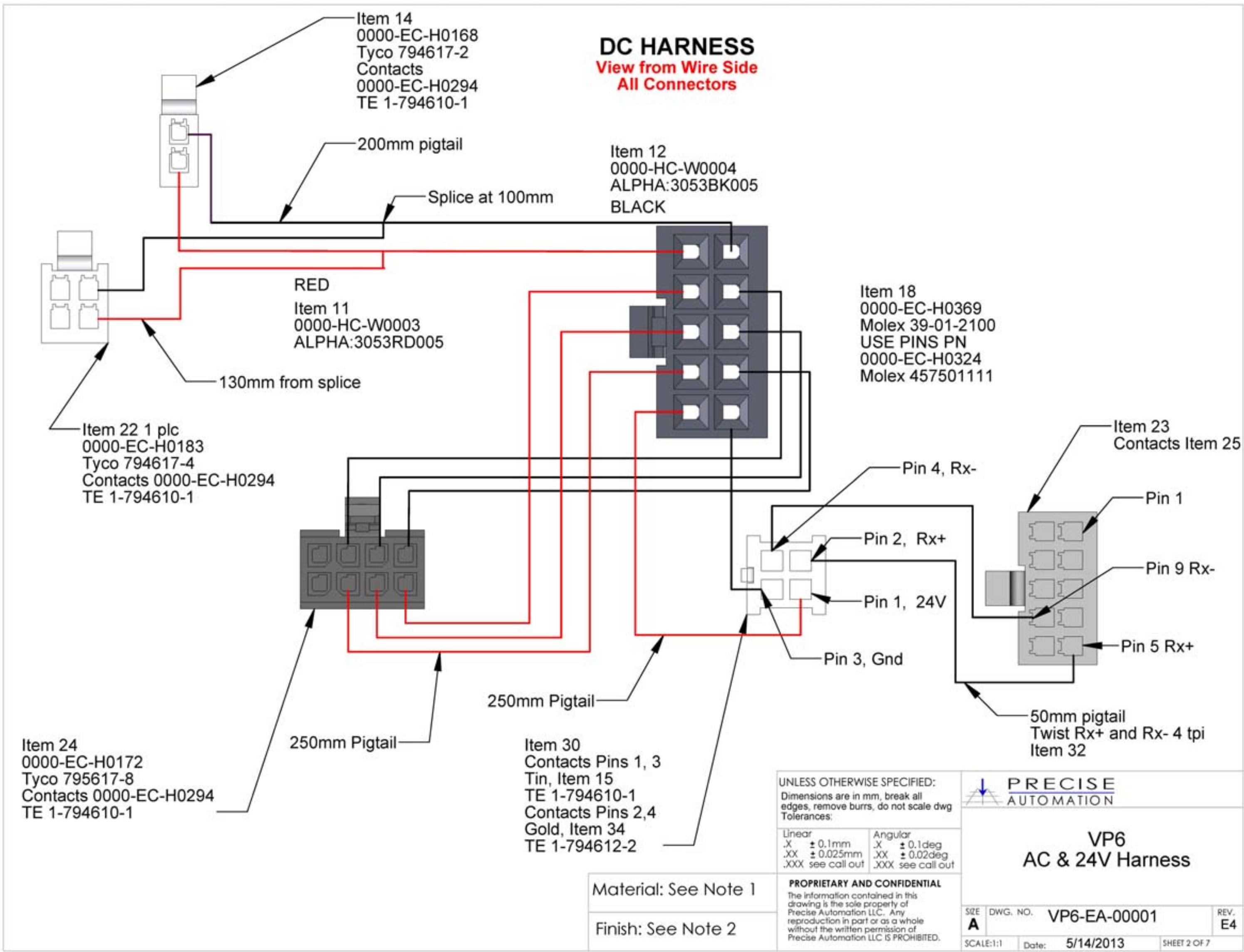


Control Board Connectors



Optional IO Expansion Board (GIO)

(Robot Configuration, Address 8)


DC HARNESS
View from Wire Side
All Connectors
Item 14
0000-EC-H0168
Tyco 794617-2
Contacts
0000-EC-H0294
TE 1-794610-1
200mm pigtail
Splice at 100mm
Item 12
0000-HC-W0004
ALPHA:3053BK005
BLACK
RED
Item 11
0000-HC-W0003
ALPHA:3053RD005
130mm from splice
Item 18
0000-EC-H0369
Molex 39-01-2100
USE PINS PN
0000-EC-H0324
Molex 457501111
Item 22 1 plc
0000-EC-H0183
Tyco 794617-4
Contacts 0000-EC-H0294
TE 1-794610-1
Item 23
Contacts Item 25
Pin 4, Rx-
Pin 1
Pin 2, Rx+
Pin 9 Rx-
Pin 1, 24V
Pin 5 Rx+
Pin 3, Gnd
250mm Pigtail
250mm Pigtail
50mm pigtail
Twist Rx+ and Rx- 4 tpi
Item 32
Item 24
0000-EC-H0172
Tyco 795617-8
Contacts 0000-EC-H0294
TE 1-794610-1
Item 30
Contacts Pins 1, 3
Tin, Item 15
TE 1-794610-1
Contacts Pins 2,4
Gold, Item 34
TE 1-794612-2
UNLESS OTHERWISE SPECIFIED:
Dimensions are in mm, break all edges, remove burrs, do not scale dwg
Tolerances:
Linear
.X ± 0.1mm
.XX ± 0.025mm
.XXX see call out
Angular
.X ± 0.1deg
.XX ± 0.02deg
.XXX see call out
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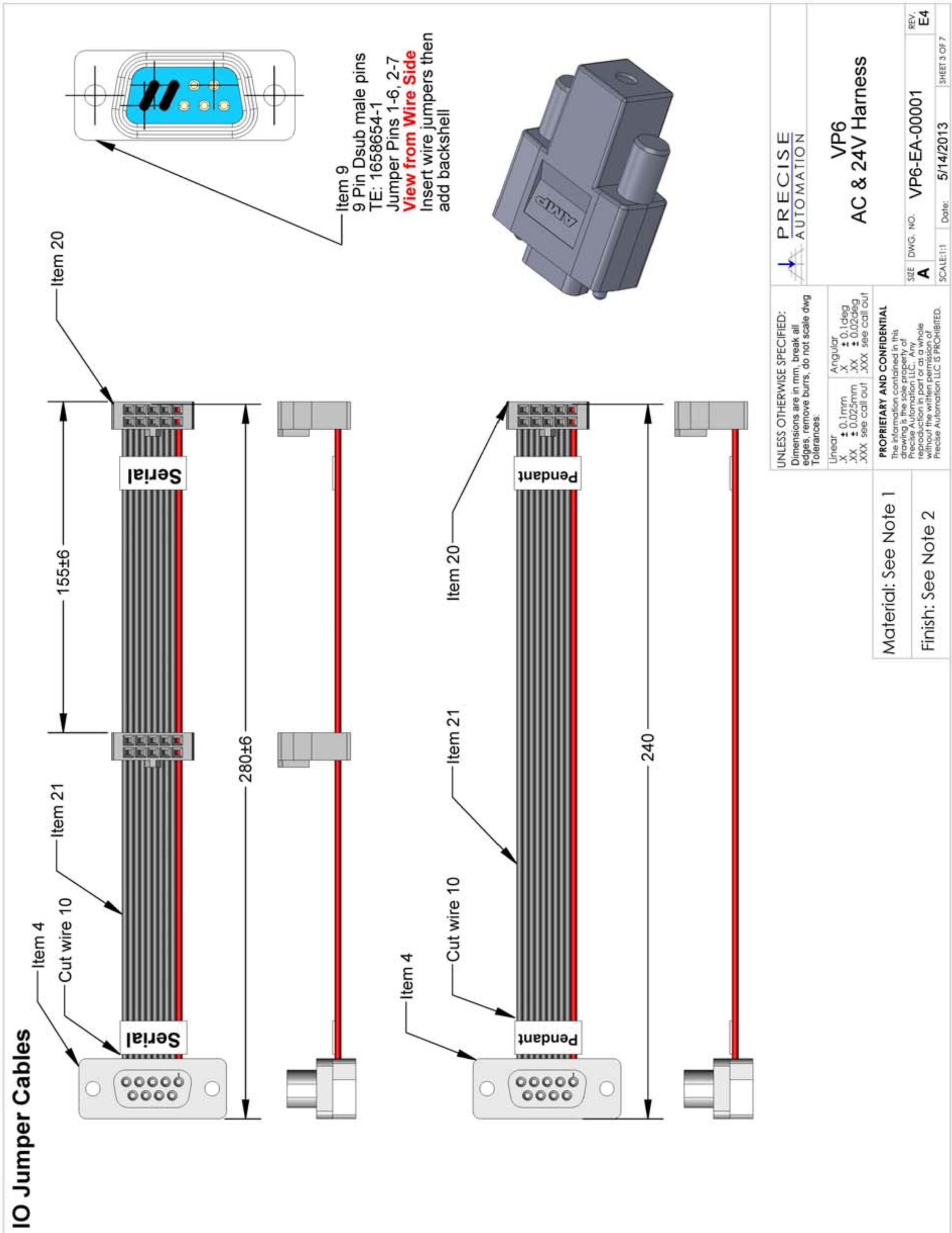
Material: See Note 1
Finish: See Note 2
PRECISE
AUTOMATION
VP6
AC & 24V Harness
SIZE A
DWG. NO. VP6-EA-00001
REV. E4
SCALE:1:1
Date: 5/14/2013
SHEET 2 OF 7


IO Jumper Cables
Item 4
Cut wire 10
Item 21
155±6
Item 20
280±6
Serial
Serial
Item 4
Cut wire 10
Item 21
Item 20
240
Pendant
Pendant
Item 9
9 Pin Dsub male pins
TE: 1658654-1
Jumper Pins 1-6, 2-7
View from Wire Side
Insert wire jumpers then
add backshell
AMP
UNLESS OTHERWISE SPECIFIED:
Dimensions are in mm, break all edges, remove burrs, do not scale dwg
Tolerances:
Linear: .X ± 0.1mm .XX ± 0.025mm .XXX see call out
Angular: .X ± 0.1deg .XX ± 0.02deg .XXX see call out
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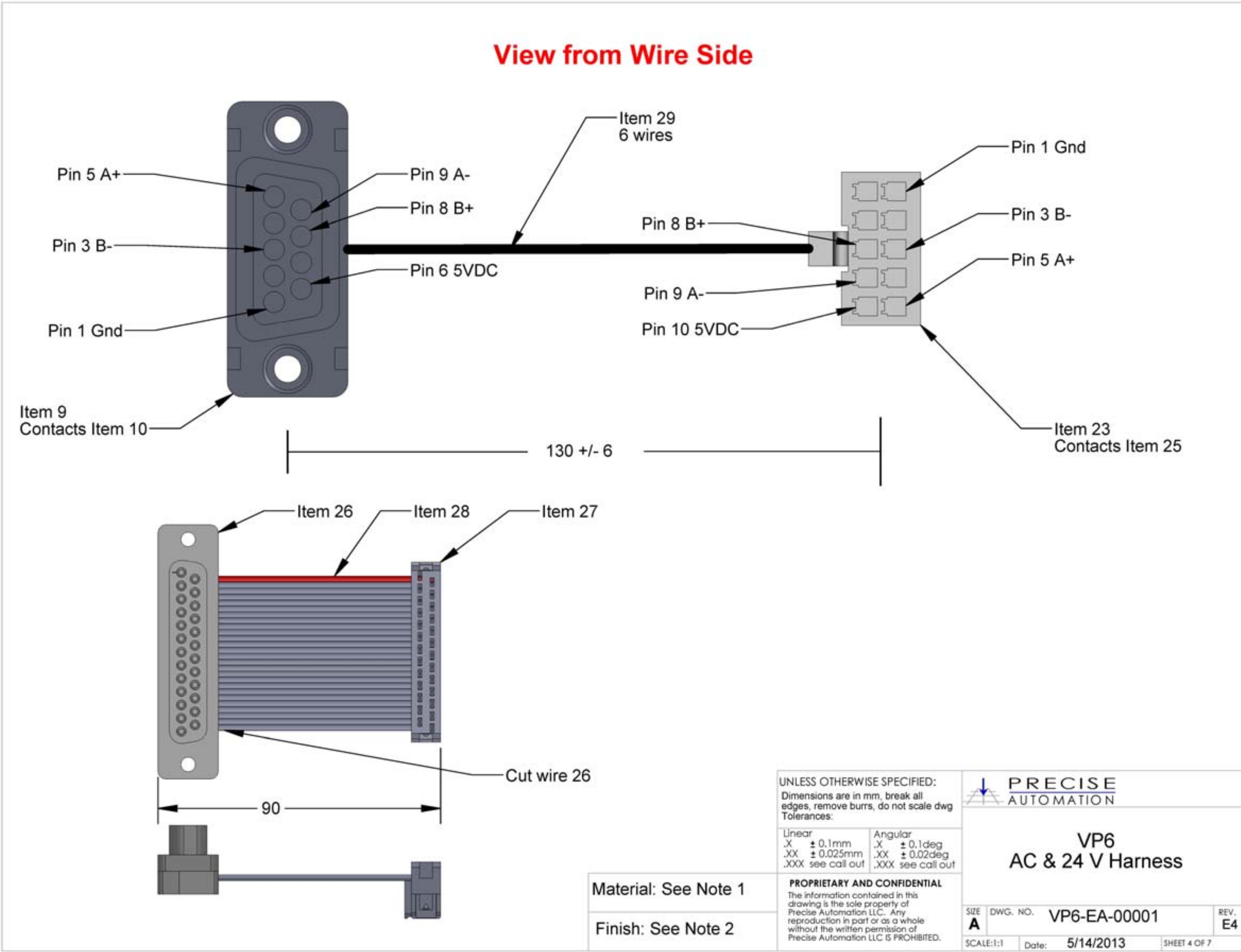
Material: See Note 1
Finish: See Note 2
PRECISE AUTOMATION
VP6
AC & 24V Harness
SIZE A
DWG. NO. VP6-EA-00001
REV. E4
SCALE:1:1
Date: 5/14/2013
SHEET 3 OF 7


View from Wire Side
Item 29
6 wires
Pin 5 A+
Pin 3 B-
Pin 1 Gnd
Pin 9 A-
Pin 8 B+
Pin 6 5VDC
Item 9
Contacts Item 10
Pin 8 B+
Pin 9 A-
Pin 10 5VDC
Pin 1 Gnd
Pin 3 B-
Pin 5 A+
Item 23
Contacts Item 25
130 +/- 6
Item 26
Item 28
Item 27
Cut wire 26
90
Material: See Note 1
Finish: See Note 2
UNLESS OTHERWISE SPECIFIED:
Dimensions are in mm, break all edges, remove burrs, do not scale dwg
Tolerances:
Linear
.X ± 0.1mm
.XX ± 0.025mm
.XXX see call out
Angular
.X ± 0.1deg
.XX ± 0.02deg
.XXX see call out
PROPRIETARY AND CONFIDENTIAL
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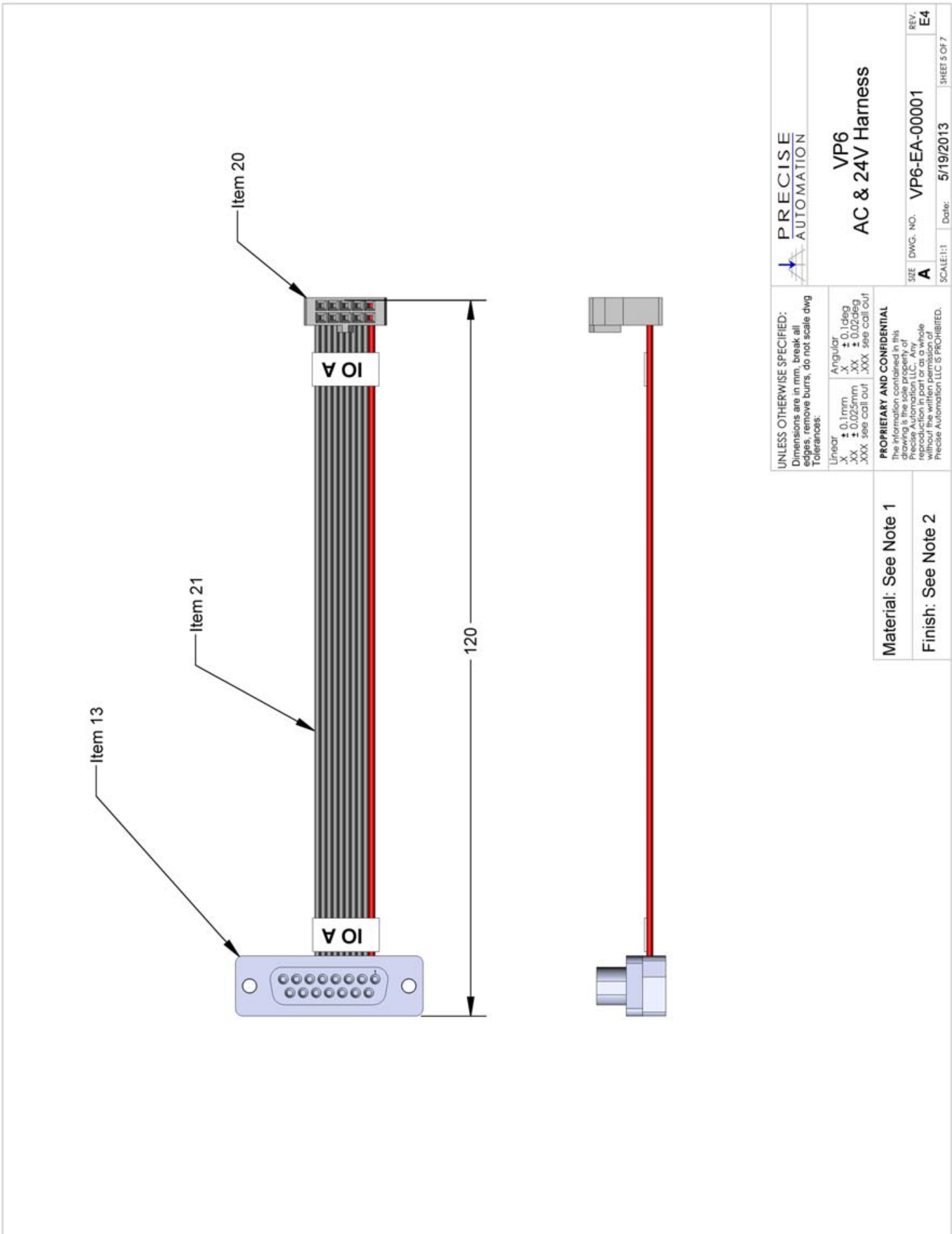
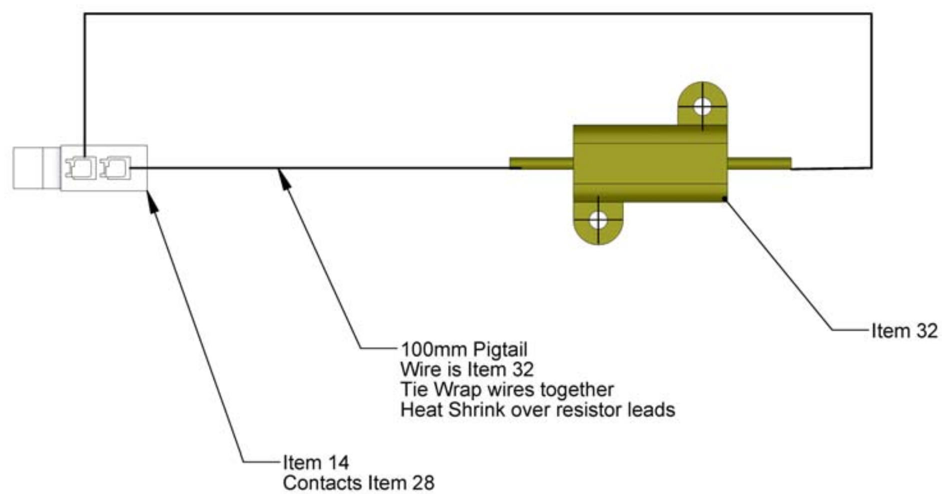
PRECISE
AUTOMATION
VP6
AC & 24 V Harness
SIZE A
DWG. NO. VP6-EA-00001
REV. E4
SCALE:1:1
Date: 5/14/2013
SHEET 4 OF 7


