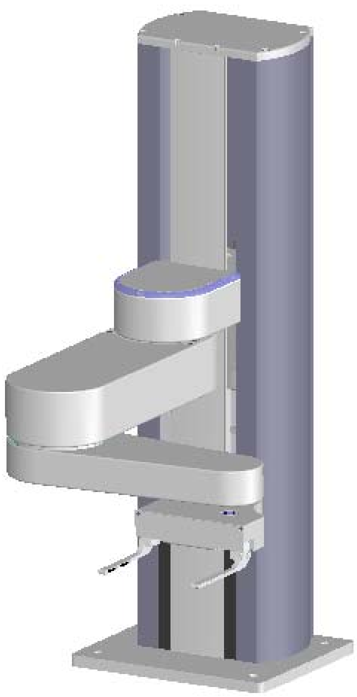
The PF400 and PF3400 Robots



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:

DANGER: This indicates an imminently hazardous situation, which, if not avoided, could result in death or serious injury.

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 PreciseFlex 400 Robot is a four-axis robot which includes an embedded Guidance 1400B four-axis motion controller, a 48VDC motor power supply, and a 24VDC logic power supply located inside the base of the robot. In addition, it may optionally include an electric gripper and electric gripper controller.

The Z axis of this robot is available with a standard travel of 400 mm, and an optional travel of 750mm. The robot is designed as tabletop unit and can carry a payload of up to 500 grams in the standard version with servo gripper, 1200 grams in the standard version without a gripper, and 2500 grams in the 3kg version without a gripper. These robots are low cost, extremely quiet and smooth, 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 either 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.

Release History

The PF400 was released in 2011. Since the initial release, designated by SN F0X-wwww-xy-zzzzz two significant upgrades have been released.

Revision B, designated by Serial Numbers F0B-wwww-xy-zzzzz, was released in 2014, and improved the high-speed, continuous duty performance of the robot. The main changes in this revision were a wider timing belt in J2 (12mm replaced 9mm), changing to all steel drive pulleys from aluminum to improve the bond strength of the drive pulleys to the motor shaft, and changing the slip ring in the wrist for improved reliability.

Revision C, designated by Serial Numbers F0C-wwww-xy-zzzzz, was released in the fall of 2016, and improved the resistance of the robot to high-speed crashes by adding clamp rings and beveled retaining rings to the J2, J3, and J4 bearings, so that these bearings cannot come loose in a high-speed crash. In addition, improved support for pneumatic grippers and control of solenoid valves in the outer link is provided, and some longer life cam followers for the J2 timing belt are installed. In January 2017, a longer life Ethernet cable is expected to be released which should last for the life of the robot running continuous duty for at least 3 years.

PF3400: 3kg Version

In 2017 a heavier payload version of the PF400 was released. This version, which appears very similar to the standard versions, is designated by Serial Numbers FO2, and has a rated payload of 3kg grams without a gripper. In this version, the torque for J1 remains the same, however the torque for J2 is increased 100%, and the torques for J3 and J4 are both increased 65%. J2 and J4 have larger motors and J2 has a 20mm wide timing belt versus 12mm wide to handle the increased torque. The Z linear bearing width has been increased from 24mm to 42mm to support the heavier payload. These units have the same top speeds as the standard versions. However, with the full 3kg payloads, the accelerations are somewhat slower than the standard version with the servo gripper and 500 gram payload. If these units are used with payloads less than 3kg, accelerations greater than 100% may be commanded to increase the accelerations to values equal or greater than the standard version robot. The 3kg payload includes the gripper. For example, the optional 60N Electric Gripper weighs 1kg, so with this gripper the workpiece payload is 2kg.

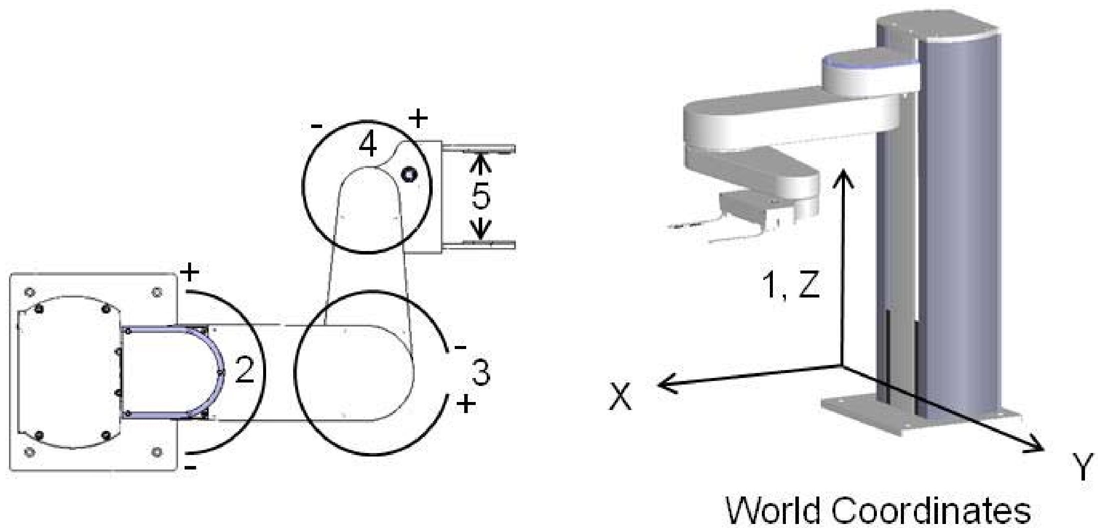
Note that for the PF3400 3kg version, it is very important to set the correct value for the payload in the Dynamic Feed Forward parameter 16071 (or use the GPL “Robot.Payload” property). 100% equals 3kg for the gripper and payload mass. For lighter masses, this value should be reduced. Setting the payload correctly is important both for optimal dynamic performance of the robot and also for proper gravity compensation, including “free” mode. Also, it is important to set the correct offset distance in value 5 of parameter 16068, in mm, for the distance of the center of mass of the gripper and payload from the J4 axis of rotation. For example, if the center of a 2kg mass is 100mm from the center of rotation of axis 4 (the wrist), this value should be set to 100mm, for the Dynamic Feed Forward calculations to compute the correct feed forward motor torques and achieve optimal performance. For pick and place applications, the property “robot.payload” can be written by the application program to change the payload. Note that when setting the payload and gripper payload offset parameters in the database, these values must be entered, saved to flash, and the controller must be re-booted for them to take effect.

In addition, the 3kg version has 8 inputs and 8 outputs available at the base connector panel in a 25 pin Dsubminiature connector and has 4 digital outputs and up to 4 digital inputs available in the outer link when the pneumatic version is ordered.

The 3kg version is nominally quoted and shipped with a standard ISO flange, and a single solenoid valve mounted in the outer link for users to add pneumatic or vacuum grippers of their design. Optionally, an additional solenoid can be ordered, or a 60N squeeze, 40mm travel electric gripper can be ordered, or a dual 23N squeeze, 60mm electric gripper can be ordered. See the “system dimensions” section for reference dimensions on these options.

System Diagram and Coordinate Systems

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



Item	Axis	Description of Motion
1	Z column	Moves Up and Down 400mm
2	Shoulder	Rotates 180 degrees
3	Elbow	Rotates 334 degrees
4	Wrist	Rotates +/- 970 degrees
5	Gripper	Opens from 77mm to 133mm Force 0 to 20N

The first axis of the robot, J1, moves the robot arm up along the Z Column, which is the Z-axis. When inner link is closest to the bottom, the Z-axis is at its 0 position in the Joint Coordinate system and Z=30mm in the World Coordinate system. As the robot arm moves upwards, both its joint position and the World Z Coordinate increase in value.

The Z column also contains the 24VDC and 48VDC power supplies and the connector panel. The Guidance controller is located inside the inner link of the robot, and the gripper controller is located inside the outer link.

When the Inner Link is centered on its range of motion the J2 axis is at its 0 joint angle. A positive change in the axis angle results in a positive rotation about the World Z-axis.

The J3 rotary axis (elbow) rotates the outer link about the world Z-Axis. A positive change in the axis angle results in a positive rotation about the World Z-axis. When the link is centered, it is at its 0 joint angle, however there is a hard stop at 10 degrees, so the link cannot reach the center position. The outer link can rotate underneath the inner link, allowing the robot to change configuration from a “left hand” robot to a “right hand” robot without swinging the J3 axis (elbow) through the zero position. This allows the robot to work in very compact workcells.