Item 13
Item 21
Item 20
IO A
IO A
120
UNLESS OTHERWISE SPECIFIED:
Dimensions are in mm, break all edges, remove burrs, do not scale dwg
Tolerances:
Linear
.X ± 0.1mm
.XX ± 0.025mm
.XXX see call out
Angular
.X ± 0.1deg
.XX ± 0.02deg
.XXX see call out
PROPRIETARY AND CONFIDENTIAL
The information contained in this drawing is the sole property of Precise Automation LLC. Any reproduction in part or as a whole without the written permission of Precise Automation LLC IS PROHIBITED.
PRECISE AUTOMATION
VP6
AC & 24V Harness
SIZE A
DWG. NO. VP6-EA-00001
REV. E4
SCALE:1:1
Date: 5/19/2013
SHEET 5 OF 7
Material: See Note 1
Finish: See Note 2

View from Wire Side



Material: See Note 1

Finish: See Note 2

UNLESS OTHERWISE SPECIFIED:
Dimensions are in mm, break all edges, remove burrs, do not scale dwg
Tolerances:

Linear		Angular	
.X	± 0.1mm	.X	± 0.1deg
.XX	± 0.025mm	.XX	± 0.02deg
.XXX	see call out	.XXX	see call out

PRECISE AUTOMATION

VP6
AC & DC Harness

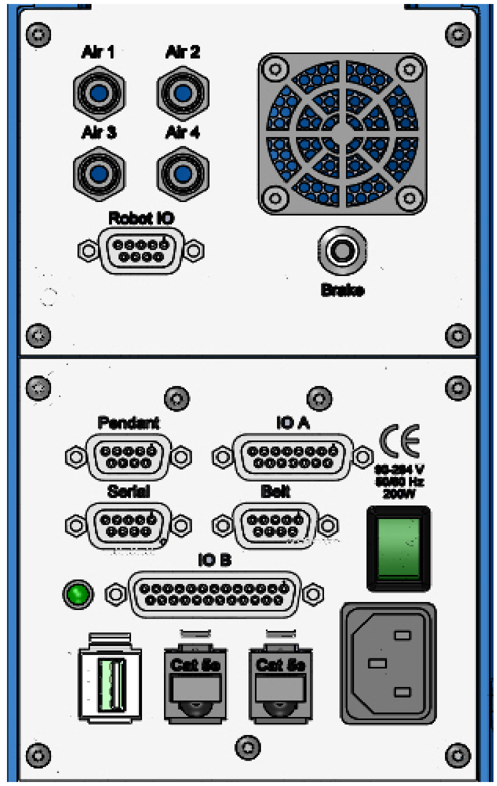
SIZE A | DWG. NO. VP6-EA-00001 | REV. E4

SCALE:1:1 | Date: 5/15/2013 | SHEET 6 OF 7

Facilities Panel

The Facilities Panel is located at the base of the robot.

Item	Description
Air 1-4	Air lines routed to wrist
Brake	Brake Release
Robot IO	9 wires to wrist
USB	(NA, Future Option)
Enet	Enet Connector
Pendant	Teach Pendant or EStop
LED	Blinks to show status
IO A	4 Inputs 4 Outputs
IO B	12 Inputs, 8 Outputs
Serial	RS485, 24V Power
Belt	Belt Encoder Input



To simplify interfacing, most of the electrical interfaces provided by the robot's embedded Guidance Controller are available on the Facilities Panel. These include:

- Digital input signals
- Digital output signals
- Ethernet port
- Remote Front Panel / MCP / E-Stop
- RS-232 serial interface
- Belt Encoder interface

Each of these interfaces is described in detail in the following sections. Please refer to the *Guidance 1000A/B Controllers, Hardware Introduction and Reference Manual and Guidance Input and Output (GIO) Module* for additional information.

DANGER: The 24 VDC power supply is an open frame electrical device that contain unshielded high voltage pins, components and surfaces. **The main AC power should always be disconnected before the Facilities Panel or bottom cover is removed.**

Air Lines. Four air lines are routed from the wrist to M4 tube fittings in the facilities panel. There are no air control solenoid valves inside the robot. These must be added by the user. When using these lines, clean, dry external air should be provided.

User wires. Nine user wires are routed from the “Robot IO” 9 pin Dsub connector to a similar connector on the wrist. These wires may be connected to the IO connectors to provide inputs and outputs for end effectors.

> ⚠ **CAUTION:** The maximum air pressure that can be conveyed by the air lines through the robot is **71 PSI**. Applying a pressure exceeding this level may disconnect interior connections or damage fittings or hoses. If a higher pressure is required, an external air line should be utilized.

MCP / E-Stop Interface

The MCP interface includes the signals necessary to connect a Manual Control Pendant, or external E-Stop circuit. These signals are provided in a DB9 female connector mounted on the robot’s Facilities Panel, and on the end cap of the optional Linear Axis.

An E-Stop box or circuit can be plugged into the Pendant connector. In order for the robot to allow motor power to be enabled the E-Stop circuit must connect the FORCE_ESTOP_L1 and FORCE_ESTOP_L2 signals to E-Stop1 AND E-Stop 2 in this connector. If no E-Stop box or circuit is connected, then both circuits must be completed with jumper plugs. (The robot is shipped with a Dsub jumper plug that satisfies these requirements.) See Harness Schematic Sheet 3 for details on this jumper plug.

If a Manual Control Pendant is not connected to the secondary RS-232 port provided in this connector, this serial interface can be accessed via a GPL procedure as device "/dev/com2" for general communications purposes. Please note that unlike the primary serial interface, THIS SECONDARY SERIAL INTERFACE DOES NOT SUPPORT FLOW CONTROL.

Pin	Pendant 9 Pin Dsub Signal Description
1	ESTOP_L1
2	ESTOP_L2
3	RS232 RXD
4	24VDC
5	Keying Plug
6	FORCE_ESTOP_L1 (Toggles ESTOP Low at Start Up, Then High)
7	FORCE_ESTOP_L2 (Toggles ESTOP Low at Start Up, Then High)
8	RS232 TXD
9	GND
Interface Panel Connector Part No	DB9 Female Connector AMP 5747150-7
User Plug Part No	DB9 Male Plug Amp 1658654-1 (crimp) Pins 22-26AWG 745253-6

Serial

The RS485 port is available on the Serial connector and is used for the GIO expansion option, and can be used to add additional GIO or GSB (slave amplifier boards) outside the robot. As such it has a dedicated protocol and is not available for general use. The RS232 primary use line is available in this connector. This port is used as the serial console port and can also be accessed by GPL procedures as device /dev/com1.

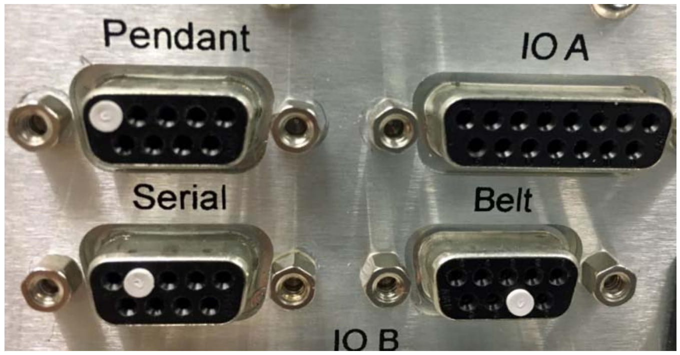
Pin	Serial Port 9 Pin Dsub Signal Description
1	24VDC
2	RS232 RXD
3	GND
4	Keying Plug
5	RS485-
6	24VDC
7	RS232 TXD
8	5VDC
9	RS485+
Interface Panel Connector Part No	DB9 Female Connector AMP 5747150-7
User Plug Part No	DB9 Male Plug Amp 1658654-1 (crimp) Pins 22-26AWG 745253-6

Belt (Conveyor Encoder)

The Belt connector is used to interface an external encoder to the controller. This external encoder may be used for conveyor tracking or for other synchronous purposes. This interface is configured for a 5 VDC differential encoder with A+, A-, B+ and B- inputs. The zero index input is not supported. In order to enable the conveyor tracking in GPL, a software license is required. If the robot has not been configured with an additional "encoder only" module please contact Precise Automation for the appropriate files. Once these have been loaded you will need to change data ID 10203: Encoder counts for resolution calc, ecnt. This should be set to the number of encoder counts per/revolution of the belt encoder.

Pin	Serial Port 9 Pin Dsub Signal Description
1	Gnd
2	NC
3	B-
4	NC
5	A+
6	5VDC
7	Keying Plug
8	B+
9	A-

Interface Panel Connector Part No	DB9 Female Connector AMP 5747150-7
User Plug Part No	DB9 Male Plug Amp 1658654-1 (crimp) Pins 22-26AWG 745253-6

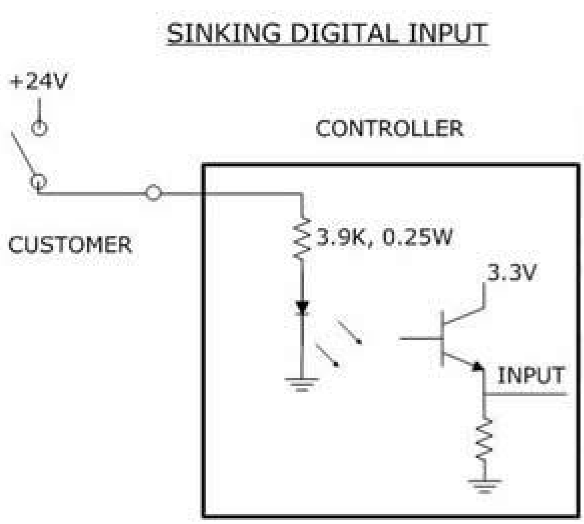


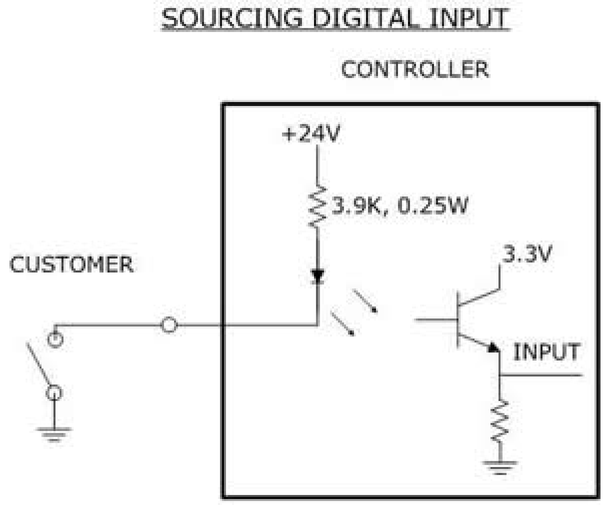
Keying Plugs in 9 Pin D-Sub Connectors

Digital Input Signals

The standard PAVP6 robot provides 4 general-purpose optically isolated digital input and 4 general-purpose optically isolated digital output signals at the Facilities Panel at connector IO A, which is a 15 pin Dsub.

The input signals can be configured as "sinking" or "sourcing". If an input signal is configured as "sinking", the external equipment must pull its input high to 5VDC to 24VDC to indicate a logical high value or must allow it to float to no voltage for a logical low. This input is configured at the factory as "sinking". All four digital inputs can be configured as a block to "sourcing" by moving the jumper shown on page 18 on the CPU board to "sourcing". However as the controller is not very accessible in the base housing, most users will use the factory "sinking configuration" for these four inputs. Additional optional inputs are available with the GIO option below, and are easily accessed to change from sinking to sourcing.

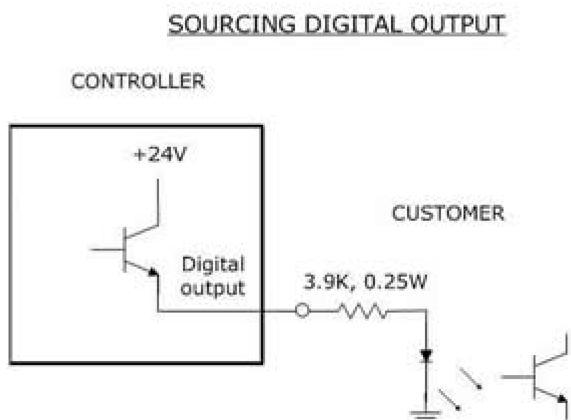




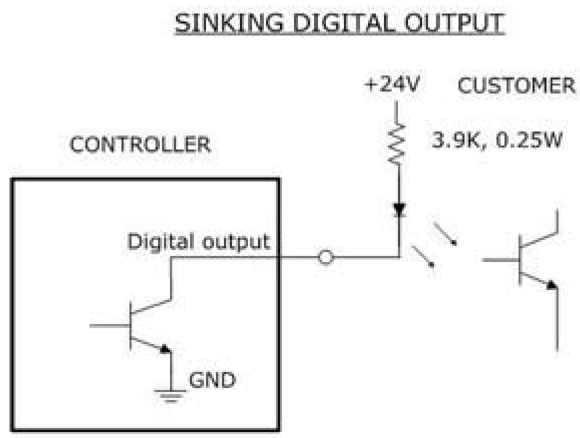
Digital Output Signals

The PAVP6 robot provides 4 general-purpose optically isolated digital output signals at the IO A connector, which is a 15 pin Dsub.

These output signals can be configured as "sinking" or "sourcing". ***As shipped from the factory, the output signals are configured as "sourcing"***, i.e. the external equipment must provide a ground return and the controller provides 24 VDC to the digital output when the signal is asserted as true.



Alternately, the output signals can be configured as "sinking", i.e. the external equipment must provide 24 V and the controller pulls this pin to ground when the signal is asserted as true.



Outputs can be individually configured as sinking or sourcing signals. However as the controller is not easily accessible most users will use factory configuration of sourcing for these outputs. For more information on configuring the jumpers, please see the *Guidance 1000A/B Controllers, Hardware Introduction and Reference Manual.*

The pin out for the G1400B Digital Input and Output Connector and the corresponding GPL signal numbers are described in the following table.

Pin	GPL Signal Number	IOA Digital IO Signal Description
1	13	Digital Output 1
9	14	Digital Output 2
2	15	Digital Output 3
10	16	Digital Output 4
3		GND
11		24 VDC output
4	10001	Digital Input 1
12	10002	Digital Input 2
5	10003	Digital Input 3
13	10004	Digital Input 4
User Plug Part No		AMP 1658656-1 (crimp) Pins 22-26AWG 745253-6, or Molex 22-55-2101 or 90142-0010. For the Molex plug, use Molex sockets 16-02-0103 or 90119-2110 and Molex crimp tool 63811-1000.