The J4 rotary axis (wrist) rotates the gripper about the World Z-axis. A positive change in the axis angle results in a positive rotation about the World Z-axis.

The outer link may include a gripper controller that provides control of the optional electric gripper. It is also possible to order the robot with a pneumatic gripper, in which case the outer link will house a solenoid to control air to the pneumatic gripper. A light bar is mounted at the top of the shoulder cover (or column for some robots) and 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.

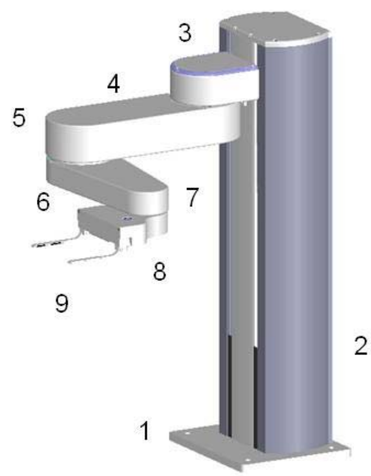
The Z-axis includes a fail-safe brake. This brake must be released to move the Z-axis up and down manually. There is a manual brake release button on the bottom of the inner link near the Z-axis. Depressing this button when 24VDC power is on will release the Z-axis brake while the button is depressed. It is not necessary for the control system to be operating for the brake release to function; the only requirement is providing 24VDC to the controller. Care should be taken to support the Z-axis when the brake release button is pushed, as the axis will fall due to gravity.

System Components

PreciseFlex 400 Robot

The PreciseFlex 400 Robot (pictured below) is a 4-axis robot that may optionally include an electric or pneumatic gripper.

Item	Name	Description
1	Base Plate	Plate to attach robot to table
2	Z Column	Vertical column
3	Shoulder	Moves up and down column, rotates Inner Link
4	Inner Link	Inner Link
5	Elbow	Joint Between Inner and Outer Links
6	Outer Link	Outer Link
7	Wrist	Joint Between Outer Link and Gripper
8	Gripper	Gripper Mechanism
9	Fingers	Fingers for Grasping Titer Plates



Optional Linear Axis Module

The PF400 and PF3400 robots 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 both power and 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 750mm vertical travel PF400 on a 1000mm Linear Axis Module. The robot is positioned in the middle of travel, which is defined as the zero position in the linear axis. 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

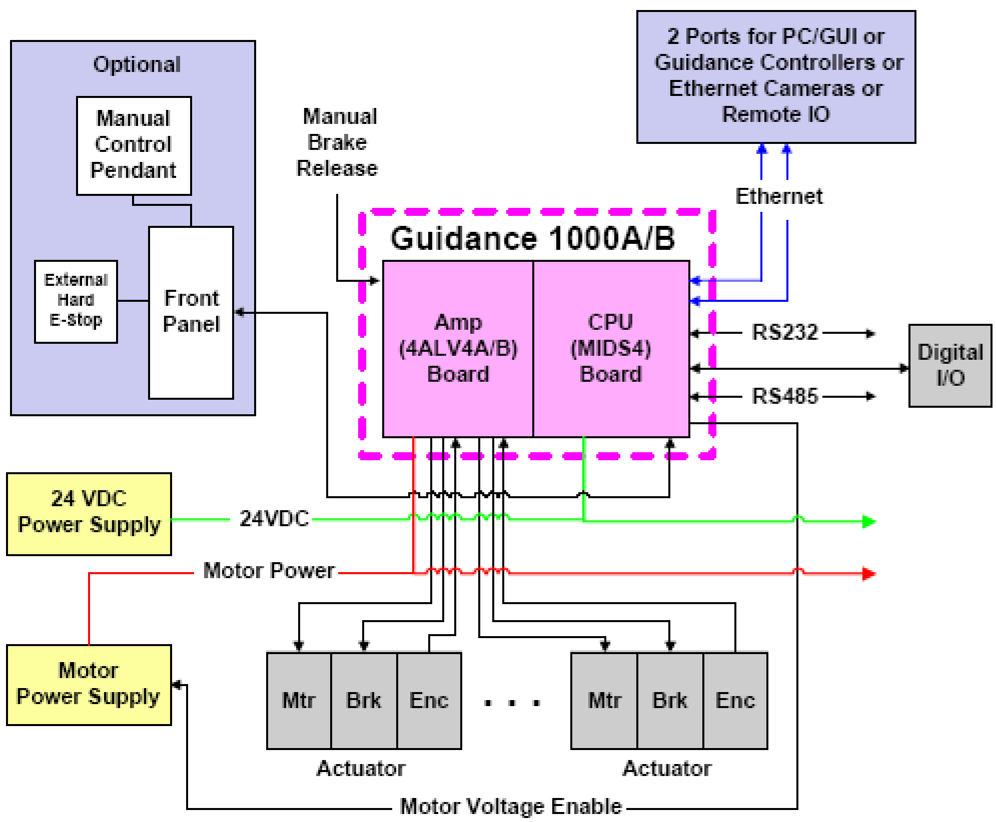
The Robot Base Plate contains a mounting hole pattern for 4 M6 Screws along with reference surfaces for locating the robot on a table or work cell surface. The Linear Axis Module contains mounting patterns for both M6 and ¼-20 screws. See Installation section for details.

Optional Gripper

The robot may be ordered with an optional Gripper. The Gripper may be either electric, pneumatic, or vacuum. Several options are available.

Guidance 1400B Controller

The Guidance 1400B Controller is a four-axis general purpose motion controller that contains four motor drives and four encoder inputs. It must be attached to a heat sink. The heat sink is provided by the inner link 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*"*.

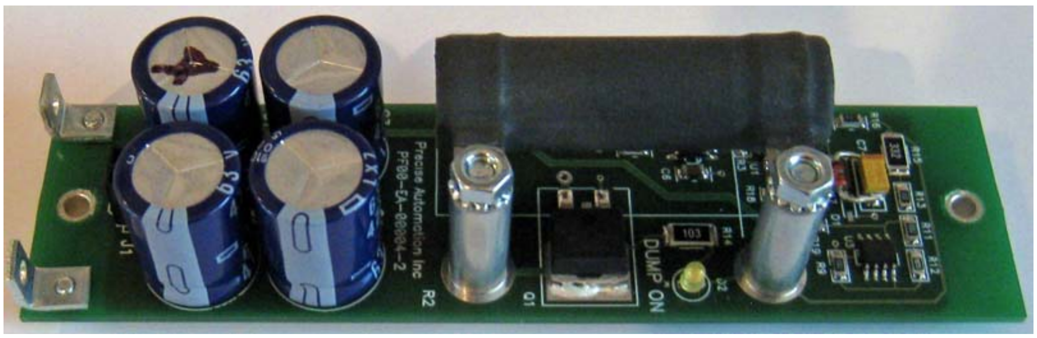
Low Voltage Power Supplies

The PreciseFlex 400 Robot has an integrated 125-watt, 24VDC Power Supply that accepts a range of AC input from 90V to 264V and an integrated 365W, 48VDC Power Supply for the motors.

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

Energy Dump Circuit

The 48 VDC supply has a regulated output and an overvoltage protection circuit that is triggered if the voltage reaches 60 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 48 VDC bus.



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 green Phoenix connector in the connector panel in the base of the robot. The E-Stop box completes a circuit from the top pin, Pin 1 (24VDC) to Pin 2 (E-Stop) in this connector. If this circuit is 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 jumper must be connected between these two pins to enable robot motor power. For those applications where an operator must be inside the working volume of the robot while teaching, a second teach pendant with a 3-position run hold switch is available. The Manual Control Pendants can be plugged directly into the 9 pin Dsub connector mounted on the robot's Facilities Panel in the base of the robot. The E-Stop connections are also present on the 9 pin Dsub connector and each of these units provides the hardware signals to permit power to be enabled and disabled.

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 PreciseFlex robot and its 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 ENISO 10218-1:2011 and 10218-2:2011 Robots for Industrial Environments, Safety Requirements, ISO/TS 15066 "Robots and Robotic Devices – Collaborative Robots" and ISO 13849-1:2006 Safety of machinery — Safety-related parts of control systems.

Standards Compliance and Agency Certifications

The PreciseFlex 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:

EN ISO 10218-1-2011 Robots for Industrial Environments, Safety Requirements
EN 610204-1 **S**afety of Machinery, Electrical Equipment of Machines
EN 61000-6-2 EMC Directive (Immunity)
EN 61000-6-4 EMC Directive (Emissions)

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 PF400 and PF3400 robots have been designed to comply with the following agency certification requirements, and carry the CE and CSA marks.

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

Moving Machine Safety

The PreciseFlex 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 PreciseFlex 400 is a light-duty robot that can only apply approximately 20-60 Newtons of 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. The PF400 and PF3400 robots have been designed 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 10218-2-2011 Robots for Industrial Environments, Safety Requirements for information on recommended safe operating practices and enclosure design for robots of various sizes and payloads.

Voltage and Power Considerations

The Guidance 1400B controller requires two DC power supplies, a 24 VDC power supply for the processor and user IO, and a separate 48VDC motor power supply.

DANGER: The Guidance 1400, the 48 VDC and the 24 VDC power supplies are all open frame electrical devices that contain 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 PreciseFlex 400 power supplies have a dual input range of 90 to 132 VAC and 180 to 264 VAC 50/60 Hz. Inrush current can be as high as 100 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. Revisions A and B of the robot are protected against over current by two 4.0 amp, 250V slow blow fuses, for example Littlefuse 0215004.MXP. For Revision C and the 3kg version, these fuses have been removed to provide for better filtering in the power entry connector. The power supplies have over-current protection, and over-voltage protection.

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

The Z column, shoulder, and elbow 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. The wrist axis has a slip ring when the electric gripper is installed, allowing unlimited rotation. However, software stops limit rotation to plus or minus 970 degrees. Since the robot has absolute encoders with battery backup, even if the robot is turned off, the encoders keep track of joint position. If the wrist axis is rotated manually beyond the 970 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) For pneumatic configurations a sliding hard stop limits the wrist rotation to 540 degrees.

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 0.5 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.

For the PreciseFlex 400 robot, the shoulder, elbow, and wrist axes do not have mechanical brakes. Therefore, leaving the motor power enabled for 0.5 sec allows the servos to decelerate the robot. The servos will typically decelerate the robot at 0.12G, or 1250mm/sec^2. If the robot is moving at a speed of 500mm/sec, the distance traveled will be 100mm to reach a full stop, and the time will be 0.4sec.

Releasing a Trapped Operator: Brake Release Switch

Should a hard E-Stop be triggered, the Z brake will engage, and motor power will be disconnected from all motors. As the J2, J3, and J4 axes have no brakes, they may be freely pushed by the operator. To release the Z brake, 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.

Collaborative Robot Safety

Summary.

The PF400 and PF3400 robots have been designed to be safe for collaborative use by means of inherent design and control when evaluated under ISO/TS 15066 “Robots and Robotic Devices – Collaborative Robots” released February 15, 2016. In all free space collisions (transient contact), up to its maximum speed and payload, these robots do not exceed the forces in the standard. In all horizontal rigid surface collisions PF400 does not exceed the forces (quasi-static) in the standard. The PF3400 can exceed the maximum recommended force in the horizontal plane if J2 is driven at maximum velocity so that the tool crashes into a rigid surface. For vertical downward collisions into a rigid surface these robots do exceed the forces (quasi-static) at higher speeds. Horizontal and vertical motions at 100% speed may be programmed as long as an approach point is specified at least 50mm above any rigid surfaces with a final motion at a speed of 60% or less. Collision testing has been performed and certified by TUV and a table of collision speeds and forces is provided in Appendix B of this section.

The PF robot is available in two versions: the PF400 500gm payload version and the PF3400 3kg payload version. Both of these robots have extensive safety features as listed in Appendix D of this section. The 3kg payload version has some additional hardware safety circuitry, including full dual Estop circuitry and a circuit to turn off the 48V motor power supply in addition to the standard amplifier disable circuitry in the 500gm version and meets Performance Level d, CAT3*. (* There is one exception to the CAT3 specification: in the PF3400 it is possible for the computer to re-enable motor power under certain conditions after a crash. This allows auto-recovery and continued motion if the application programmer wishes to include this capability.)

All controller failures for both versions which might result in an uncontrolled motion have been listed and tested under supervision by TUV. None of these failures can result in an uncontrolled motion. For the 500gm payload version of the PF400 a single, PLd, EStop circuit is provided. However, this robot can also be stopped safely by hand, providing a redundant means of stopping. For the PF3400, a safety/IO board in the base of the robot provides two redundant Estop circuits compliant with CAT 3.

Background.

Recently there has been increased interest in humans and articulated machines working in the same workspace in a safe manner. Safety standards are being updated based on a wider variety of application conditions and taking into consideration that many articulated manipulators are now low payload devices with limited power. The current safety standard used by most organizations for evaluating the safety of “Industrial” robots is EN ISO 10218-1:2011 and 10218-2:2011. These standards have recently been augmented in 2016 by ISO/TS 15066 “Robots and Robotic Devices – Collaborative Robots”. “Collaborative Operation” is defined in section 3.4 of 10218:1:2011 as “a state in which purposely designed robots work in direct cooperation with a human within a defined workspace”.

One of the requirements listed as sufficient to meet the 10218:1:2011 standard is:

5.10.5 Power and force limiting by inherent design or control
"The power or force limiting function of the robot shall be in compliance with 5.4. If any parameter limit is exceeded, a protective stop shall be issued."

Section 5.4 requires the system designer to perform a Performance Level (PL) or Safety Integrity Level *requirement* (SIL) check based on the robot AND the application tooling and workcell. For example, a safe robot may still need safety interlock screening if it is moving a dangerous tool. This requires the application designer to review the requirements of 10218-2:2011 which addresses robots in workcells.

Determining a Machine's Required Performance Level (PLr). ISO 13849-1:2006 Annex A provides tables and a worksheet to identify a machine's Required Performance Level requirements. Figure 1 below shows a flow chart for determining Performance Levels. Briefly these are: Select S1 for slight injuries (normally reversible) and S2 for serious injuries or death. Select F1 for infrequent exposure to a hazard (for example only from time to time) and F2 for frequent exposure (for example continuously entering workcell). Select P1 for easily recognizing and avoiding a hazard (for example a repetitive motion) and P2 for a hazard that may be difficult to avoid (for example a sudden, non-repetitive motion that may trap an operator). An example of determining PL for a PF400 workcell is given in Appendix A of this section, where it is shown that a PL of "a" is sufficient for the workcell.

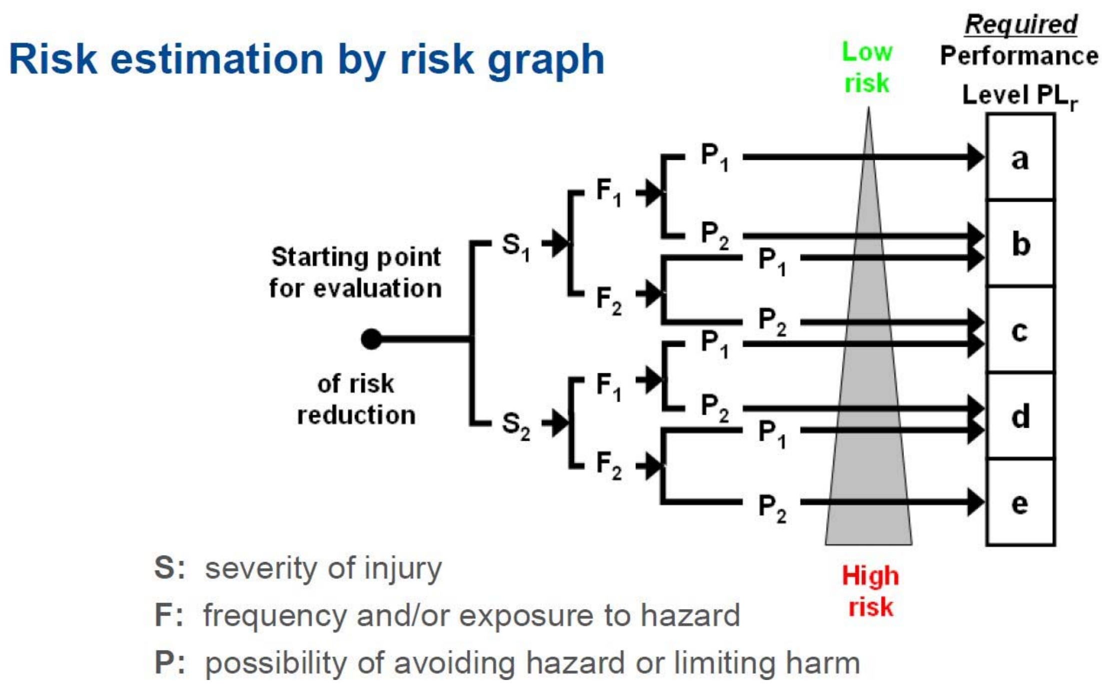


Figure 1

In determining whether operators should be prevented from entering a workcell while a robot is moving, the first question that must be answered when performing a risk assessment is determining the likely severity of injury if a robot strikes a person. If the robot will not injure a person in the event of a collision, and there is no other equipment in the workcell that can injure a person, then a person may be allowed to enter the workcell while the robot is moving.