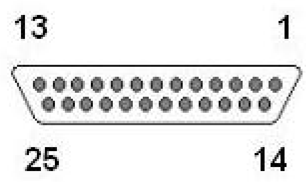
Optional RS485 Remote IO Module (GIO)

Customers who need additional digital IO may order the RS485 Remote IO Module. This module installs in the base of the robot and provides 12 Digital Inputs and 8 Digital Outputs at IO B in a 25 pin Dsub connector. Two inputs, 11 and 12, can be optionally configured as analog inputs by means of jumpers J1 and J2. Connecting J1 to pins 1 and 2 (default) configures these inputs as digital and connecting pins 2 and 3 configures them as analog (if the analog option has been installed).

The RS485 Remote IO Module (GIO) provides 12 general-purpose optically isolated digital input signals and 8 general-purpose optically isolated digital output signals. These input and output signals are intended for interfacing to tooling and sensors or for general application needs. This board is connected to the controller by an RS485 serial line that allows the controller to scan the GIO I/O with a nominal period of 4 milliseconds.

The DIO signal addresses are determined by a base address set by a DIP switch on the DIO board. For the PAVP6 robot without the linear axis option the DIO option is located at the robot connector panel and for this location all the address jumpers will NOT be installed, which sets the address of this module to “8”. This address avoids conflicts with other RS485 network controllers for the optional linear axis. When installing the GIO in the linear axis, the address jumpers will be set to “7” to avoid any conflict with a GIO in the robot. See “Installing the optional G IO Board” under Service Procedures for details on installing this module.

The software addresses will then be as follows for base address 8.

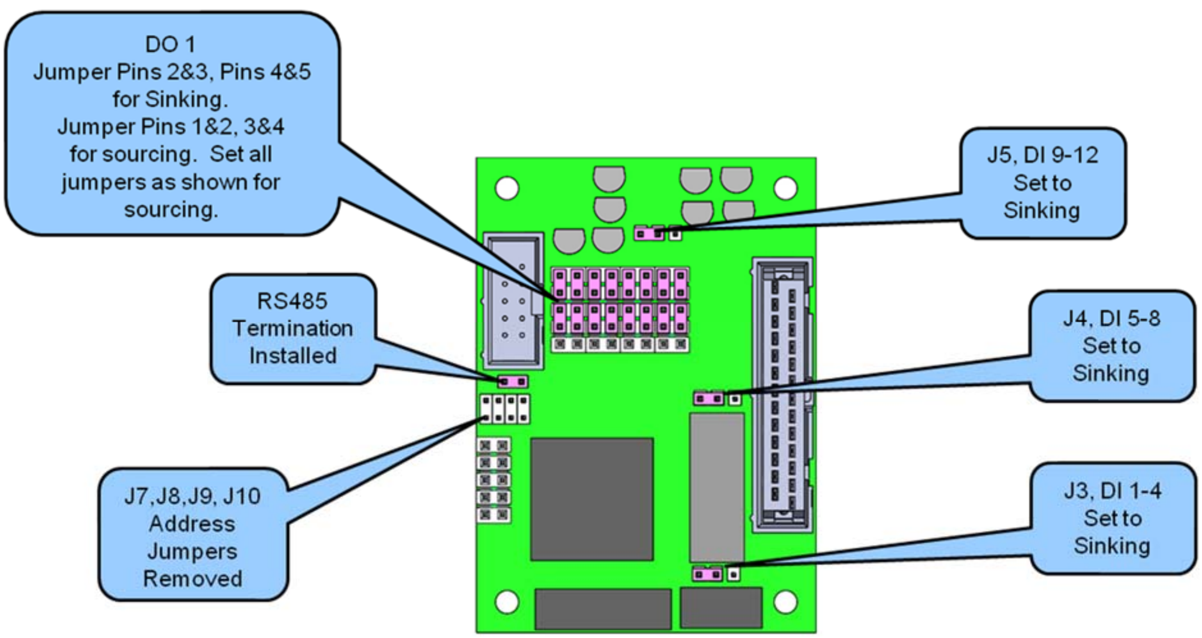


DB25 Female

Pin	GPL Signal Number	Description
1		Gnd
2	810001	Digital Input 1
3	810003	Digital Input 3
4	810005	Digital Input 5
5	810007	Digital Input 7
6	810009	Digital Input 9
7	810011	Digital Input 11
8		24VDC
9	800013	Digital Output 1
10	800015	Digital Output 3
11	800017	Digital Output 5
12	800019	Digital Output 7
13		24VDC
14		Gnd
15	810002	Digital Input 2
16	810004	Digital Input 4

17	810006	Digital Input 6
18	810008	Digital Input 8
19	810010	Digital Input 10
20	810012	Digital Input 12
21		24VDC
22	800014	Digital Output 2
23	800016	Digital Output 4
24	800018	Digital Output 6
25	800020	Digital Output 8
Interface Panel Connector Part No		DB25 Female Connector
User Plug Part No		DB25 Male Plug AMP 1658658-1 (crimp) Pins 22-26AWG 745253-6

The inputs can be set as sourcing or sinking in banks of four. The outputs can be individually set as sourcing or sinking. It is possible to access the optional GIO board by removing the bottom cover of the robot base. The factory default is sinking for the inputs and sourcing for the outputs. If an additional GIO or GSB board is installed outside the robot, the RS485 termination jumper must be removed on this board and installed in the last board on the RS485 serial chain.



Ethernet Interface and Default IP Address

Precise robots include an Ethernet switch that implements two 10/100 Mbit Ethernet ports. This capability was designed to permit the controller to be interfaced to multiple Ethernet devices such as other Precise controllers or robots, remote I/O units and Ethernet cameras. The Ethernet switch automatically detects the sense of each connection, so either straight-thru or cross-over cables can be used to connect the controller to any other Ethernet device.

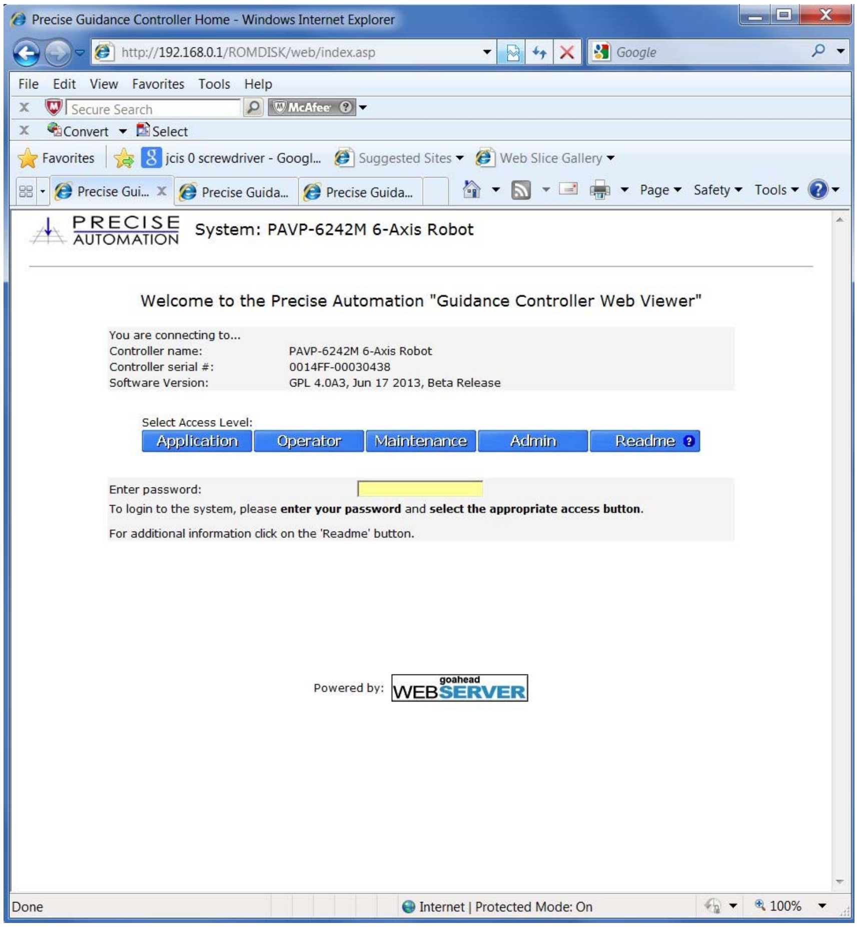
See the *Setup and Operation Quick Start Guide* for instructions on setting the IP address for the controller. The factory default IP address is 192.168.0.1.

Software Reference

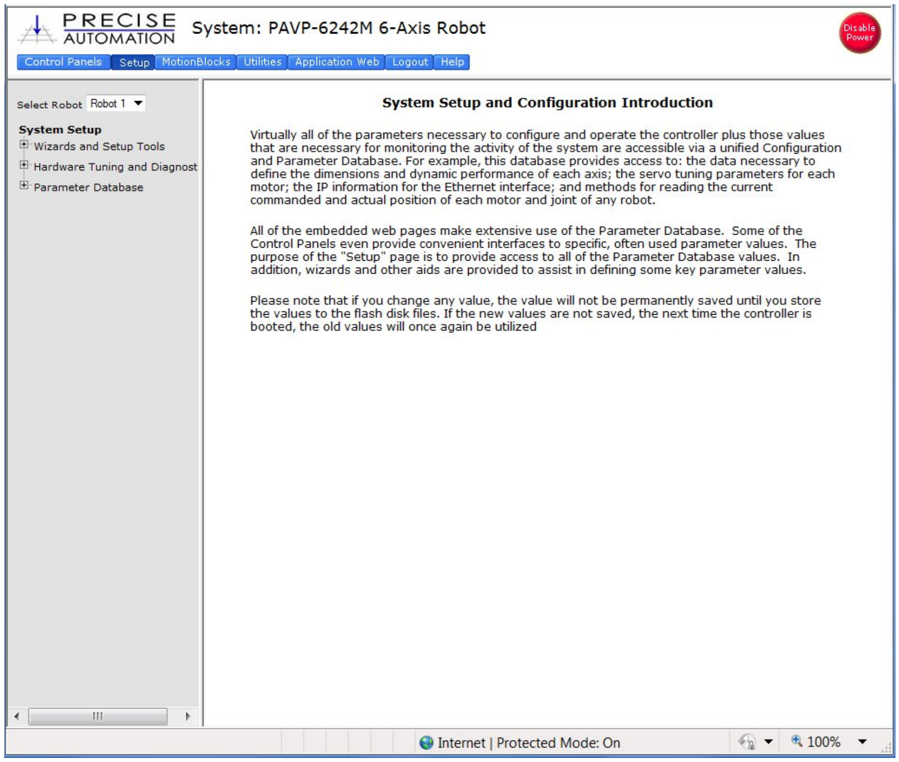
Accessing the Web Server

Many OEM customers run the PAVP6 using a PC to provide an application-specific operator interface. In order to update software in the controller, and view certain error messages, it is necessary to access the Web Server Interface embedded in the controller.

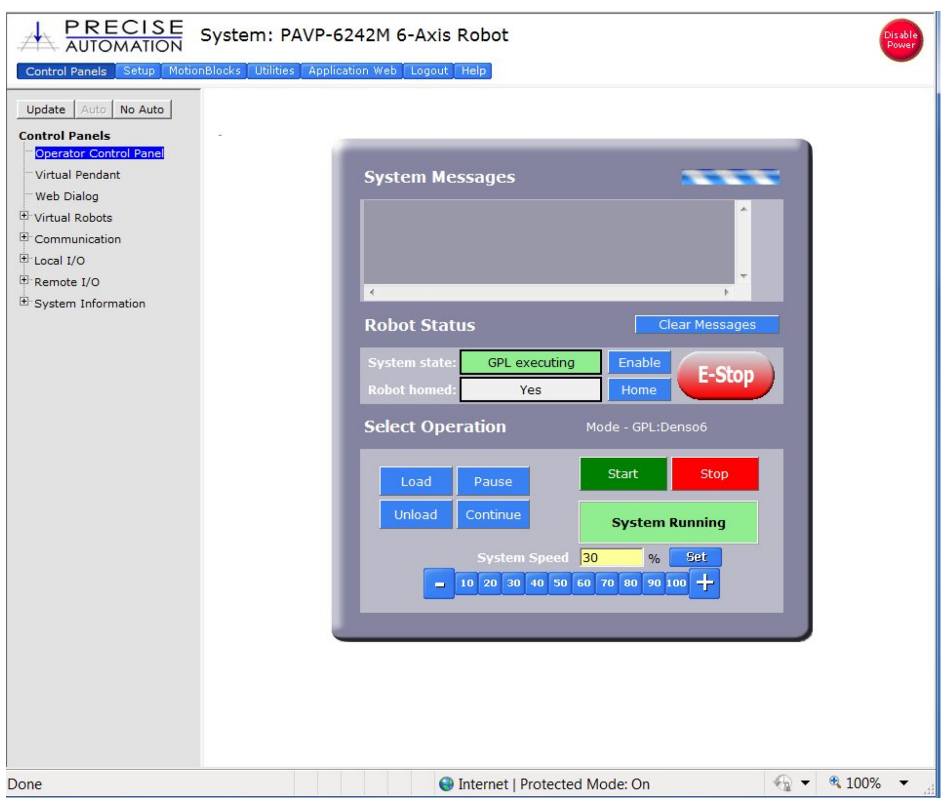
The Web Server Interface may be addressed by opening a browser (such as Internet Explorer) in a PC or other device that is connected to the robot via Ethernet. You must know the IP address of the robot controller. Two common IP addresses are 192.168.0.1 and 192.168.0.10. The PC LAN interface address must be configured correctly (for example 192.168.0.100, with subnet mask 255.255.255.0). The Web Server Interface will come up with the window below.



It may be necessary to enter a password if your company has protected access to the Web Interface. Once the password has been entered, click on "Admin" to access all the features to perform system upgrades. The window below will open up.



Click on “Control Panels”, then “Operator Control Panel”. The window below will appear.



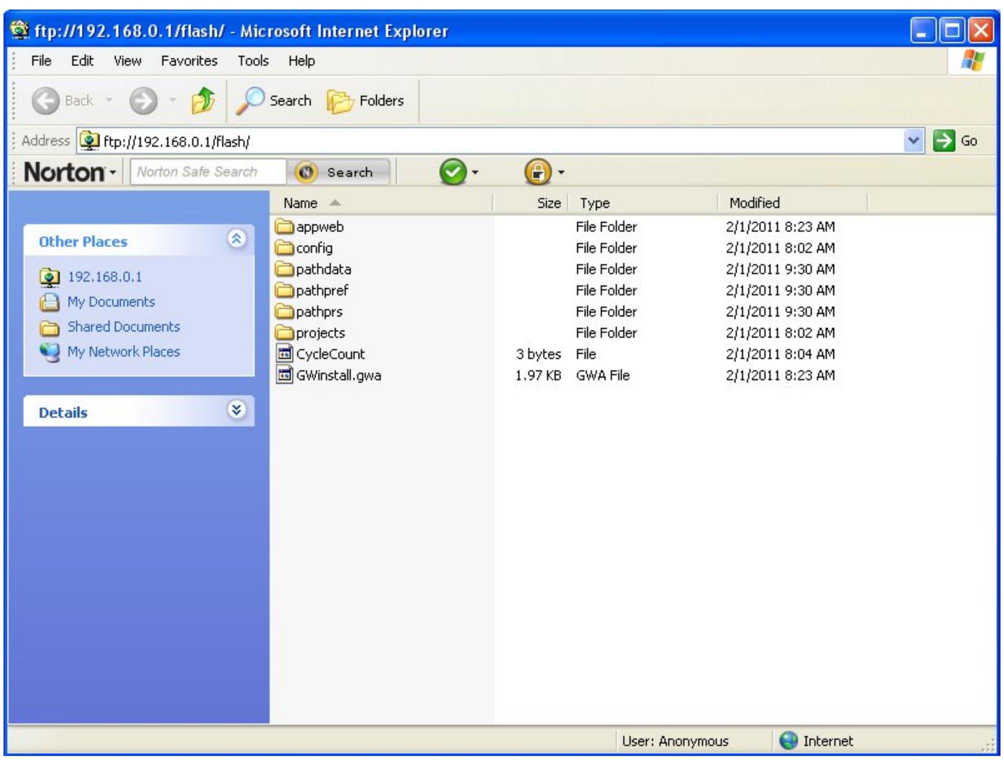
If an application is running, the “System Running” panel will display in green. In order to run diagnostics, you must stop the application from running. Click “Stop Application” and then “Perform Operation”. This will stop the application from running. You should click the “Disable Power” button to be sure motor power is off. If you need to load a new project (for example CAL_PP) you will need to click on “Unload” before you can load the new project into RAM.

You may now perform the procedures below.

Loading a Project (Program) or Updating PAC Files

If CAL_PP or a different program needs to be loaded into the controller from an external computer, this may be done using the Web Interface.

1. In the Web Based Operator Interface, select “Utilities/Backup and Restore
2. Click on Start File Manager. It may be necessary to hold down the Control Key to allow the pop-up. An ftp directory pop-up will come up. In the “Page” menu in Windows Internet Explorer select “Open ftp site in Windows Explorer”. Another window will open showing several folders, including “Config” and “Projects”.