EN/ISO 13849-1 defines a reliability level of any safety components in a machine by performance level in terms of average probability of dangerous failure per hour. It then attempts to provide a statistical method to compute this number for safety systems based on failure rates for various system components to determine the actual Performance Level (PL), which can be compared to the Required Performance Level (PLr).

Maximum Allowable Forces to Prevent Operator Injury.

ISO/TS 15066 provides detailed force limitations (Appendix C) based on extensive ergonomic testing of both pressure (force per unit area) and forces on various parts of the human body. The reader is referred to this document for detail, but a rule of thumb for maximum pressure to avoid injury is less than 200N/cm^2, and the maximum crushing force against a rigid surface (quasi-static) to avoid injury ranges from 65N for the face to 200N for less sensitive parts of the body, with **130-150N** being a good rule of thumb for any part of the body other than the face. Maximum free space collision forces (transient forces) are typically two times the allowable crushing force and therefore typically range from **260-300N**.

Note that there are other well established references for force levels that will not cause injury to humans. These include:

Automotive Power Windows: **135N**(1)
Power Operated Pedestrian Doors: **180N**(2)
Elevator Door Maximum Closing Force: **135N**(3)

Note also that recent studies have shown that it is impact force, rather than moving mass, that determines whether an unconstrained collision in free space will injure a person. For impact forces with blunt surfaces with the human maxilla (upper jaw bone) must reach 600N to break the bone. This can require a velocity of over 2 meters/sec.[4]

Additional research for safety for collaborative robots is ongoing. The Institute for Occupational Safety and Health (IFA) in Germany has surveyed the literature relating to crushing and impact injuries. **Figure 2** below summarizes their findings, which has contributed to the current draft 15066 standard. Note in particular the column for CC, or compression constant, for various parts of the body. This data is useful in determining the stiffness or compliance for force sensors when taking collision data. If a rigid robot part is driven into a rigid sensor the forces will be unrealistically high when compared to bumping into a more compliant human.

A useful number that may be extracted from this data for testing is a **compression constant of 75N/mm**, which is consistent with the hand and the face. For collisions, a higher compression constant will generate higher collision forces. It is interesting to note that while front of the neck has a fairly low impact force pain threshold of 35N, the neck must be compressed 3.5mm to reach this force, while in the case of the hand, which has an impact force pain threshold of 180N, the compression distance is less, at 2.4mm even though the force is much higher.

In considering the design and testing of a robot that meets these “Collaborative” standards, the likelihood of an impact to a particular area should be considered. The hand is most likely to be pinched in any pinch points, whereas the skull is less likely to be pinched as most operators that may be extending their hands into the workspace will be quite wary of getting their heads between a moving robot and a hard surface.

(1) National Highway Traffic Safety Administration, 49 CFR Part 571, [Docket No. NHTSA-2004-19032] RIN 2127-AG36, Federal Motor Vehicle Safety Standards; Power-Operated Window, Partition, and Roof Panel Systems
(2) ANSI/BHMA A156.10-1999 American National Standard for Power Operated Pedestrian Doors
(3) Department of Public Safety Division 40 Chapter 5 Elevators
(4) Safe Physical Human-Robot Interaction: Measurements, Analysis & New Insights, 2010, Sami Haddadin, Alin Albu-Schaffer, Gerd Hirzinger, Institute of Robotics and Mechatronics DLR e.V. - German Aerospace Center, P.O. Box 1116, D-82230 Wessling, Germany

Limit values (literature survey/exemplary control tests)

- *Preliminary study: bibliographical research of injury data caused by mechanical effects (details: injuries, acting mechanical factors such as static/dynamic breaking strengths, pain-tolerance level values, pressure values, energies, speeds, durations, etc.)*

Main body regions	Body region code	Individual body regions	CSF [N]	IMF [N]	PSP [N/cm²]	CC [N/mm]
Main region 1 : Head with neck	1.1	Skull/Forehead	130	175	30	150
	1.2	Face	65	90	20	75
	1.3	Neck (sides/neck)	145	190	50	50
	1.4	Neck (front/larynx)	35	35	10	10
Main region 2 : Trunk	2.1	Back/Shoulders	210	250	70	35
	2.2	Chest	140	210	45	25
	2.3	Belly	110	160	35	10
	2.4	Pelvis	180	250	75	25
	2.5	Buttocks	210	250	80	15
Main region 3 : Upper extremities	3.1	Upper arm/Elbow joint	150	190	50	30
	3.2	Lower arm/Hand joint	160	220	50	40
	3.3	Hand/Finger	135	180	60	75
Main region 4 : Lower extremities	4.1	Thigh/Knee	220	250	80	50
	4.2	Lower leg	140	170	45	60
	4.3	Feet/Toes/Joint	125	160	45	75

CSF	Clamping/Squeezing force
IMF	Impact force
PSP	Pressure/Surface pressing
CC	Compression constant

Example:

- *Upper extremities*
- CSF = 135 N
- IMF = 180 N
- PSP = 50 N/cm²
- CC = 75 N/mm

© IFA 2010 26

Figure 2

Types of forces

There are four types of forces that should be considered and tested when designing a "Collaborative" robot workcell. These are:

1. **Clamping/squeezing force.** This is the quasi-static case of the robot pressing a compliant part of the human body against a surface. This force should be considered when the robot is under manual control and for **low speed** collisions.
2. **Impact force in free space (Transient contact).** This is the dynamic case of the robot colliding with person where the person is free to recoil from the collision. In some cases the speed and inertia of the person should be added to the speed and inertia of the robot. The inertia of the robot will include the payload, the robot structure, and the forward reflected inertia of the motor and gear train, which can be quite significant. Impact force is considered to be a transient force of short duration.
3. **Impact force against a surface. (Trapping)** This is the case where the person or appendage is trapped between the robot and a hard surface with the **robot moving at speed**. While this can be rare for many applications given proper workcell design, it should be considered. High speed impacts which trap an operator against a surface may be avoided by teaching an "Approach" position which is a greater distance from a fixture than any operator appendage that might enter the workcell, and moving to this "Approach" position at high speed, then moving to the final position at a rigid surface at a slow speed which will not create excessive force in the event of a trapped operator.
4. **Pressure, or force per unit area.** 130N of force applied to a large area, for example 50mm X 50mm is quite different from this same force applied to a small area, for example 1mm X 1mm.

Note that ISO/TS 15066 does not differentiate between clamping/squeezing force (low speed) and impact forces against a rigid surface (high speed) and refers to both cases as "quasi-static" even though they are quite different, as the high speed impact will include dynamic forces from the moving mass, while the low speed clamping forces will be mainly due to motor torques.

Robot Testing and Safety Circuits

While some robots have 6 or even 7 axes and can move in many directions, generally testing can be done in the horizontal plane and in the vertical direction. Since gravity adds to the force in the downwards vertical direction, and since in the horizontal plane forces are symmetric in opposite directions, testing in +X, +Y, and –Z (downwards) is generally sufficient to characterize robot forces.

Precise uses a test stand, to which a certified force gage can be attached in either the vertical or horizontal direction, for testing forces. A “compliance plate” assembly is attached to the robot to simulate the compliance of the human hand of 75N/mm.

Clamping/squeezing force is measured by moving the robot slowly into the force gage until the robot reaches its maximum force and generates an error. **Based on Table A2 from ISO/TS 15066 (Appendix C), Precise has selected the maximum clamping force (quasi-static) to be 140N for a collaborative robot.**

Transient impact force in free space is measured by moving the robot at its maximum permitted speed and payload with the compliance plate impacting the force sensor when the force sensor is held by a person in free space. **Based on Table A2 from ISO/TS 15066, Precise has selected the maximum impact force (transient force) in free space to be 280N for the hand and forearm and 130N for the skull for a collaborative robot.**

Impact force against a rigid surface (trapping) is measured by moving the robot at speeds up to its maximum permitted speed and payload with the compliance plate impacting the force sensor when the force sensor is fixed to a rigid surface.

Pinch points. If a robot has pinch points, a full speed impact in these pinch points should not exceed the quasi-static force above.

Pressure, or force per unit area, may be derived from the above tests and is not tested directly, since it will depend on the application, including the end effector design. It is desirable to eliminate sharp edges or points on the robot or end effector that can result in high pressures. In some case foam padding or spring-loaded end effectors may be used to limit pressure during a collision. Rounded covers and compliant covers (plastic) are helpful in limiting pressure during clamping or impact collisions.

Precise has tested, and TUV has verified the forces for the PF400 robot (See Appendix B of this section). This data is intended to aid the integrator in performing a Performance Level Assessment for determining whether collision forces in a particular workcell may cause operator injury.

An example PLr workcell application assessment based on ISO 13849-1:2006 is given for a PF400 workcell in Appendix A of this section.

Controller Requirements

Early industrial robots were often large, powerful machines with payloads that could exceed 100kg. As a result, the industrial robot safety standards such as ISO 10218-1 often specified a Category 3 control system for these machines, see ISO 10218-1:2011 5.4.2 and 10218-2:2011 5.2.2. However, these standards now recognize that not all robots are large, dangerous machines and include clauses that allow less expensive controllers to be used if a risk assessment justifies this. 10218-1:2011 5.4.3 states "The results of a comprehensive risk assessment performed on the robot and its intended application may determine that a safety-related control system performance other than that in 5.4.2 is warranted for the application". 10218-2:2011 5.2.3 makes a similar statement. Note that in performing a risk assessment under ISO 13849, the first determination, S1 or S2, is made based on whether an operator may sustain a serious or non-recoverable injury. For large, heavy payload robots, S2 is typically selected and this immediately directs the evaluation result to a PLr of c, d, or e, which indicate a Cat 3 controller. For low payload robots, S1 is typically selected which directs the evaluation to a PLr of a, b, or c. In Appendix A of this section an example risk assessment is provided for a PF400 robot with a 500 gram payload and the PL is determined to be "a". This does not require a Cat 3 controller or robot system.

Possible Precise Controller Faults and Controller Testing

Notwithstanding the above, Precise controllers are designed so that no single failure can disable the safety features in the controller and cause an uncontrolled motion. However, the 500gm payload PF400 robots are not Category 3 robots as they cannot cause serious injury and the expense and complexity of 100% redundant safety systems is not warranted. For the 3kg payload version of the PF400 an additional circuit board has been added in the base of the robot*. This circuit board provides redundant, PLd CAT 3 Estop and other safety circuits.*

Safety circuits, Failure Modes, and TUV Testing for the PF400 robots. (Appendix D)

1. **Force Limits by Design or Control.** The PF400 is a low power robot by inherent design and control. For axes 2, 3, 4, and the gripper, the maximum forces that can be applied by the motors, multiplied by the transmission are well under 140N. In the case of the Z axis, the maximum force required to support the Z axis gravity load of up to 80N plus a reasonable additional force for acceleration against gravity of 60N, results in a total force of 140N, and is restricted by current limits in firmware. A further reduction in force is set by collaborative force limits in software, so that the clamping/squeezing force (quasi-static) does not exceed 60N.

PF400 Maximum Forces, Newton

	PF400 500gm			PF400 3kg		
	Unlimited	Current Limited	Collab limit	Unlimited	Current Limited	Collab limit
Z axis	314	140	60	314	140	60
J2 at elbow	33	33	33	64	64	18
J3 at wrist	18	18	18	25	25	9
J4 at gripper	11	11	11	17	17	9
Gripper squeeze	23	23	23	23	23	23

2. **Estop circuit for 500gm payload PF400.** For the 500gm payload PF400 plate handler, there is a single Estop circuit. However, the forces applied by this machine are so low (less than 60N at low speeds – see TUV test certification) that most users simply use their hand to stop the plate handler and do not employ an Estop button or pendant. If the Estop circuit is interrupted the robot will decelerate and stop in a Category 1 Estop (decelerate using motor power then turn off motor power). The Estop circuit for the 500gm plate handler is not CAT 3 in that there are not two redundant external Estop circuits. However, a redundant Estop method is available for this low power robot: users can very easily stop it with their hand by grabbing the gripper or links. For TUV testing the forces required to stop the robot and trigger an Estop are measured with a NIST

certified force gage. For Estop testing, the Estop button is depressed and motor power is shut down. *TUV has verified this Estop operation by both button and by stopping the robot by hand.*

3. **Estop circuit for 3kg payload PF3400.** The 3kg PF3400 robot has an additional circuit board in the base of the robot which provides redundant Estop circuits that are tested by forcing the supply voltage low and checking both circuits to be sure Estop is asserted before allowing motor power to be enabled. If either Estop is asserted the motor power supply is shut down after a 1 second delay, AND the motor power amplifiers are disabled. *<u>This Estop circuit is PLd and CAT 3 if a dual circuit Estop button is attached.</u>*

4. **Power failure while the robot is moving.** If AC Power is turned off while the robot is moving at 100% speed, a fail-safe brake on the Z motor is immediately applied to ensure that the robot does not collapse under gravity. Note that for robot axes without brakes, this will result in a Category 0 (axes without brakes can coast) EStop.

5. **Encoder failure at any time.** Precise robots use serial absolute encoders which are checked every 125 micro seconds for any data or checksum errors on the transmitted data. If 8 data errors occur in a row (1ms), motor power is shut down. Communication errors are also checked before allowing motor power to be enabled, and every 4ms thereafter. If 3 communication errors occur in a row the robot is shut down within 12ms. *<u>As either an encoder failure or a broken wire between the encoder and controller will shut down the motor power, the encoder circuits are compliant with CAT 3</u>*. *TUV has verified this fail-safe operation.*

6. **Wireless pendant connection failure.** It is possible to drive Precise robots using a wireless teach pendant, which is in the form of a web server application, in manual mode from a wireless tablet or laptop. In this case, a heartbeat connection is maintained between the controller and the wireless pendant. If this heartbeat connection is lost, the robot will stop moving, but power will remain on (Category 2 soft stop). For this test, the robot is moved under manual control using a wireless pendant and the wireless router is unplugged. The robot should stop. While the wireless pendant function supports an Estop, it is not recommended to use this function for a CAT 3 Estop as it is not redundant, although the robot can also be safely stopped by hand. *TUV has verified this fail-safe operation.*

7. **Power amplifier Command or Amp fault.** Both the total current command and the PID component of the current command are monitored by a separate monitor task for saturation. If either of these current commands saturate for longer than a specified time, a fault is generated and the motor power is shut down. All motors except certain gripper motors in Precise robots are 3 phase brushless motors. These motors require a rotating electrical field which must switch between the 3 phases in order for the motor to turn. If a power transistor shorts to one of the power busses, only a single phase will be energized. The motor will lock up and not turn. *<u>Because a shorted transistor in the power amp cannot cause uncontrolled motion, this is a fail-safe situation and therefore CAT 3 compliant.</u>* This can be demonstrated on the bench by applying DC power from a power supply across one of the motor phases. If one of the motor leads is shorted to ground or another motor lead, the amplifier will detect a fault and shut down within 10 micro seconds. *TUV has verified this fail-safe operation.*

8. **CPU failure or software lockup**. Precise controllers all contain both hardware and separate firmware watchdog timers that must be refreshed every 4 ms by the software running in the CPU or the motor power is disabled and the brakes are set. *<u>This circuit is both PLd and CAT 3 compliant.</u>* This can be demonstrated by dropping the CPU into debug mode via the serial debug port which simulates a software crash. This will disable motor power. *TUV has verified this fail-safe operation.*

9. **Position error, force limits and collision detection**. The PF400 has a control function that limits the maximum force of any axis. This function is used to limit the Z crushing force in both the 500gm and 3kg robots. If the force limit is exceeded due to a collision, a position tracking

error will be generated and will generate either a Category 2 or Category 1 Estop, depending on the magnitude of the error. The controller continuously monitors the commanded robot trajectory versus the actual position at a rate of 2000Hz. If the position error exceeds a threshold, typically set to a few tenths of a degree, the controller stops the robot motion. This function works at all times if the controller CPU is operating. This can be demonstrated by pushing on the robot while stationary to generate a position envelope error. There are redundant monitor functions that check that the position error and force limits are operating correctly. *This is a CAT 3 compliant function.* *TUV has verified this fail-safe operation.*

10. **Motor overheating**. Precise controllers have a “motor duty cycle” monitor which computes the average power level in a motor and shuts down the motor power if a maximum permissible power level is exceeded. This can be demonstrated by driving an axis back and forth rapidly enough that the maximum duty cycle is exceeded and the motor power is turned off.