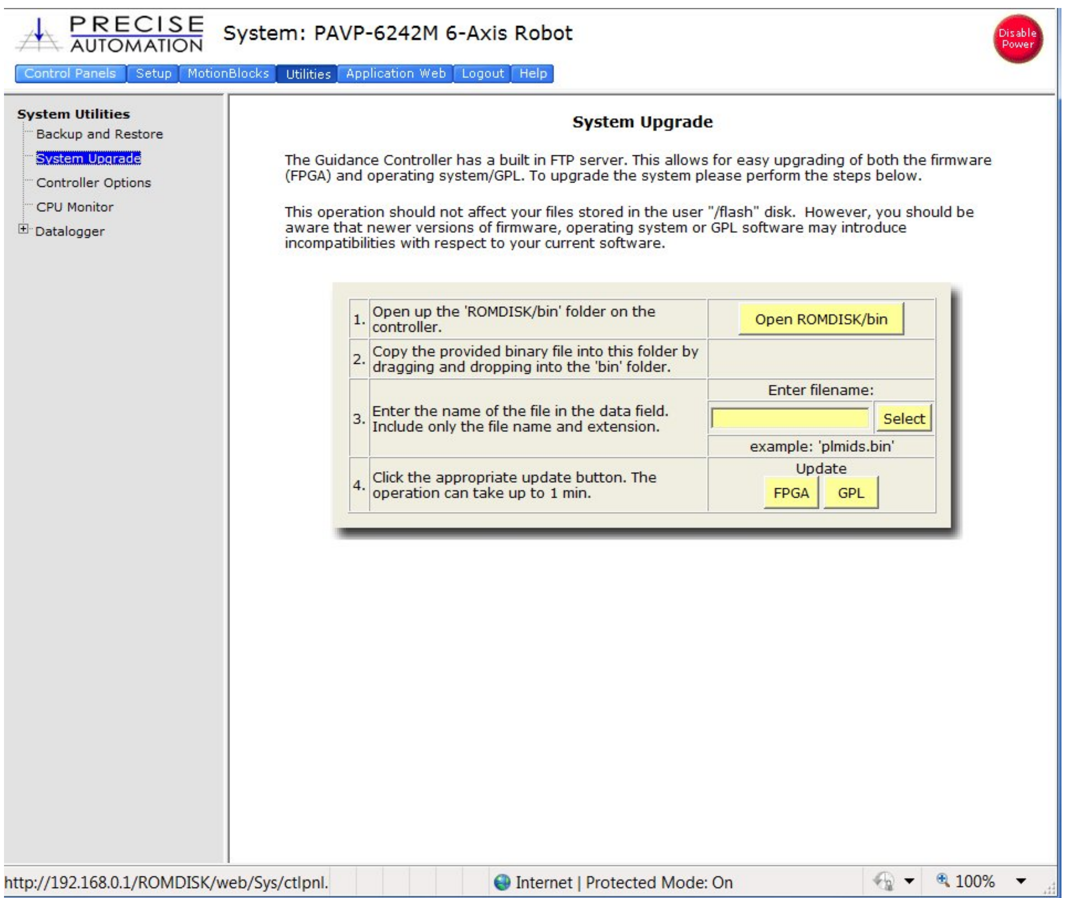
3. To load a Project, Open the “Projects” folder and paste the Project folder into this area. There may be several other projects (programs) loaded into this folder, which is stored in flash ram in the controller. A project folder is a software folder than may have several files inside it. You must load the entire folder, not just the files inside.
4. To load or update PAC files, open the “Config” folder and paste a backup copy of the PAC files into the “Config” folder. These files will all have a **.pac** extension. The robot must be re-booted after new PAC files are installed for them to take effect.

5. Once the appropriate project (for example CAL_PP) has been loaded into flash memory, it must then be loaded into dynamic memory in order to execute. See the section below on “Calibrating the Robot” for an example on how to load and execute the CAL_PP program.

Updating GPL (System Software) or FPGA (Firmware)

Both GPL (the system software) and the FPGA firmware may be upgraded in the field. To perform an upgrade:

1. Obtain the appropriate upgrade software from Precise, in the form of a .bin file.
2. In the Operator Interface, go to the Utilities/System Upgrade menu.



3. Click on Open ROMDISK/bin. This will open an FTP window. You will need to select “page” in Internet Explorer and scroll to the bottom of the page menu and click “Open site in Windows Explorer”. This will open a second ftp window in Windows. Paste the appropriate GPL or FPGA .bin file in this window.
4. Under item 3 in the System Upgrade menu, click on the Select button. A pick list will open up. Highlight the upgrade code in this pick list and click on the Select button again. The name of the file will appear in the filename field.

5. Then in step 4 in the menu click on either FPGA or GPL to upgrade the appropriate file. The banner in the Upgrade menu will start flashing for about 10 seconds while the flash RAM is being written with the new file. Wait about 10 additional seconds after this banner stops flashing, then reboot the robot, and the new code will be installed.

Recovering from Corrupted PAC Files

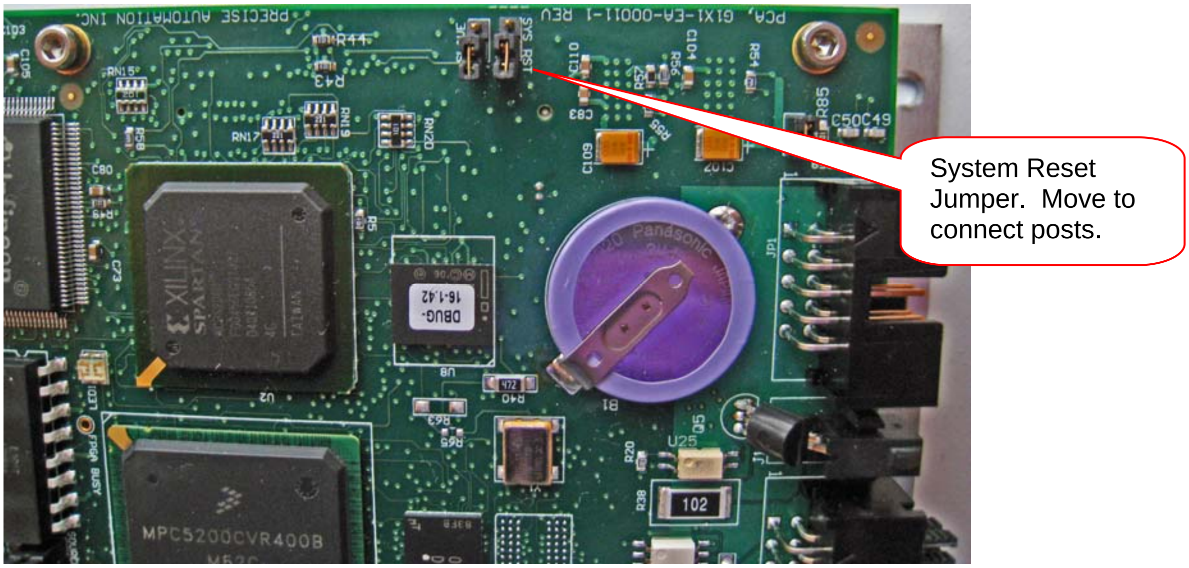
PAC files are configuration files that determine the configuration of the robot for the software, including the robot factory calibration data. These files are stored in Flash RAM. Flash RAM is also used to store robot programs. The Flash RAM requires some time for a complete write cycle. During the write cycle, the console will display a flashing warning not to turn off robot power. If robot power is turned off during the Flash RAM write cycle, the Flash data may be lost or corrupted. If this happens, it is necessary to reload both the robot PAC files and any user programs that were stored in Flash RAM. This problem should typically not be encountered by a user unless the user is changing configuration files in the robot.

Precise maintains a record of PAC files shipped with each robot Serial Number. If the PAC files have been corrupted, it is possible to get a back up copy from Precise. The backup copy will contain the factory configuration and calibration data, but will not contain any changes, including any new calibration data, made after the robot has left the factory.

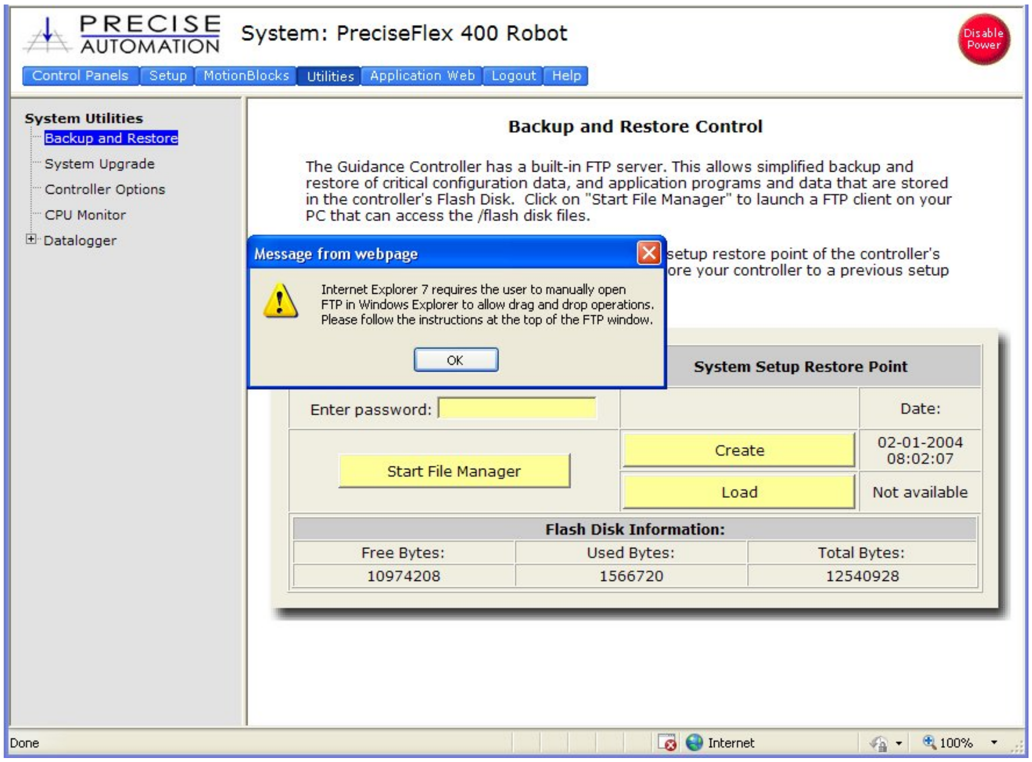
In order to allow the controller to recover from corrupted PAC files, a set of recovery boot up PAC files is loaded in a the system area of the Flash.

To configure the controller to boot up in recovery mode the user must:

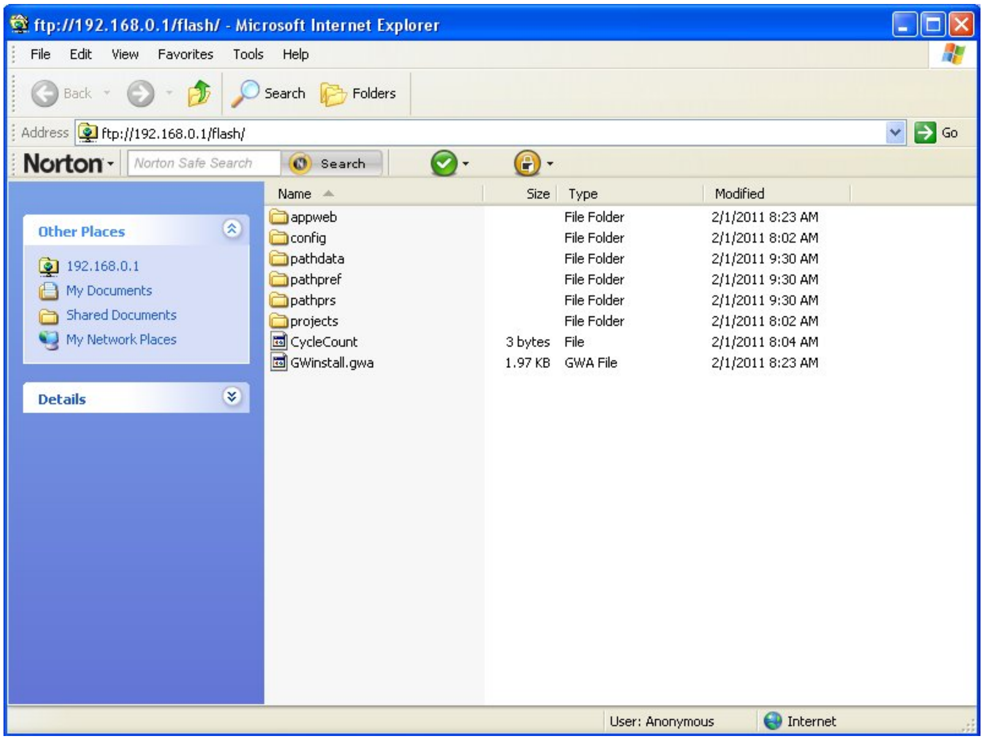
1. Obtain a set of backup PAC Files from Precise or local backup.
2. Remove the bottom cover from the robot and remove the controller chassis as described under “Replacing the Robot Controller”.
3. Remove the power supply chassis. This will expose the controller CPU board.
4. Move Jumper J8 (see figure below) so that it connects the two jumper posts. This will cause the factory default configuration files to be loaded at controller boot up.



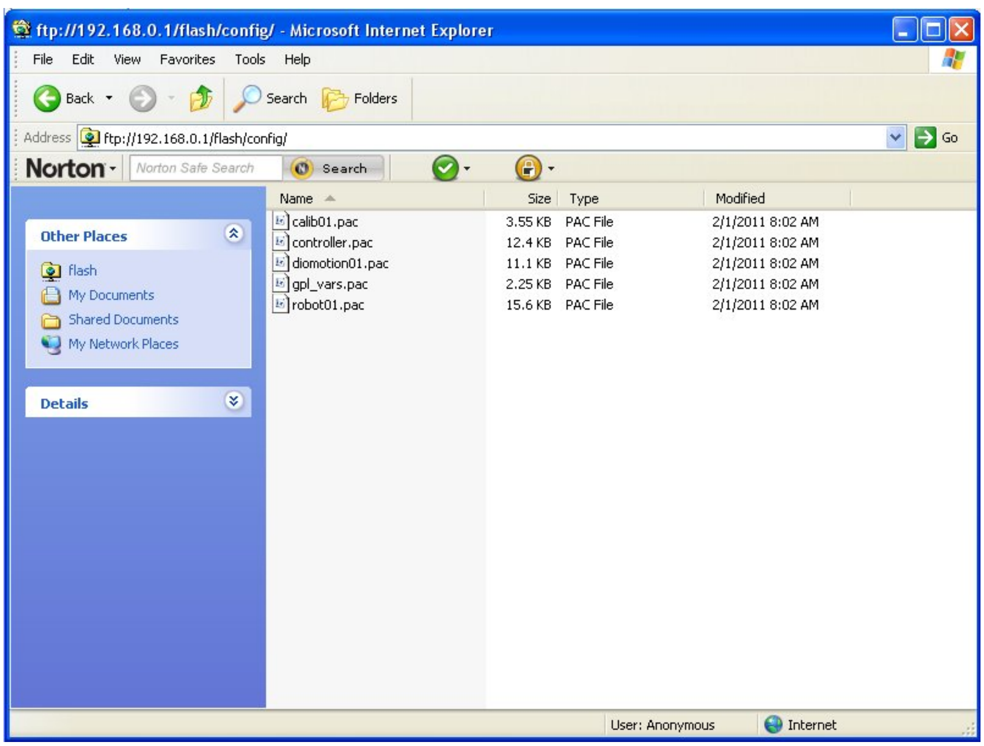
5. Cycle robot power to reboot the controller.
6. In the Web Based Operator Interface, select “Utilities/Backup and Restore



7. Click on Start File Manager. It may be necessary to hold down the Control Key to allow the pop-up. An ftp directory pop-up will come up. In the “Page” menu in Windows Internet Explorer select “Open ftp site in Windows Explorer”. Another window will open showing several folders, including “Config” and “Projects”.



8. Open the “Config” folder and paste the backup copy of the PAC files into this folder.



9. Wait until the console prompt stops flashing, about 10-15 seconds.
10. Turn off robot power.

11. Restore Jumper J8 to its previous position.
12. Reboot the robot. The PAC files should be restored and the robot should run.
13. If the robot has ever been recalibrated since the back up PAC files were created, it will be necessary to recalibrate the robot, as the calibration files will be out of date.
14. Replace the Controller in the base of the robot. If the power supply chassis was removed during this process, be sure to use Loctite 222 (screwlock) on the power supply chassis screws when replacing them.

Collaborative Mode

The PAVP6 robot contains parameters that allow software to limit crushing and collision forces to much less than the full force capability of the robot. For example, with no collaborative limits set, the robot can push downwards with a force of 440N or 44kgf. With typical settings for collaborative mode, this downwards crushing force is reduced to about 100-110N for low speed collisions. However, high speed collisions add large inertial forces from the moving mass of the robot and payload, as well as the inertias of the motors and harmonic drives. For a 1.25kg payload, the effective moving mass is about 4.0kg. This moving mass must be decelerated over a reasonable distance in a collision to limit the collision forces, which will add to the crushing force of the robot. For an end effector moving at speeds of 700mm/sec or less, a 20mm stopping distance can limit the collision force to a value that meets the generally accepted "Collaborative" force limit of 150N. If an effective moving mass of 4.0kg (1.25kg payload for this robot) is linearly decelerated over a distance of 20mm from 700mm/s, it requires a force of 50N to stop.   A moving mass of 4.0kg linearly decelerated over a distance of 20mm from a speed of 1m/s requires a force of 100N to stop. Note the force increases with the square of velocity, a 41% increase in speed doubles the force required to stop in a given distance.