Test Procedure for the PF400

The worst-case crash condition for the PF400 is when the Z axis is moving downwards at the 100% speed of 500mm/sec and crashes into the relatively non-compliant hand of an operator pinching the hand into a hard surface. A test setup to measure this force is shown below in Figure 4.

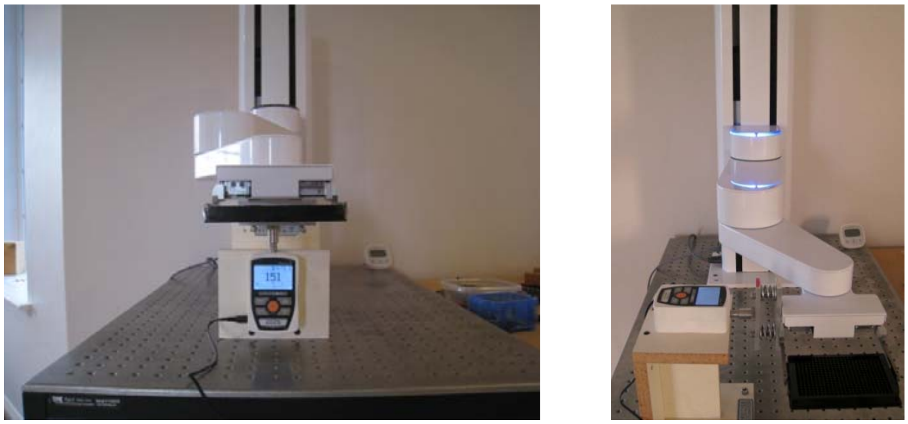


Figure 4: Vertical and Horizontal Test Setup

In this test setup a digital force gage (traceable to NIST standards) is mounted below (or to the left for horizontal testing) of the gripper of the robot and a “hand compliance simulator” consisting of two plates separated by compression springs with a compression constant of 75N/mm equal to the compression constant of a human hand (from figure 2) is attached to the force gage. For the Z test the robot is driven downwards in the Z direction at various speeds and crashes into the hand simulator attached to the force gage. For the Horizontal tests the robot is driven horizontally at various speeds into the hand simulator. A worse case horizontal crash is measured with arm at full extension and J2 (the shoulder) rotating the arm at various speeds into the force gage. This data is shown under the “J2 rot” column.

A typical case of a robot contacting a person is bumping into the person in free space where the person is not trapped against a hard surface, or where there is some distance between the person’s appendage and the hard surface (for the PF400 any distance over 20mm is adequate for the person to stop the robot with a force less than 40N in the horizontal plane and approximately 60N in the –Z direction.

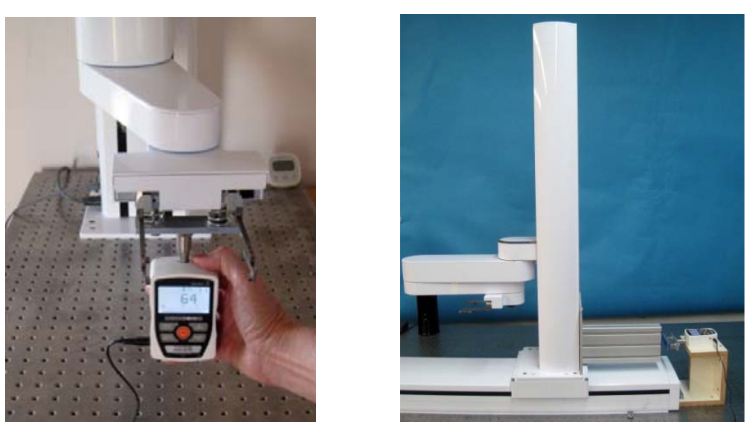


Figure 5: Free Space Collision Test and Linear Rail Test

Robot Workcell Design

Introduction. The PF400 is always configured as a "Collaborative Robot". It is designed for light duty applications with a payload of either 500gms or 3kg depending on the model. The plate handler robot is designed so that maximum forces in the horizontal plane do not exceed approximately 60 Newtons and maximum slow motion forces in the downward Z direction do not exceed 60 Newtons. At the maximum Z downwards speed of 500mm/sec, crash forces can reach 206N for collision with a hard surface. High speed impacts for the robot or linear rail, which could trap an operator against a surface may be avoided by teaching an "Approach" position which is a greater distance from a fixture than any operator appendage that might enter the workcell, and first moving to this "Approach" position at high speed, then moving to the final position at a slow speed which will not create excessive force in the event of a trapped operator.

Workcell Design Recommendations for the PF400

Workcell designers are referred to EN ISO 10218-2:2011 for information on designing safe workcells. Note especially that even a safe robot, when equipped with a tool that renders it dangerous, should be protected from contact with an operator. For example, a robot which can only apply 60 Newtons of force could plunge a sharp needle through a person's hand.

Note that designing a robot workcell can be compared to driving a car. When approaching obstacles (or parking) you slow down.

Safety Glasses. It is required that operators who will move inside the work volume of any robot wear safety glasses at all times, both to prevent any poking injury to the eyes, and also because the machine is often moving around liquids which may be hazardous to the eyes.

Workcell Layout. The PF400 is designed so that the gripper is the lowest point on the robot and cannot descend all the way to the mounting surface (table). Because of this feature, the workcell designer typically does not need to worry about the outer link or inner link of the robot trapping an operator's appendage. The workcell designer will be programming the robot to move 80 to 500 gram workpieces from storage into expensive instruments and back to storage. When moving in and out of storage racks, the robot may make large motions at higher speeds in the Z direction outside the storage rack. As long as the workcell designer leaves 50mm or so between the table and the lowest access point on the storage rack, the robot will never pin an operator's hand to the table at a high speed. When the robot is moving horizontally in and out of the storage racks the maximum forces are well below any injury threshold.

See Appendix A below for an example PLr evaluation for an example PF400 workcell.

Appendix A: Example Performance Level Evaluation for PF400

Example Workcell description: A PF400 Plate Handler moves 80 gram plastic trays from storage racks to an instrument and back to the storage racks. Gripper is an electric parallel jaw gripper with maximum 23N of gripping force for plastic trays and is spring loaded so it will not drop trays if power fails. Robot motion is programmed with approach point 50mm above the instrument tray and final motion into instrument is made at 50mm/sec. Lowest storage rack position is 50mm above table surface.

Figure 9: Example PF400 Workcell: Courtesy of Biosero

Normal Operator Interaction with robot:

Teaching locations in workcell by hand guiding or teach pendant. Maximum robot forces under manual control from PF400 Table 1 are 60N.

Pausing robot and removing racks from workcell with no safety interlocks in workspace. Robot is stopped.

Possible Low Frequency (rare) Interaction with Robot:

Untrained operator reaches into workcell while robot is moving and robot collides with operator. Maximum free space collision force from PF400 Table 1 is 80N.

Untrained operator reaches into workcell while robot is moving into instrument tray and hand is trapped between robot and instrument tray. From PF400 Table 1 max trapping force in downwards Z direction at 50mm/sec (10% of max speed of 500mm/sec) is 80N.

Performance Level: From the above, based on ISO 13849-1:2006:

S is S1, as possible operator collision forces will not injure operators.
F is F1 as normal operation does not involve collisions with robot.
P is P1 as the robot does not make unexpected motions

So PL is "a", and even a Category B controller is sufficient, given the low speeds and small possible collisions forces involved which cannot injure an operator. (See 5.2.3 under EN/ISO 10218-1:2011).