Collaborative Mode works by setting joint based limits on the maximum feedback torque that can be generated by "PID" errors. The controller calculates feedforward torque to drive the robot based on acceleration, friction, and gravity compensation. If this model were perfect the feedforward torque would drive the robot along the commanded trajectory with the defined payload with no tracking errors. However, the model is never perfect, and the PID error signal provides additional torque to compensate for inaccuracy in the feedforward model. Limiting the maximum torque that the PID loop can generate can limit crushing forces during a collision.

There are two parameters in the controller database, Parameter 10351 and 10352 that limit the positive and negative torque commands to the motors in units of "tcnts" or torque counts. These values are protected and cannot be changed by the user.

Dynamic forces will add to crushing forces as described above. Compliance, in the form of a foam cushion or a spring-loaded slide, is often required to control dynamic forces.   It may be possible to eliminate safety screens if applications and tooling are designed correctly, and motions are limited to speeds which allow acceptable dynamic forces in the event of a collision.

In order to provide safety for operators who may intrude into the working volume of the robot, end-effectors should be designed with no sharp edges or points and some foam cushioning and possibly spring loaded vertical compliance with a travel of 20mm or so to provide a deceleration distance for the dynamic mass of the robot in the event of a collision.

In order to help users, design safe workcells Precise performs collision testing for both free space collisions and collisions against rigid surfaces for the PAVP6 at various speeds. This collision test data has been observed and certified by TUV.

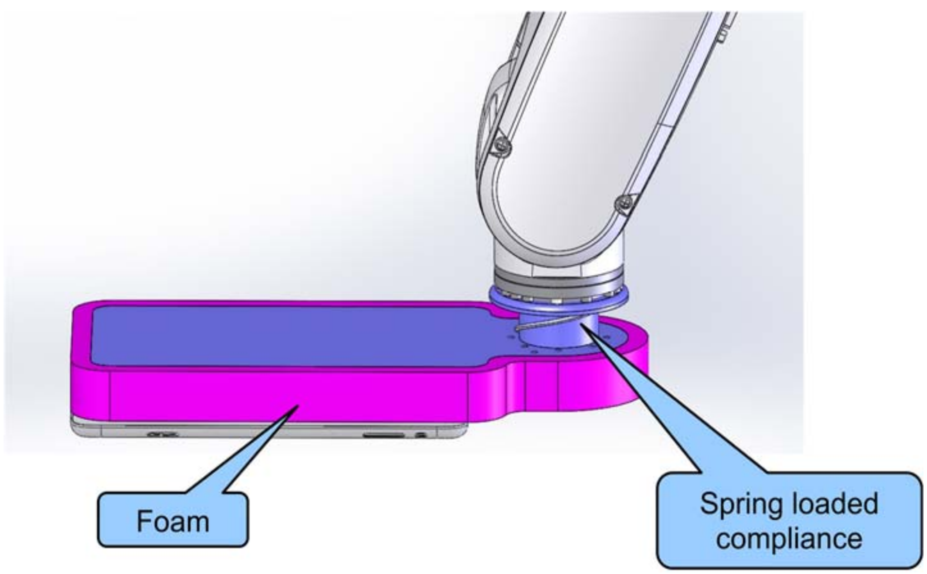
The table below shows the results of the collision test data and robot and collaborative parameter configuration for this data. When collision forces against a rigid surface exceed the recommend TS_15066 limits (140N for the hand for a quasi-static rigid surface collision), the motion should be slowed down as the robot approaches within 50 or 100mm of the rigid surface to a speed where the collision force is acceptable.

PAVP6 Test Data							
160112							
PAC Files PAVP-6242M 6-Axis Robot Rev 1.0							

Configuration	J1	J2	J3	J4	J5	J6	XYZ
Parameter 10351	4200	7500	7500	0	0	0	
Collab 1 and 2, Parameter 10352	-4200	-10000	-10000	0	0	0	
Peak current, tcnts	30217	24021	26100	15569	24912	24912	
PID Error % of peak	14%	42%	38%	100%	100%	100%	
Config for crash tests (angles)	0.0	96.5	37.8	0.0	43.8	0	
100% Joint Speed	150	90	150	180	180	180	
100% Joint Accel	602	451	602	723	723	723	
100% XYZ Speed							800
Collab 1 and 2, 100% XYZ Accel							3000

PAVP6 Collisions at Gripper

Speed	Manual Control			Free Space Collision			Rigid Surface Collision, 2kg				35% decel
	X	Y	-Z	X	Y	-Z 2.0kg	X	Y	J1 rot	-Z 2.0kg	-Z 2.0kg
100%	106	47	132	67	81	128	237	141	199	240	180
80%	89	43	127	80	74	133	170	127	163	208	162
60%	85	41	121	69	51	106	130	103	126	175	148
40%	74	39	115	77	68	122	100	75	90	149	138
20%	63	36	110	70	66	93	84	56	57	135	129
10%	54	36	109	68	40	107	73	44	44	123	118



A safety evaluation of the workcell should be performed per EN ISO 10218-2 (2011) "**Robots and robotic devices — Safety requirements for industrial robots —**Part 2: **Robot systems and integration", and ISO TS_15066 "Robots and Robotic Devices – Collaborative Robots".**

Controller Software Extensions

This section discusses extensions to the standard Guidance Controller software that are specific to the PAVP6 Robot. Precise offers a Command Server software package that allows a PC to send high level commands to the Precise robots. This package is available upon request.

Adding or Removing the Optional Linear Axis (Not released)

The optional Linear Axis may be added to existing PAVP6 robots by simply placing the robot on the Linear Axis and plugging in the connectors from the Linear Axis stage. However the GPL version must be 4.0 or later and the PAC files must be changed to support the robot with Linear Axis. If a robot is installed on, or removed from, a linear axis new PAC files must be obtained from Precise and installed in the robot controller and the robot must be re-calibrated, using CALPP_Rev24 or later.

There is a configuration parameter in the PAC files which determines whether the Linear Axis is configured to add to the robot's Y Cartesian Axis or X Cartesian Axis. The 5th element of the "Kinematic dimension constants" (16050) will specify the orientation of the rail. A value of 0 has the rail moving along +Y. To have the rail move along +X, the 5th parameter must be set to -90 (degrees).

The Linear Axis Option is configured so that the zero position is in the middle of the range of travel. The software is configured so that the Linear Axis position is added to either the Y axis or X axis Cartesian position of the gripper. The Linear Axis appears as Joint 6 in Joint Coordinates and in the Virtual Pendant Coordinates. It may be moved by the "Move.OneAxis" command by selecting Joint 6.

Service Procedures

For maintenance and service procedures for the robot mechanism, please see the *Denso Robot VP-F Series Service Manual.*

Trouble Shooting

Precise robots and controllers have an extensive list of error messages. Please refer to the HTML document *Precise_Documentation_Library.chm* to search for a specific error message and cause. Listed below are a few errors that may be generated by hardware failures.

Symptom	Recommended Action
System error message generated	
“ESTOP not Enabled”	Check 9 pin Dsub in Pendant connector for Estop jumpers.
“Encoder Battery Low”	Replace absolute encoder batteries in base of robot
“Encoder Battery Down”	If encoder cable has been disconnected, recalibrate robot. If battery voltage has dropped below 2.5V replace encoder battery and recalibrate robot.
“Encoder Operation Error”	Joint rotated too quickly with power off. See Procedure below.
“Encoder Data, Accel/decel Limit Error”	Encoder cable may be damaged and encoder is getting intermittent communication, causing apparent jumps in position. Check encoder connectors. Replace harness or motor/cable.
“Encoder Communication Error”	Check encoder connectors. Replace encoder cable or motor/encoder.
"Encoder quadrature error"	(External belt encoder only) Replace cable or encoder.
“Motor duty cycle exceeded”	Reduce speed or acceleration of robot
“Amplifier under voltage”	Motor power supply has reached current limit and shutdown. Slow down robot. Replace 24V supply. Replace controller amp board.
“Amplifier Fault”	Check harness and motor for shorts.
“Amplifier Over Voltage”	Replace controller amp board. Check power resistor in controller.
“Soft Envelope Error”	Make sure robot not pressing against surface.
“Hard Envelope Error”	Typically means robot has crashed into something.
“Time Out Nulling Error”	Check that joint is free to move with brake off. Check that joint is not vibrating or unstable. If unstable check belt tension.
“Joint Out of Range”	The joint actual or commanded position may be beyond the software limit stop. Move joint back into range while monitoring virtual pendant or check program for commanded position.
“PAC Files Corrupted”	See recovering from corrupted PAC Files
Physical or audible problem	
Mechanical noise from any joint	Check joint bearings for failure. Re-tension belt.
Loud buzzing or vibration from any joint	Re-tension timing belts.

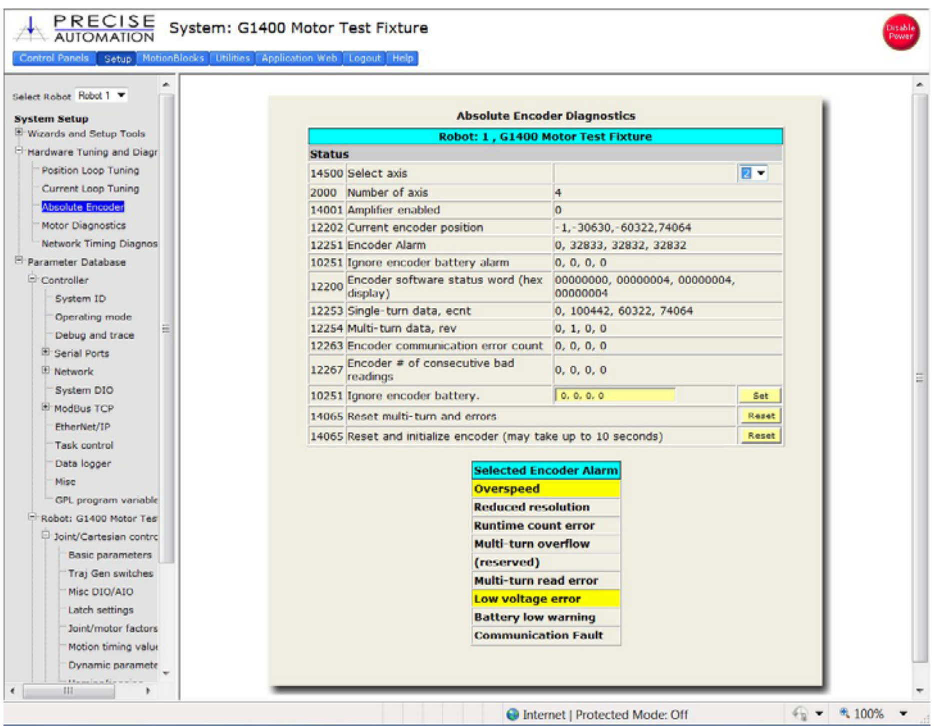
Encoder Operation Error

The PAVP6 robot is equipped with absolute encoders that keep track of the robot position even when AC power to the robot is disconnected. There is a battery in the base of the robot that provides standby power to the encoders. In standby mode, there is a limit on how quickly the motor can turn and still have the standby counter operate properly. The limits are 6,000 rpm and 4000 rad/s^2. Even at 100% speeds the robot joints normally do not move faster than about 2,000 rpm and 1300 rad/s^2. However if the robot is shocked during shipping, it is possible the standby operation acceleration error limit may be exceeded. This can generate an encoder operation error that will prevent the robot from homing after power up.

This error will be displayed in the Operator Window of the Web Interface as “Encoder Operation Error” Robot 1: <axis number>.

Assuming the robot has not been damaged by the shipping process, this error can be reset by the following procedure:

1. Access the Web Operator Interface to the robot with either “Maintenance” or “Administrator” privileges.
2. In the “Setup” menu, select “Hardware Tuning and Diagnostics”, then select “Absolute Encoder”. You should see a screen similar to that shown below.



3. In the pull down menu at the top right of the screen, select the robot axis that was associated with the error and check to see if the Overspeed panel is yellow. This indicates an overspeed error during encoder standby mode due to shock or vibration. This error can be reset by selecting the reset button next to “Reset and initialize encoder”. This button resets error flags, but does not reset the encoder counters. The robot can then be homed normally.
4. For cases where the encoder operation error was triggered by shipping vibration, IN MOST CASES the encoder will not have lost any position data. However after homing the robot it is a good idea to move the robot to the calibration position defined by the Rang calibration procedure,

and check the joint angles in the Virtual Pendant in the Web Operator Interface against the Rang on the sticker on the base of the robot. If the robot joints after this procedure followed by homing are different from the above, then the robot needs to be re-calibrated. See procedure below.

Replacing the Encoder Battery

> **DANGER:** Before replacing the encoder battery, the AC power should be disconnected.

The Encoder Battery Pack is designed to last for several years with robot power turned off. With robot power turned on, there is no drain on the battery. The battery voltage is monitored by the system. The nominal battery voltage is 3.6 volts. If the battery voltage drops to 3.3 volts an error message “Encoder Battery Low” is generated. At this level the absolute encoder backup function will still work, however the Battery should be replaced. If the voltage drops to 2.5 volts, an error message “Absolute Encoder Down” is generated. At this point, the absolute encoder backup function will not work.

Note that if any motor/encoder is disconnected from the encoder battery by disconnecting the encoder cable, the “Encoder Battery Low” or Encoder Battery Down” message will be generated. However in this case the encoder battery does not need to be replaced. It is only necessary to re-calibrate the robot, see below.

Please refer to *Denso Robot VP-F Series Service Manual* for the procedure to replace the encoder backup batteries.

If the error message “Encoder Battery Down” was generated, the robot must be re-calibrated after this procedure. Otherwise it is not necessary to re-calibrate the robot.

Calibrating the Robot: Setting the Encoder Zero Positions

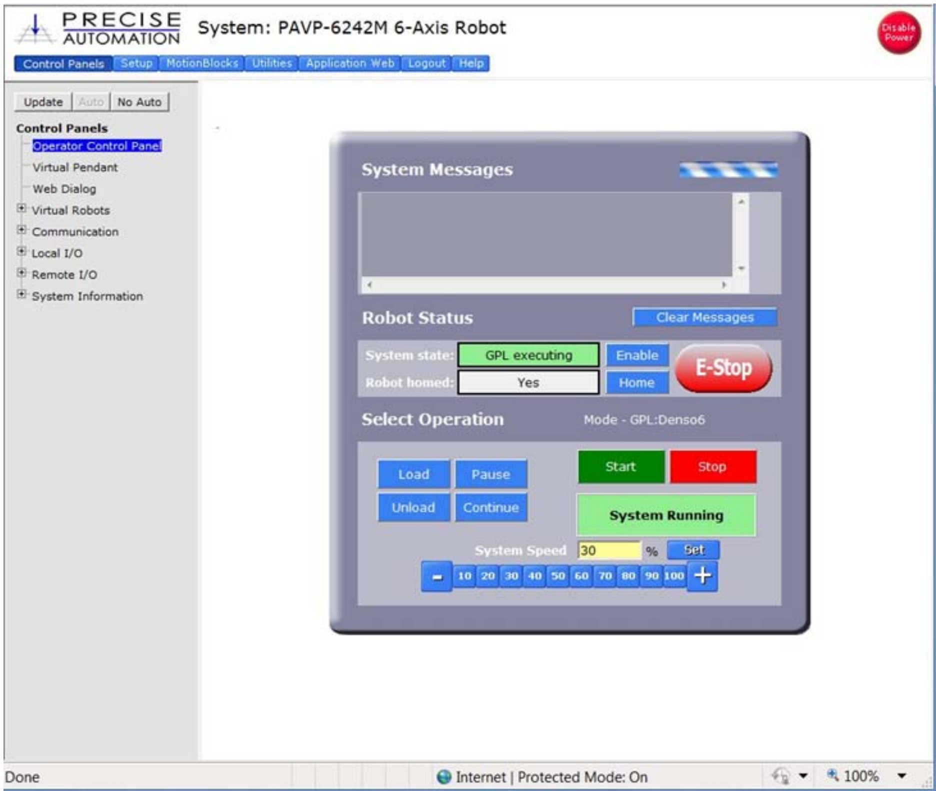
Cal_PP is a service program that must be run to set the zero positions of the absolute encoders on each motor. The zero positions must be re-established if any of the motors are replaced, their cables disconnected for a long duration, or the encoder backup battery has been disconnected.

Cal_PP is supplied on the *Guidance Controller System Software CD*. To run Cal_PP, the controller must be configured to run GPL programs and Cal_PP must be loaded into the controller's memory (See Appendix D).

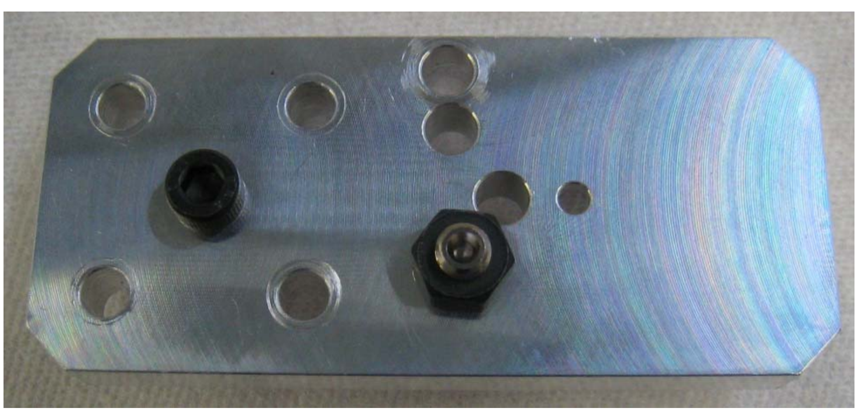
The following describes the procedure for defining the zero positions of the PAVP6 robot axes using Cal_PP.

1. Enable power to the robot’s controller, but do not turn on power to the motors.
   (This procedure should be executed with motor power off. The robot does not move.)
2. The CALPP program is typically installed at the factory and should be loaded into flash memory. Using the Web based Operator Control Panel first unload any currently loaded programs. Select the***"UnLoad"*** item in the left scrolling window and press the "***Perform Operation***" button. This

ensures that no GPL project is currently selected for execution. Select the "***Load***" item and press the "***Load***" button. This displays a popup list of Projects that are in the flash disk and available for execution. In the popup display, click on CALPP_RevXX and press "***Select***". When you are ready to execute the Project, press the "***Start*** " button. If CALPP is not loaded in the robot, first Load Cal_PP into the controller's memory from a PC, using the web Operator Control Panel, as described above in the Software Reference Section.



3. Press the brake release button and manually move the robot into the configuration shown below (CALSET position).   You will need the CALSET jig (below) for accurately locating the J6 axis rotation for CALSET.



   a. **If the optional Linear Axis is installed, move the Linear Axis carriage to the hard stop at the connector end cap. For the Linear Axis calibration be sure to use CALPP Rev 24 or later.**

Axis		CALSET position
Position	1st axis	Positive direction rotation end (counterclockwise end when viewed from top)
	2nd axis	Negative direction rotation end
	3rd axis	Positive direction rotation end
	4th axis	Positive direction rotation end (counterclockwise end when viewed from the tip of arm)
	5th axis (VP 6242F)	Positive direction rotation end (5th arm upper direction end)
	5th axis (VP 5243F)	Negative direction rotation end (5th arm upper direction end)
	6th axis	Positive direction rotation end set by CALSET jig (See **Fig. 3-2**)

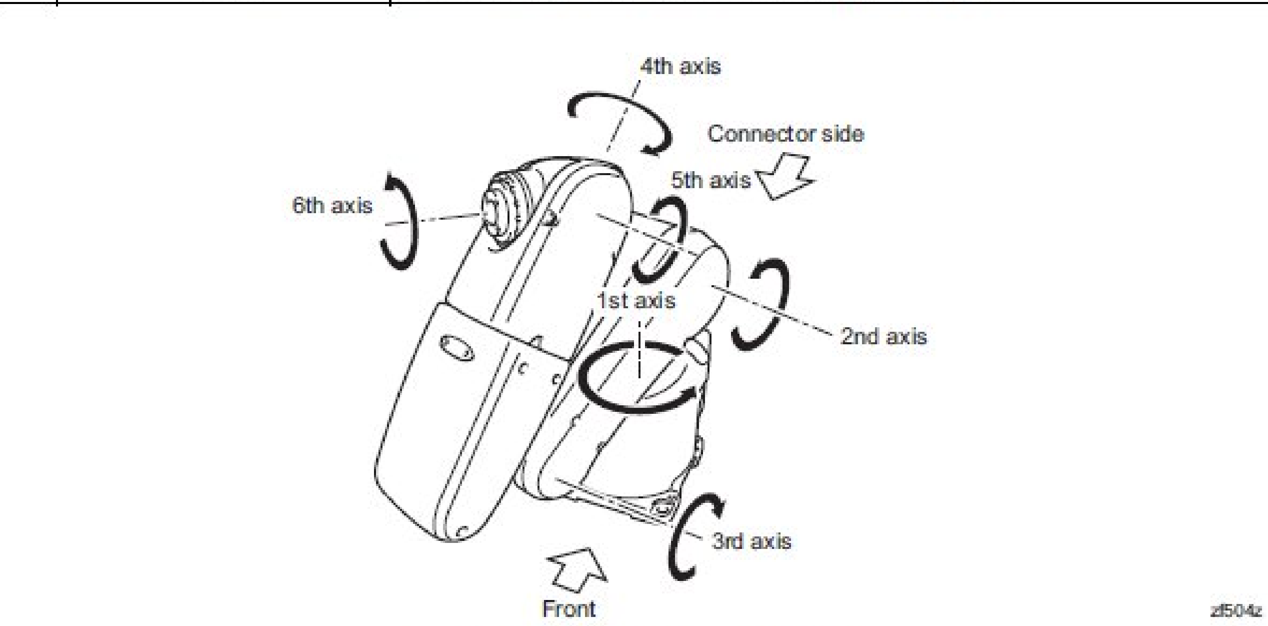


Fig.3-1: CALSET Setting Positions of 1st to 6th Axis

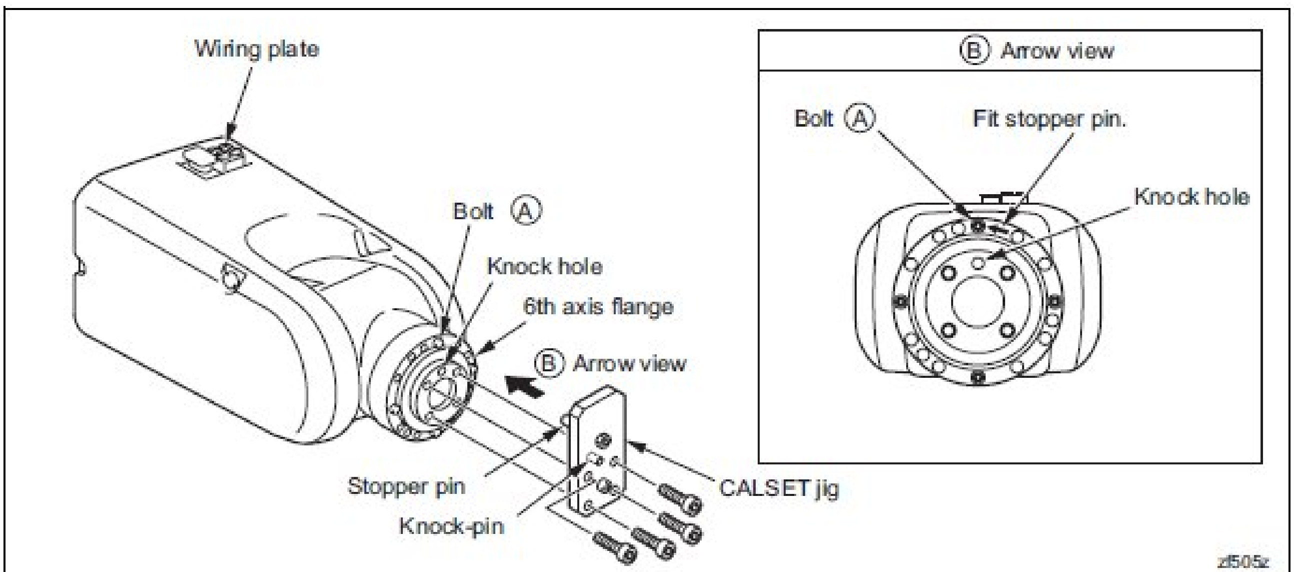
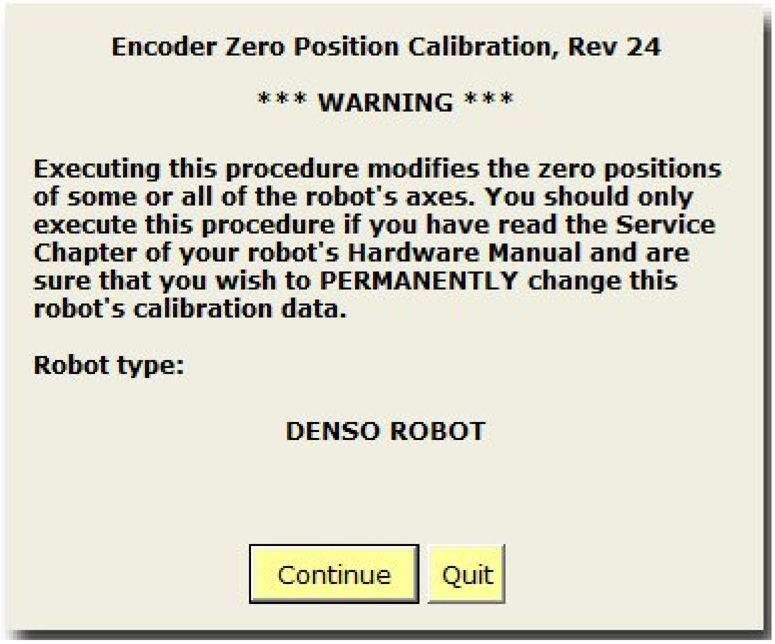
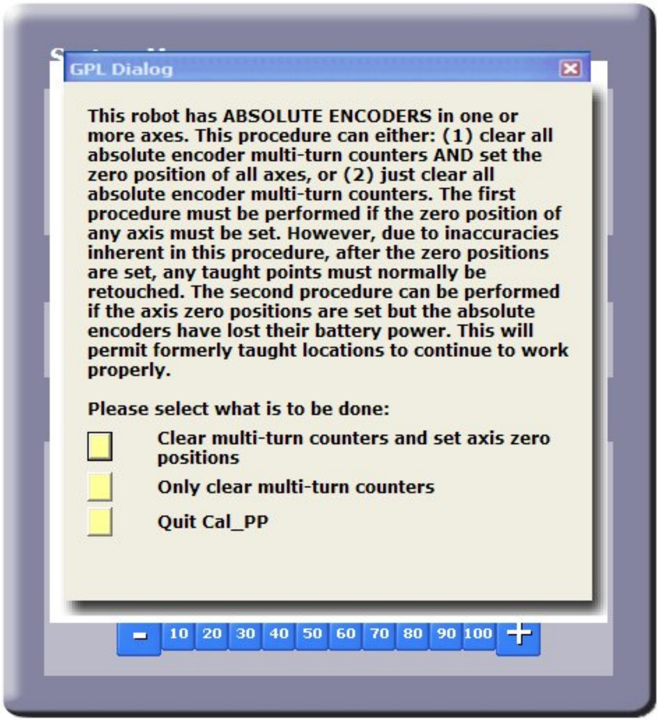


Fig.3-2: Attaching 6th Axis CALSET Jig

4. With the CALPP application loaded, press "Start"
   a. Application should start and prompt user to confirm correct robot position for calibration

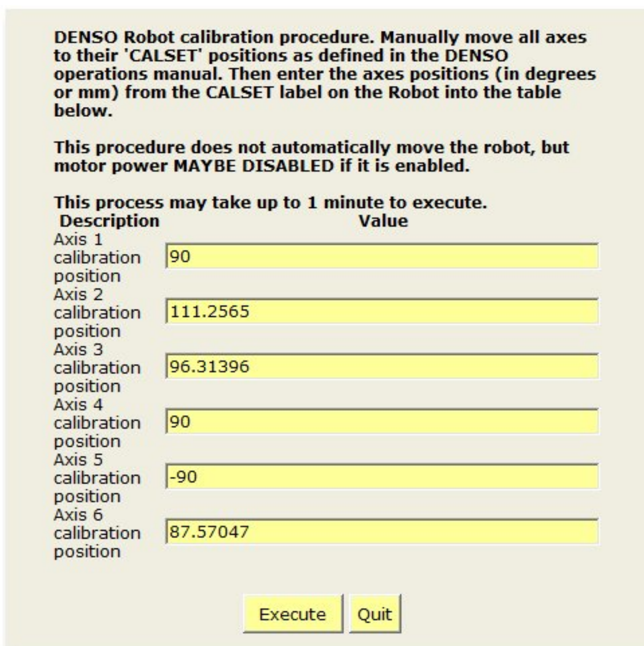


   b. The absolute encoders have two outputs: a "single turn" value and a "multi-turn" value. The single turn value is absolute within a single turn and does not depend on battery backup. The multi-turn value represents the number of complete turns of the encoder and uses battery power to drive the counter if robot power is not present. The calibration pins locate the robot with a repeatability of a fraction of a degree. However they are not accurate enough to locate the robot to a repeatability of a single encoder count (which for this robot is a few microns). Therefore the robot is assembled with the encoder single turn value in the middle of its range when the robot is in the calibration position. If no mechanical change that would affect the relation of the motor to the robot axis has been made to the robot prior to recalibration (for example changing a timing belt or a motor) only the multi-turn value needs to be reset. Therefore, after changing the encoder battery after an "Encoder Battery Down" error, or disconnecting the controller, or unplugging a motor encoder without removing the motor, select the button "Only Clear Multi-turn Counters". This will reset the multi-turn counters to zero and will preserve the repeatability of the robot to a single encoder count. However if the mechanical relationship of the motor to the robot axis has been changed by removing a belt or a motor, or if this is the first time the robot is calibrated, select the button "Clear Multi-Turn Counters and Set Axis Zero Position". This will reset an offset value that is added to the single turn encoder value to properly calibrate the robot. After this procedure however the robot will only be re-calibrated to the repeatability of the calibration pins and positions may be off by a few encoder counts.



c. Enter the “Rang” values from the sticker on the base of the robot into the fields in the display below. The defaults values displayed are for the factory calibration fixture. The Rang values should be similar to:

   i. J1: 162.7
   ii. J2: -123.2
   iii. J3: 161.8
   iv. J4: 161.8
   v. J5: 120.9
   vi. J6: 93.8



d. The CALPP application takes about 1 minute to run.

5. After calibration is complete, use the brake release button and move the axes away from the hard stop. Failing to do this will produce an error as the robot is outside of the soft stop limits.
6. **Make sure the J6 CALSET Jig is removed.**
7. **Enable power and home the robot. Calibration does not take effect until the robot is homed. The robot will not move during the homing operation.**

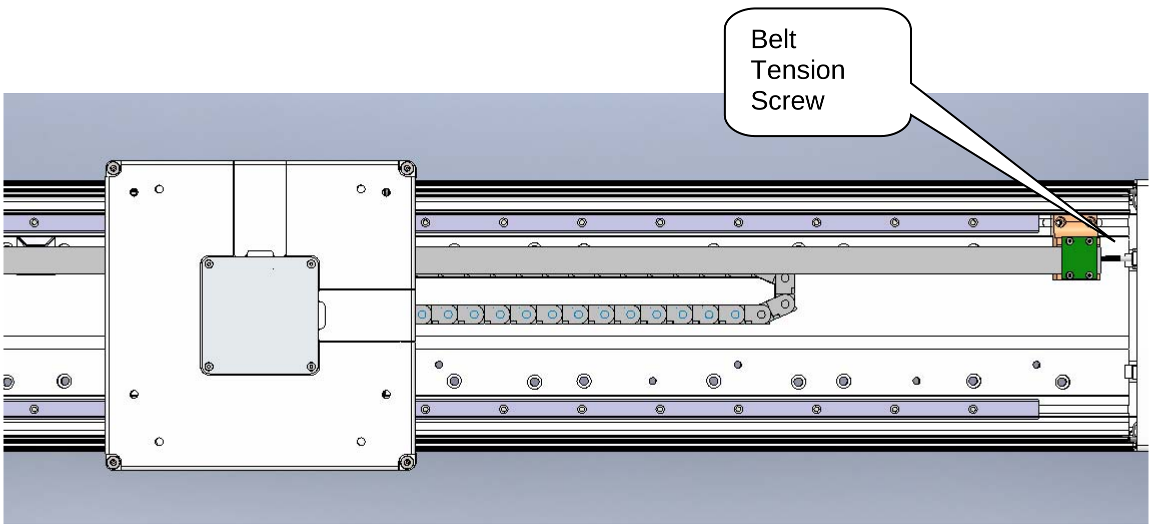
Tensioning the Belt on the Optional Linear Axis

Tools Required:

1. Gates Sonic Belt Tension Meter, Model 507C
2. 3.0mm hex driver or hex L wrench

To tension the Linear Axis Belt the user must:

1. Remove the linear axis cover by sliding the carriage to one end of travel, remove 4 M4 X 30 SHCS from the end caps retaining the cover. It may also be necessary to loosen the connector end cap by loosening the screws attaching the connector end cap to the Linear Axis Extrusion, so that the cover can be lifted up and removed.
2. Slide the carriage so that there is a 500m span of the belt between the belt tension clamp block and the idler roller on the carriage.
3. Loosen the two clamping screws on the belt tension clamp block slightly. Adjust the belt tension screw to adjust the belt tension to the values in Appendix D. Tighten the clamping screws.
4. Move the carriage back and forth the full length of travel and check the belt tension again.
5. Replace the cover.



Replacing the Power Supply or Controller

DANGER: Before replacing the power supply or controller, the AC power should be removed.