Appendix B: TUV Verification of PF400 Collision Forces

Technical Report No. 72112676-001

Rev. 0

Dated: January 18, 2016

Client:	*Precise Automation* *47350 Fremont Blvd., Fremont, CA 94538*
Manufacturing place:	Jabil Industries 1565 S. Sinclair St., Anaheim, CA 92806
Test subject:	Product: Collaborative Robot Type: PF400
Test specification:	*Maximum applied forces testing*
Purpose of examination:	• Verification of operation as a Collaborative Robot when applied as instructed by Precise Automation using the provided and confirmed force data included in this report. The Force data and Settings information are provided so that the end-user has sufficient information to perform a Risk Assessment and determine how the robot may safely be used in a Collaborative application. In the table below, green cells indicate crushing forces less than 150N for manual control and impact forces less than 180N for free space and rigid surface collisions. Red cells indicate collision forces greater than 180N.The operation of the Robot was verified for safe operation in selected single fault failures. However, the overall reliability of the control system per applicable standards was not verified.
Test result:	*positive:* The test subject was found to be in compliance with • the requirements of the test specification

1 Description of the test subject

1.1 Function

Manufacturer's specification for intended use:
According to the user manual

Manufacturer's specification for predictive misuse:
According to the user manual

1.2 Technical Data: Witnessed Force Testing as a Collaborative Robot

PF400 Test Data

160112

PF400 standard length

PAC Files PreciseFlex 400S Handler Prod_B40

Configuration	J1	J2	J3	J4	J5	Rail	XYZ
10351	9000	0	0	0	0	0	
10352	-4500	0	0	0	0	0	
Peak current, tcnts	32767	31491	32767	19450	4004	22933	
PID Error (10352) % of peak	14%	100%	100%	100%	100%	100%	
Standard Config for crash tests	131	-52	112	299	80	-230	
Config J2 Rotation (max velocity)	131	-27	53	335	80	NA	
100% Joint Speed	500mm/s	360deg/s	720deg/s	720deg/s	400mm/s	750mm/s	
100% Joint Accel	3500	1500	2300	4000	10000	1000	
100% XYZ Speed							500
100% XYZ Accel							2500

	PF400 Collisions at Gripper									Z decel	
Speed	Manual Control			Free Space Collision			Rigid Surface Collision			100%	40%
	X	Y	-Z	X	Y	-Z .5kg	X	Y	J2 rot	-Z .5kg	-Z .5kg
100%	62	20	60	31	52	75	98	97	163	206	153
80%	61	20	57	31	43	77	85	76	116	175	135
60%	62	19	58	23	31	92	72	64	97	144	114
40%	61	20	57	22	32	79	60	37	68	112	101
20%	61	19	57	22	30	73	50	22	33	94	86
10%	58	29	57	22	29	66	46	22	21	79	75

Linear Rail Collisions at Z Column			
Speed	Manual	Free	Rigid
	X	X	X
100%	148	159	235
80%	149	162	205
60%	143	160	184
40%	141	168	177
20%	140	164	155
10%	140	157	150

2. Order

2.1 Date of Purchase Order, Customer's Reference

January 4, 2016

2.2 Receipt of Test Sample, Location

N/A

2.3 Date of Testing and/or Evaluation

January 11 thru 12, 2016

2.4 Location of Testing and/or Evaluation

At Precise Automation, Fremont, CA

2.5 Points of Non-compliance or Exceptions of the Test Procedure and/or Evaluation procedure.

Positive

3. Test/Evaluation Results

3.1 Positive Test/Evaluation Results

- Operation safety during single failure
- Mechanical safety – Applied forces: Manual Control, Free Space Collision and Rigid Surface Collision

3.2 Points of non-compliance according to the test/evaluation specification

None

4. Remark

The user manual has been examined according to the minimum requirements described in the product standard. The manufacturer is responsible for the accuracy of further particulars as well as of the composition and layout.

4.1 Remarks to Factory

None

5. Documentation

None

6. Summary

TÜV America, Inc.
Product Safety Services

January 18, 2016

Engineer: Rick Grumski Technical Report checked: Chris Caserta

Collision Force Table for PF3400

PAC Files PreciseFlex 3400S

170713

Configuration	J1	J2	J3	J4	J5	Rail	XYZ
10351	4000	12000	14000	9000	0	NA	
10352	-2600	-12000	-14000	-9000	0	0	
Peak current, tcnts	7077	27702	24279	14837	6356	22933	
PID Error (10352) % of peak	37%	43%	58%	61%	100%	100%	
Standard Config for crash tests	50	-52	113	-61	102	-230	
Config for J2 Rotation (max velocity)	44	-1	66	-334	102	NA	
100% Joint Speed	500mm/s	90deg/s	720deg/s	720deg/s	400mm/s	750mm/s	
100% Joint Accel	1800	1100	1200	4000	10000	1000	
100% XYZ Speed							500
100% XYZ Accel							2000

PF400 Collisions at Gripper, 50mm programmed interference										Z deceleration %	
Speed	**Manual Control**			**Free Space Collision**			**Rigid Surface Collision**			100%	40%
	X cart	Y cart	-Z 1kg	X cart	Y cart	-Z 1.0kg	X cart	Y cart	J2 rot	-Z 1.0kg	-Z 1.0kg
100%	20	30	95	85	85	100	105	138	223	234	164
80%	21	29	90	64	82	100	89	114	149	195	139
60%	20	24	88	50	51	100	72	94	116	155	118
40%	19	21	81	34	28	96	50	70	87	121	104
20%	17	20	75	18	24	85	23	41	47	105	92
5%	16	12	72	18	23	93	16	22	19	80	77

Appendix C: Table A2 from ISO/TS 15066: 2016

Table A.2 — Biomechanical limits

Body region	Specific body area		Quasi-static contact		Transient contact	
			Maximum permissible pressure [a] p_S N/cm²	Maximum permissible force [b] N	Maximum permissible pressure multiplier [c] P_T	Maximum permissible force multiplier [c] F_T
Skull and forehead [d]	*1*	*Middle of forehead*	*130*	*130*	*not applicable*	*not applicable*
	2	*Temple*	*110*		*not applicable*	
Face [d]	*3*	*Masticatory muscle*	*110*	*65*	*not applicable*	*not applicable*
Neck	4	Neck muscle	140	150	2	2
	5	Seventh neck muscle	210		2	
Back and shoulders	6	Shoulder joint	160	210	2	2
	7	Fifth lumbar vertebra	210		2	2
Chest	8	Sternum	120	140	2	2
	9	Pectoral muscle	170		2	
Abdomen	10	Abdominal muscle	140	110	2	2
Pelvis	11	Pelvic bone	210	180	2	2
Upper arms and elbow joints	12	Deltoid muscle	190	150	2	2
	13	Humerus	220		2	
Lower arms and wrist joints	14	Radial bone	190	160	2	2
	15	Forearm muscle	180		2	
	16	Arm nerve	180		2	

[a] These biomechanical values are the result of the study conducted by the University of Mainz on pain onset levels. Although this research was performed using state-of-the-art testing techniques, the values shown here are the result of a single study in a subject area that has not been the basis of extensive research. There is anticipation that additional studies will be conducted in the future that could result in modification of these values. Testing was conducted using 100 healthy adult test subjects on 29 specific body areas, and for each of the body areas, pressure and force limits for quasi-static contact were established evaluating onset of pain thresholds. The maximum permissible pressure values shown here represent the 75th percentile of the range of recorded values for a specific body area. They are defined as the physical quantity corresponding to when pressures applied to the specific body area create a sensation corresponding to the onset of pain. Peak pressures are based on averages with a resolution size of 1 mm². The study results are based on a test apparatus using a flat (1,4 × 1,4) cm (metal) test surface with 2 mm radius on all four edges. There is a possibility that another test apparatus could yield different results. For more details of the study, see Reference [5].

[b] The values for maximum permissible force have been derived from a study carried out by an independent organization (see Reference [6]), referring to 188 sources. These values refer only to the body regions, not to the more specific areas. The maximum permissible force is based on the lowest energy transfer criteria that could result in a minor injury, such as a bruise, equivalent to a severity of 1 on the Abbreviated Injury Scale (AIS) established by the Association for the Advancement of Automotive Medicine. Adherence to the limits will prevent the occurrence of skin or soft tissue penetrations that are accompanied by bloody wounds, fractures or other skeletal damage and to be below AIS 1. They will be replaced in future by values from a research more specific for collaborative robots.