Tools Required:

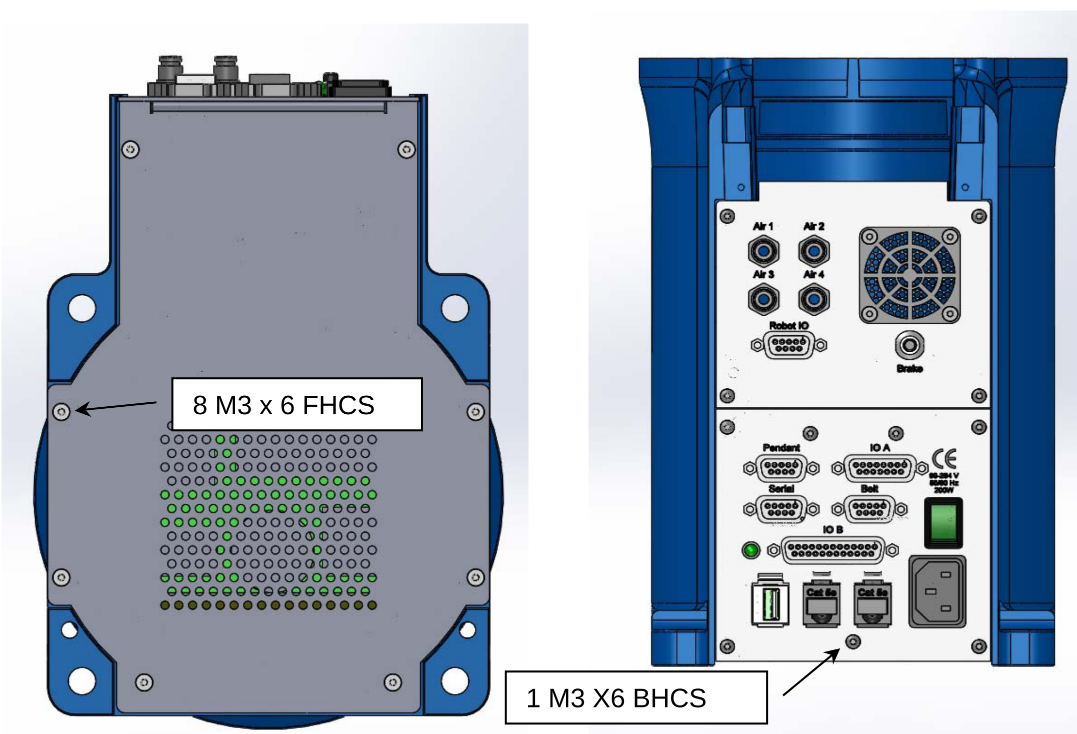
1. 3.0mm hex driver or hex L wrench
2. 2.5mm hex driver or hex L wrench
3. 2.0mm hex driver or hex L wrench

Spare Parts Required:

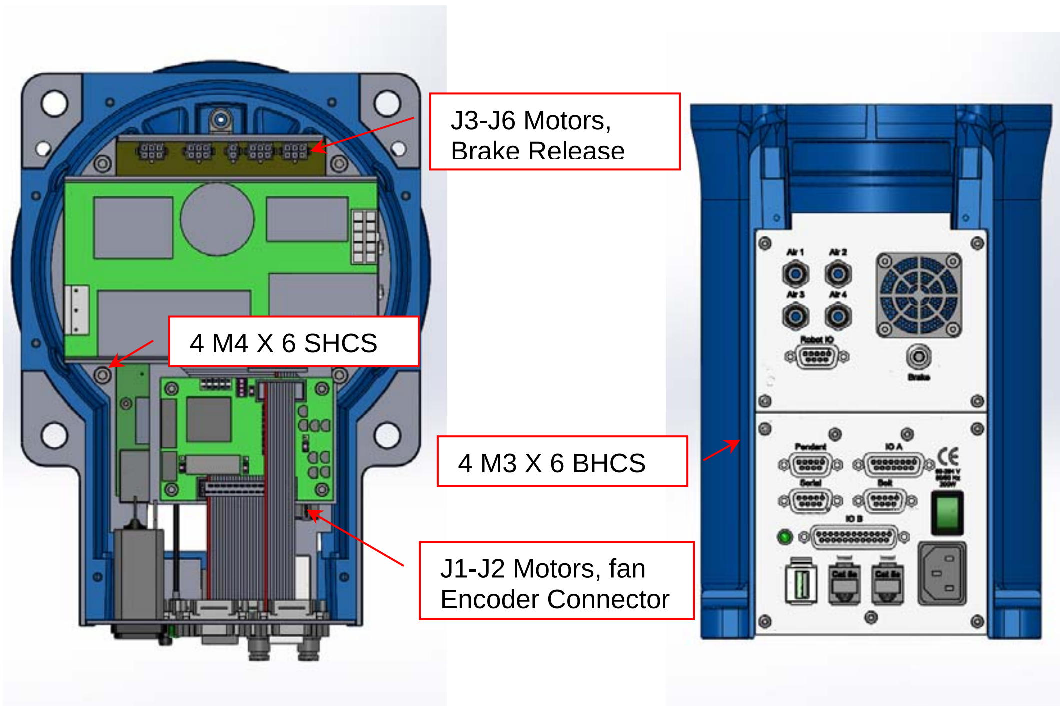
1. See “Spare Parts List”

The user must:

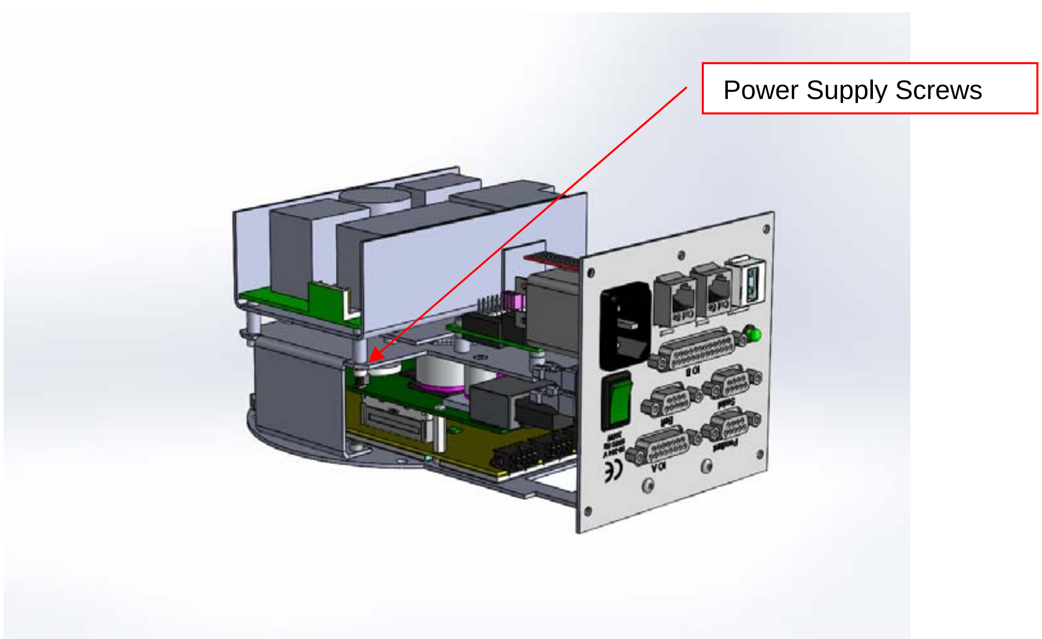
1. Turn off the robot power and remove the AC power cord.
2. Remove the robot from its mounting surface and lay it on its side.
3. Remove the Bottom Cover from the robot base casting removing the 8 M3 X 6 flat head screws from the bottom cover and 1 M3 X 6 button head screw attaching the bottom cover to the lower front facilities panel.



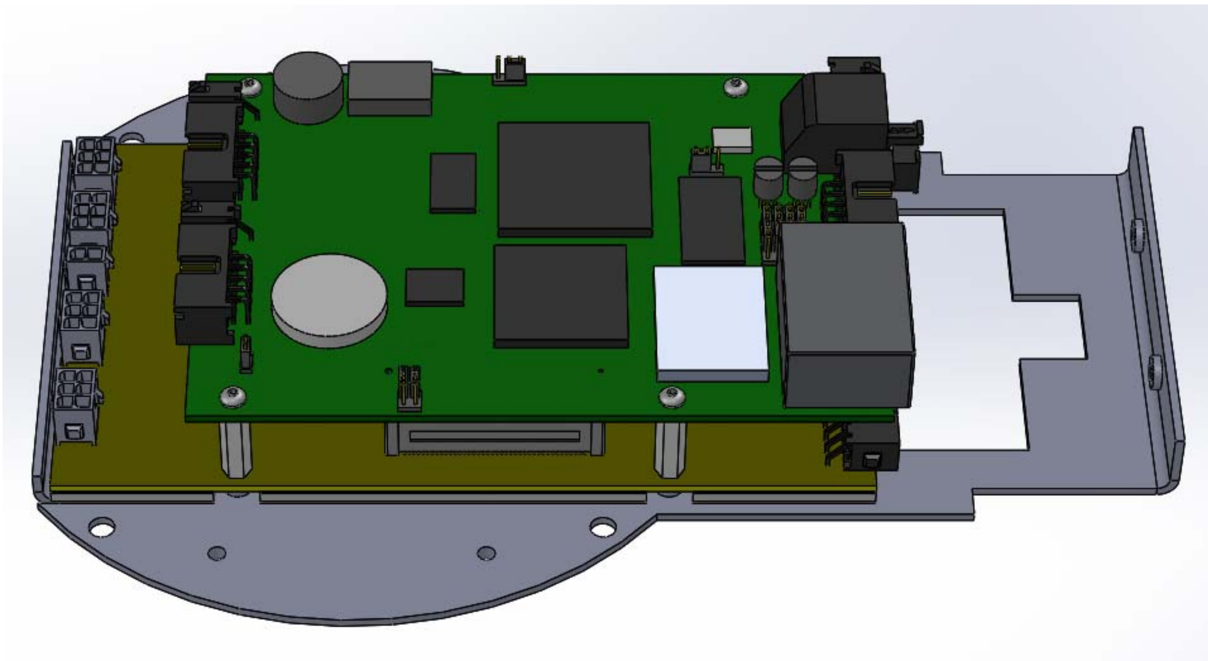
4. Unplug the connectors Motors J1 – J6, Brake Release, Encoder to robot, and Fan. Refer to the controller Power Amplifier drawing, Page 18 for connector detail.
5. Remove 4 M3 X 6 button head screws attaching the lower facilities panel to the base.
6. Remove 4 M4 X 6 socket head cap screws attaching the controller chassis to the base.



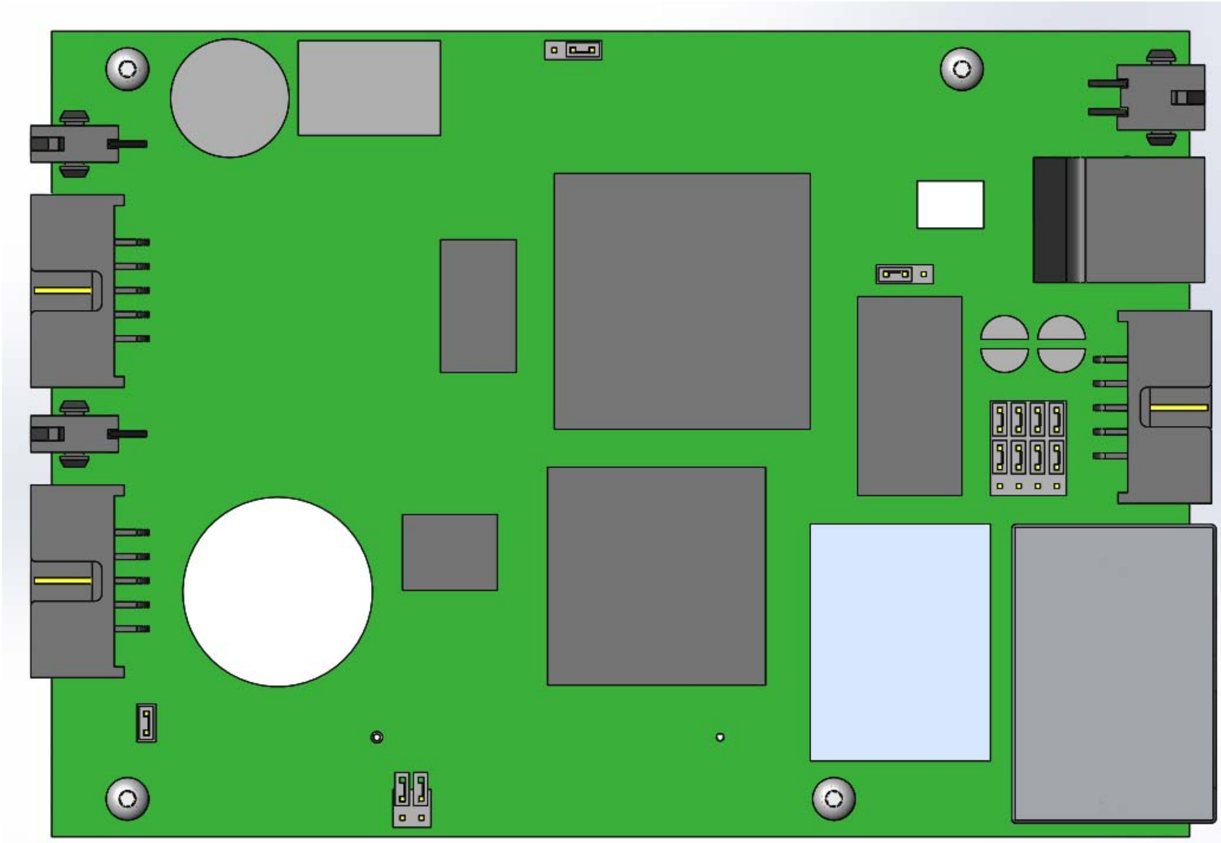
7. Remove the controller assembly from the base casting.
8. Replace the power supply if necessary.



1. Replace the robot controller if necessary by first removing the power supply bracket from the controller mount plate, and then removing 4 M2.5 X 6 button head cap screws attaching the controller CPU board to the power amplifier standoffs.
2. Remove the controller CPU board and then remove the 4 M2.5 X 16 hex standoffs attaching the power amplifier board to the controller mount plate and remove the amplifier.



3. Replace the amplifier board making sure the thermal pad sticky side is attached to the bottom of the amplifier board.
4. Replace the CPU board.
5. Carefully check all the jumpers on the new CPU board to be sure they are in the same locations as the jumpers on the old board. The factory jumper locations are shown below.
6. Replace the power supply bracket and re-insert the cables from the front panel. Refer to the circuit board drawings in the Hardware Reference Section for connector details.



7. Re-attach the power supply cables if necessary and re-assemble the robot.
8. Recalibrate the robot.

Replacing the Linear Axis Controller

Tools Required:

2.5 mm hex driver or hex L wrench

2.0 mm hex driver

Spare Parts Required:

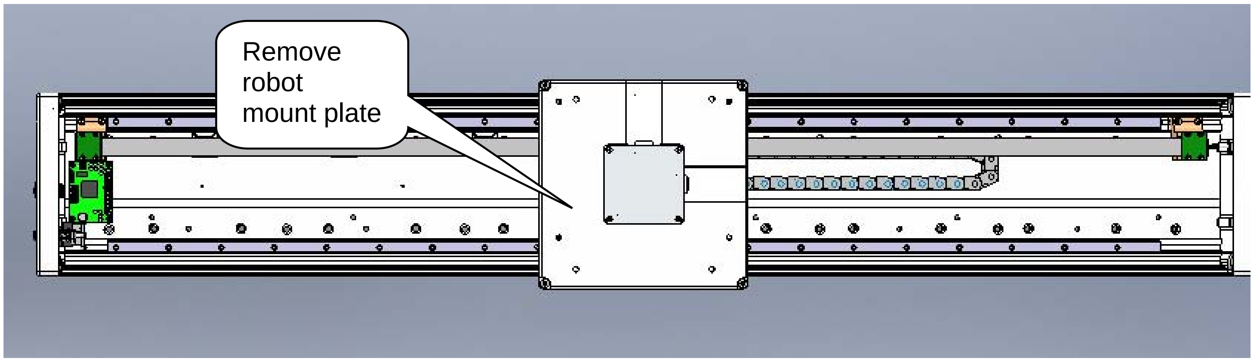
G1100T Slave Controller (“GSB3”) see “Spare Parts List”

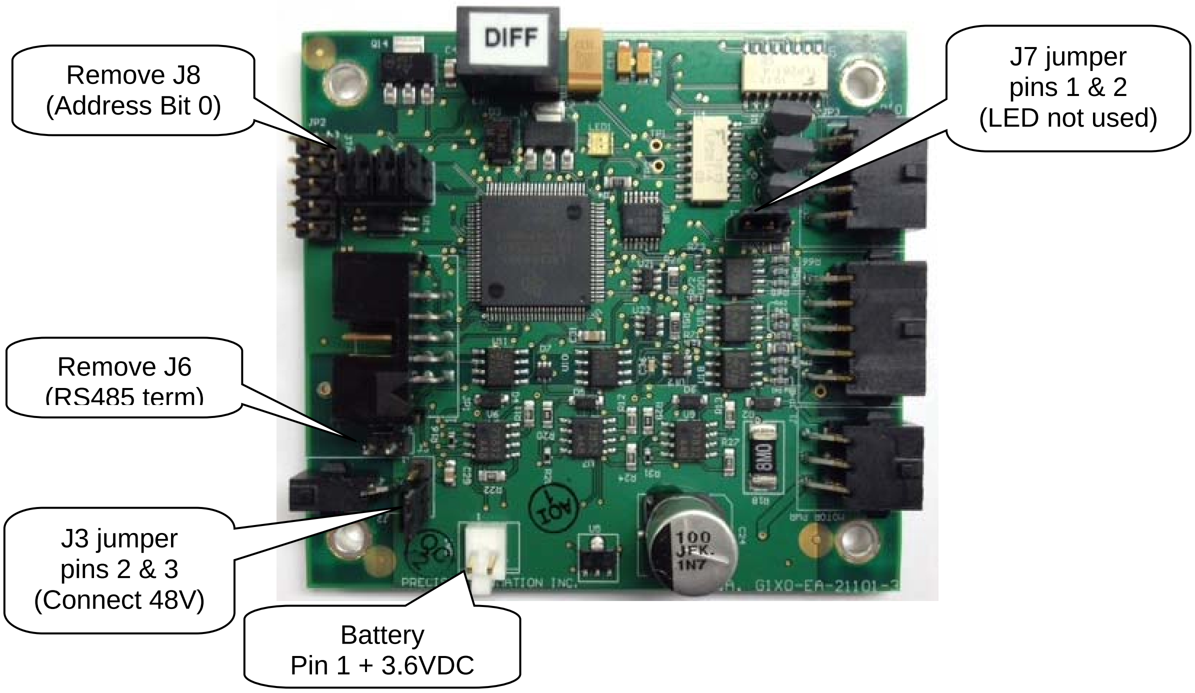
To replace the Linear Axis Controller the user must:

Remove the linear axis cover by sliding the carriage to one end of travel, remove 4 M4 X 30 SHCS from the end caps retaining the cover. It may also be necessary to loosen the connector end cap by loosening the bottom two screws attaching the connector end cap to the Linear Axis Extrusion, so that the cover can be lifted up and removed.

Remove the cable covers on the robot mount plate. Remove the robot mount plate.

Replace the Linear Axis Controller Board. Be sure all jumpers are set as shown below and the battery wires are re-connected as shown. It will be necessary to recalibrate the robot if this board is replaced and the absolute encoder battery wires are disconnected.





Linear Axis Controller (GSB Rev 3)

Installing the Optional GIO Board

Precise sells a digital IO board that provides 12 inputs and 8 outputs as an option. This board may be installed either in the base of the robot for standalone robots, or in the Linear Axis extrusion for robots with the Linear Axis option.

This board is provided with a 150mm pigtail harness to a 25 pin Dsub connector. The board is attached with 4 M3 X 10 SHCS and the 25 pin Dsub is attached with standard D-sub 4-40 mounting standoffs.

This board is typically installed at the factory, but can be installed in the field if necessary.

To install the GIO in a robot:

Tools Required:

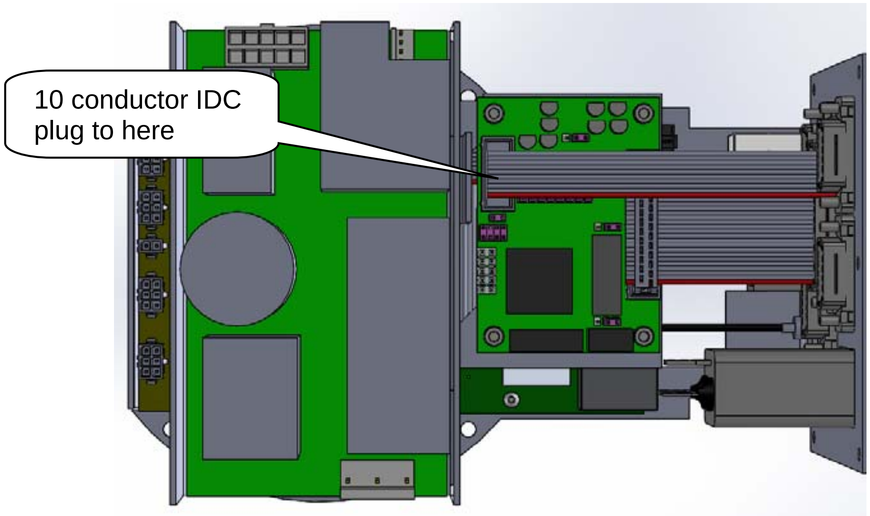
1. 2 mm hex driver or hex L wrench
2. 2.5 mm hex driver
3. M5 socket driver
4. M5 open end wrench

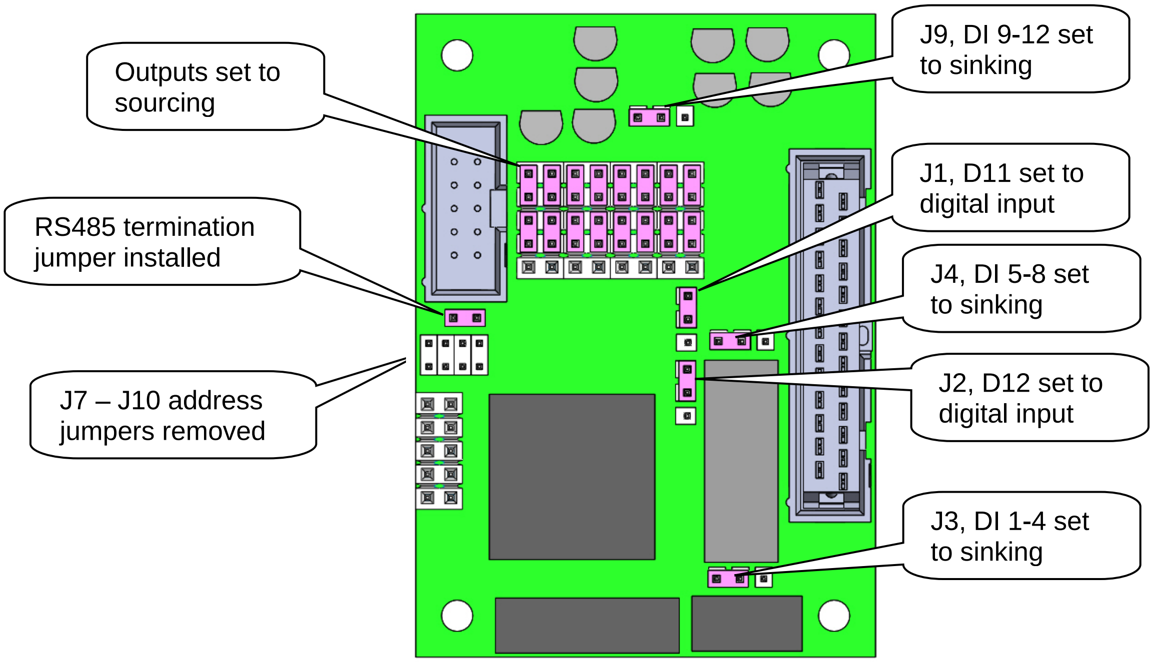
Spare Parts Required:

1. GIO Digital IO Board see "Spare Parts List"

To install the GIO Board in a robot the user must:

1. Disconnect AC power and lay the robot on its side.
2. Remove the bottom cover plate from the robot per the previous procedure.
3. Remove the 25 pin Dsub blanking plate from the front panel and install the 25 pin Dsub with pigtail for the GIO board.
4. Check the jumpers on the GIO board against the factory configuration below.
5. Attach the GIO board to the Power Supply Bracket as shown below with 4 M3 X 12 SHCS.
6. Plug the 10 pin IDC connector on the serial cable into the GSB Board.

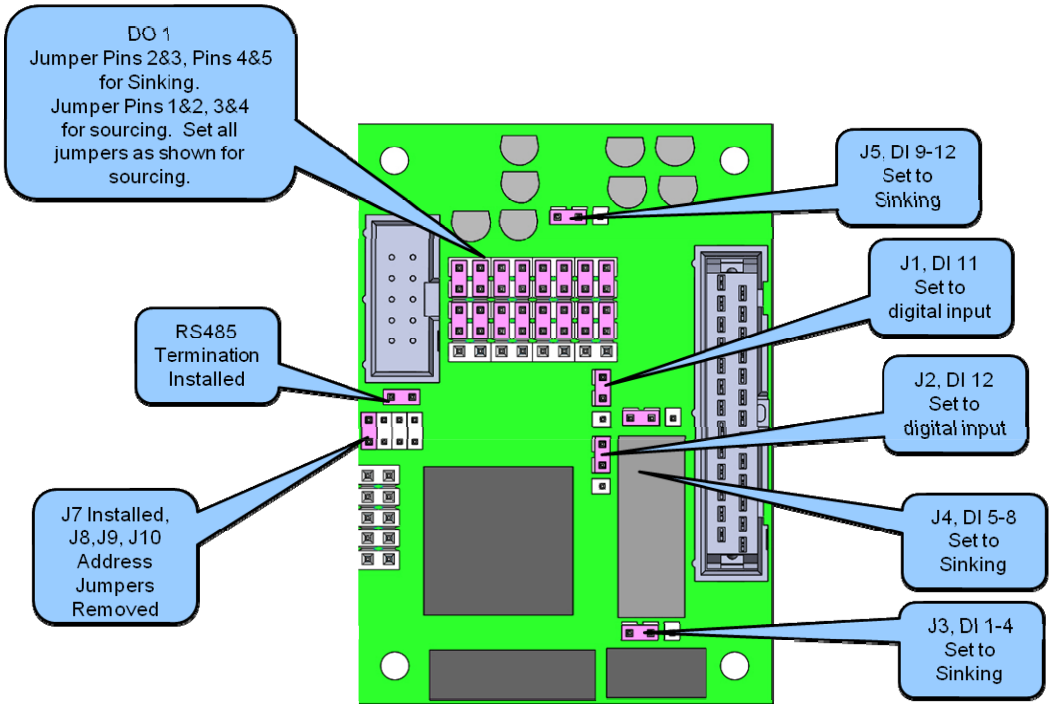




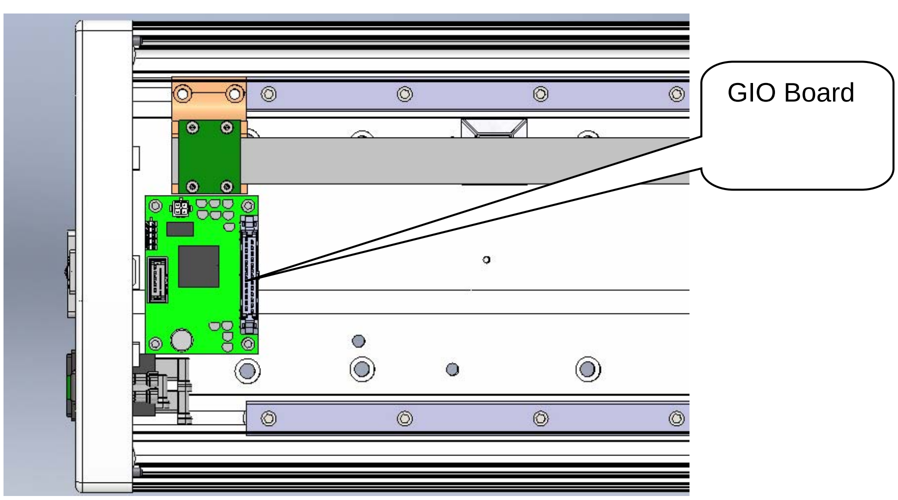
7. **Remove all 4 address jumpers on the GIO board J8-J11, see picture above.**
8. Replace the covers.
9. **Set value 8 in Data ID 151 to "GIO_8", so that this ID reads "<Controller Serial No>", "", "","","","","","","GIO_8"** This parameter may be found in Setup/Parameter Database/Controller/System ID.
10. GIO signals may then be checked under Control Panels/Remote IO/Network Node 8.

To install the GIO Board in a Linear Axis the user must:

1. Determine if the robot has a GIO board installed. If so, remove the bottom cover from the robot and remove J6, the RS485 termination jumper to avoid having multiple terminations.
2. Slide the carriage of the Linear Axis to one end of travel.
3. Remove the top cover from the Linear Axis by removing 4 M4 X 30 SHCS from the end caps. It may be necessary to loosen the two bottom screws on the connector end cap to provide clearance to remove the cover.
4. **Remove J8, J9 and J10 address jumpers on the GIO board J7-J10, see picture below. Leave J7 installed to set the GIO address to "7".**



5. Install the GIO Board in the linear axis using 4 M3 X 10 SHCS and lockwashers.



6. Remove the termination resistor from the 10 pin connector plug attached by 4 wires to the 9 pin Dsub Pendant connector and plug the 10 pin connector into the GIO board.

7. Install the GIO output pigtail by plugging the 26 pin connector into to the GIO board and attaching the 25 pin Dsub connector to the end cap with the 4-40 standoffs provided. Make an accordion fold with the extra ribbon cable and tie wrap to hold the fold down over the GIO board.
8. Replace the covers.
9. **Set value 7 in Data ID 151 to "GIO_7", so that this ID reads "<Controller Serial No>", "GSB_1", "","","","","GIO_7",GIO_8". The last value will be GIO_8 if the robot GIO is also installed, otherwise it will be empty.** This parameter may be found in Setup/Parameter Database/Controller/System ID.
10. Linear axis GIO signals may then be checked under Control Panels/Remote IO/Servo Node 7.

Appendix A: Product Specifications

PAVP6 Specifications

General Specification	Range
Range of Motion & Resolution	
J1 Axis	± 160 degrees
J2 Axis	± 120 degrees
J3 Axis	+ 160 + 19 degrees
J4 Axis	± 160 degrees
J5 Axis	± 120 degrees
J6 Axis	± 360 degrees
Linear Axis	1000mm, 1500mm, 2000mm
Repeatability	20 microns at center of tool flange
Performance and Payload	
Maximum acceleration	6000mm/sec^2 with 2kg payload
Cycle Time	1.4 second for standard 25mm X 300mm X 25mm cycle
Controller	*AVAILABLE GUIDANCE CONTROLLERS*: Guidance 1600A, Guidance GSB Slave Amplifier, GIO optional IO Board
Interfaces	
General Communications	RS-232 channel, 100Mb Ethernet
Digital I/O Channels	4 optically isolated inputs and 4 optically isolated outputs, 24 volts 100ma, available on facilities panel at base Additional 12 isolated inputs and 8 isolated outputs available as option at facilities panel. Remote I/O also available.
Pneumatic Lines	Four air lines, 71 PSI maximum, provided at outer link and routed internally to fittings on the Facilities Panel.
Operator Interface	Web based operator interface supports local or remote control via browser connected to embedded web server.
Programming Interface	Three methods available: Guidance Motion (Graphical), embedded Guidance Programming Language (standalone), PC controlled over Ethernet using TCP/IP.
Required Power	Dual range: 90 to 132 VAC and 180 to 264 VAC, auto selecting, 50-60 Hz, 400 watts maximum, 200 watts typical operation
Weight	28 kg typical, 30 kg for 1000mm Linear Axis option, 60kg for 2000mm Linear Axis Option

Appendix B: Environmental Specifications

The PAVP6 Robot must be installed in a clean, non-condensing environment with the following specifications:

General Specification	Range & Features
Ambient temperature	5ºC to 40ºC
Storage and shipment temperature	-25ºC to +55ºC
Humidity range	5 to 90%, non-condensing
Altitude	Up to 3000m

Appendix C: Spare Parts List

Description	Part Number
Absolute Encoder Battery (Order from Denso)	410611-0070
G1600A Controller CPU Board	G1X1-EA-00011-5
G1600A Controller Power Amplifier Board	G1X6-EA-00001-1
G1100T Slave Controller (“GSB3”)	G1X0-EA-T1101
GIO Digital IO Board with pigtails	GIO1-EA-01104
24 VDC Supply	PS10-EP-24365

Appendix D: Gates Tension Meter

In some cases it may be desirable to confirm the belt tension of one of the axes in the robot. This is not normally required, as the robot has been designed with spring tensioners that only require loosening and then re-tightening some clamping screws to reset the belt tensions. However in the case of the long Z column belts it is possible that after several years of operation, the belt may stretch enough that the tension spring pre-load screw may need to be adjusted. If it appears a belt tension is not being adjusted properly by the pre-load spring, the tension can be checked with a Gates Sonic Tension Meter, Model 507C.

To use the tension meter

1. Turn on the power
2. Press the “Mass” button and enter the belt mass from the table below.
3. Press the “Width” button and enter the belt width from the table below.
4. Press the “Span” button and enter the belt free span from the table below.
5. Press “Select” to record the data.
6. Press “Measure” to take a tension reading.
7. Place the microphone near the belt, typically within 3mm or so. Gently pluck the belt so that it vibrates. The tension meter will calculate the belt tension from the acoustic vibrations and display the tension in Newtons. Compare the tension to the table below. Adjust the belt tension preload screws if necessary.

Belt	***Mass (g/m)***	***Width (mm)***	***Span (mm)***	***Tension (N)***	***Frequency Min Hz***	***Frequency Max Hz***
Linear Axis	4.1	20	500	140-170	41 Hz min	46 Hz Max

Appendix E: Warranty

Precise Automation provides a warranty from the date of shipment for the robot, provided the robot and controller are not misused, damaged in shipment, or subjected to environmental damage. The standard warranty period is one year from the date of purchase. An extended warranty may be purchased upon request.

Warranty service is provided by Denso, and robots which require warranty service should be returned to the appropriate Denso office for repair after received an RMA from Precise. Denso Wave shall repair the robot free of charge when a failure occurs and is attributable to the design, manufacture or material of the robot within the warranty period in spite of proper use.

Shipping to Denso is paid for by the customer and return shipping is paid for by Precise/Denso.

Items Not Covered

1. Failures caused by improper repair, modification, transfer or handling by customer or a third party;
2. Failures caused by the use of a part or lubrication other than those specified in the related manuals;
3. Failures caused by a fire, salt damage, earthquake, storm or flood, or other acts of God;
4. Failures caused by the use of the robot in an environment other than environment specified in the related manuals, such as dust and water ingress;
5. Failures caused by a worn-out consumable, such as fan filter;
6. Failures caused by improper performance or non-performance of lubrication, maintenance or inspections stated in the Denso Robot Manual.
7. Damages other than the robot repair costs.

Appendix F: Revisions

1.5, 141215: Added GIO DIN 11 and DIN12 jumpers to page 62, 63 GIO installation

1.6, 150824: Added picture of CALSET JIG in Calibration Section with proper pins installed

1.7 160104: Added keying plugs to DB9 connectors to prevent errors

1.8 170620: Revised Warranty Policy

1.9 170913: Added CAT3 detail and updated Collaborative Mode Section