[c] The multiplier value for transient contact has been derived based on studies which show that transient limit values can be at least twice as great as quasi-static values for force and pressure. For study details, see References [2], [3], [4] and [7].

[d] Critical zone (*italicized*)

Table A2, Continued

Table A.2 *(continued)*

<table>
<tr><th rowspan="2">Body region</th><th rowspan="2" colspan="2">Specific body area</th><th colspan="2">Quasi-static contact</th><th colspan="2">Transient contact</th></tr>
<tr><th>Maximum permissible pressure [a]
p_S
N/cm^2</th><th>Maximum permissible force [b]
N</th><th>Maximum permissible pressure multiplier [c]
P_T</th><th>Maximum permissible force multi-plier [c]
F_T</th></tr>
<tr><td rowspan="9">Hands and fin-gers</td><td>17</td><td>Forefinger pad D</td><td>300</td><td rowspan="9">140</td><td>2</td><td rowspan="9">2</td></tr>
<tr><td>18</td><td>Forefinger pad ND</td><td>270</td><td>2</td></tr>
<tr><td>19</td><td>Forefinger end joint D</td><td>280</td><td>2</td></tr>
<tr><td>20</td><td>Forefinger end joint ND</td><td>220</td><td>2</td></tr>
<tr><td>21</td><td>Thenar eminence</td><td>200</td><td>2</td></tr>
<tr><td>22</td><td>Palm D</td><td>260</td><td>2</td></tr>
<tr><td>23</td><td>Palm ND</td><td>260</td><td>2</td></tr>
<tr><td>24</td><td>Back of the hand D</td><td>200</td><td>2</td></tr>
<tr><td>25</td><td>Back of the hand ND</td><td>190</td><td>2</td></tr>
<tr><td rowspan="2">Thighs and knees</td><td>26</td><td>Thigh muscle</td><td>250</td><td rowspan="2">220</td><td>2</td><td rowspan="2">2</td></tr>
<tr><td>27</td><td>Kneecap</td><td>220</td><td>2</td></tr>
<tr><td rowspan="2">Lower legs</td><td>28</td><td>Middle of shin</td><td>220</td><td rowspan="2">130</td><td>2</td><td rowspan="2">2</td></tr>
<tr><td>29</td><td>Calf muscle</td><td>210</td><td>2</td></tr>
</table>

[a] These biomechanical values are the result of the study conducted by the University of Mainz on pain onset levels. Although this research was performed using state-of-the-art testing techniques, the values shown here are the result of a single study in a subject area that has not been the basis of extensive research. There is anticipation that additional studies will be conducted in the future that could result in modification of these values. Testing was conducted using 100 healthy adult test subjects on 29 specific body areas, and for each of the body areas, pressure and force limits for quasi-static contact were established evaluating onset of pain thresholds. The maximum permissible pressure values shown here represent the 75th percentile of the range of recorded values for a specific body area. They are defined as the physical quantity corresponding to when pressures applied to the specific body area create a sensation corresponding to the onset of pain. Peak pressures are based on averages with a resolution size of 1 mm^2. The study results are based on a test apparatus using a flat (1,4 × 1,4) cm (metal) test surface with 2 mm radius on all four edges. There is a possibility that another test apparatus could yield different results. For more details of the study, see Reference [5].

[b] The values for maximum permissible force have been derived from a study carried out by an independent organization (see Reference [6]), referring to 188 sources. These values refer only to the body regions, not to the more specific areas. The maximum permissible force is based on the lowest energy transfer criteria that could result in a minor injury, such as a bruise, equivalent to a severity of 1 on the Abbreviated Injury Scale (AIS) established by the Association for the Advancement of Automotive Medicine. Adherence to the limits will prevent the occurrence of skin or soft tissue penetrations that are accompanied by bloody wounds, fractures or other skeletal damage and to be below AIS 1. They will be replaced in future by values from a research more specific for collaborative robots.

[c] The multiplier value for transient contact has been derived based on studies which show that transient limit values can be at least twice as great as quasi-static values for force and pressure. For study details, see References [2], [3], [4] and [7].

[d] Critical zone (*italicized*)

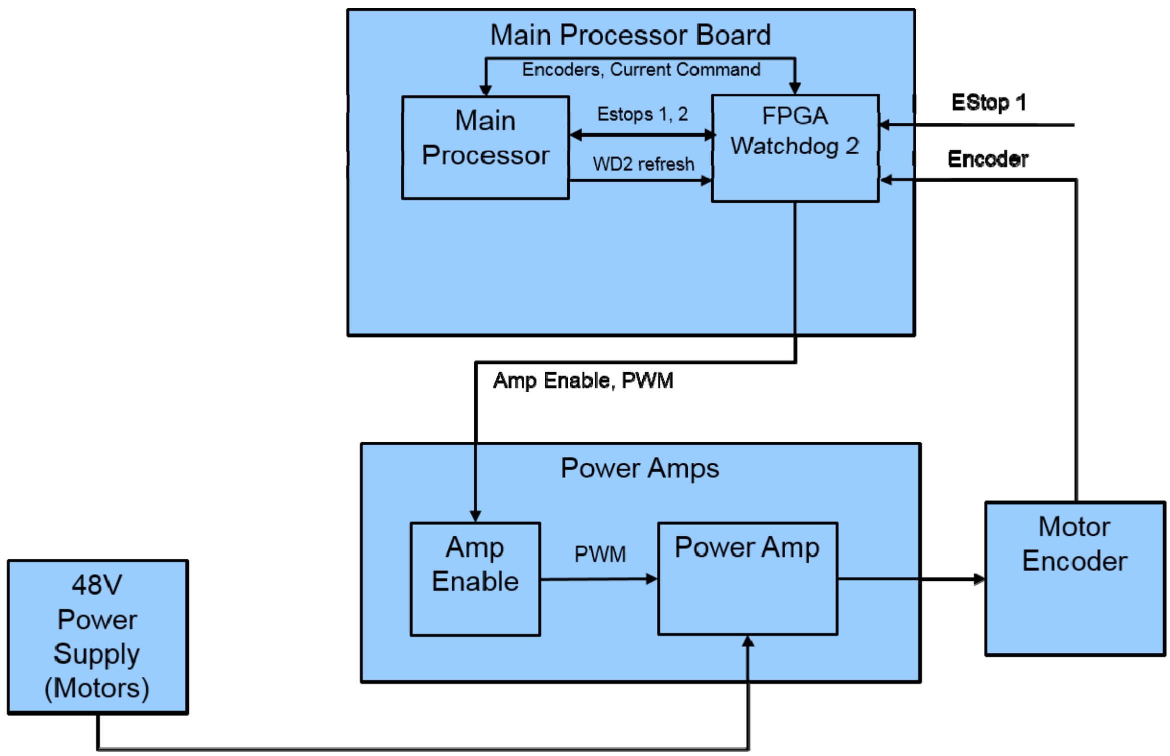
Appendix D1: Safety Circuits for PF400 500gm Payload

14-Jun-17	PF400 500gm								
Safety Circuit	Start up Test [1]	Redundant	Continuous Test	Diagnostic Coverage	MTTFdl, Years	Power Off On Failure	PL	Category Safety	Notes
Estop	No	Yes	No	50%	92	Yes	c	1	Estop turns off amp enable and PWM
									Stopping robot with hand turns off amp enable and PWM to amp
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
CPU Monitor	No	No	Yes	99%	100	Yes	d	1	FPGA watchdog timer turns off amp enable and PWM
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 amp enable, PWM and 48V
									Counter embedded in position word to confirm CPU read from FPGA
Power amp Fault	Yes	Yes	Yes	90%	100	Yes	d	3	Startup test confirms zero current when 48V 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
Collab Force Limit	Yes	Yes	Yes	90%	SW	Yes	d	3	Tests 2, 3, 4 above test HW. Motor driven against brake to test SW current
									Current saturation triggers separate fault, turns off amp enable and PWM
									Monitor function with WD turns off amp enable and PWM to amp
									Assymetric current limits limit Z force even with gravity load
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

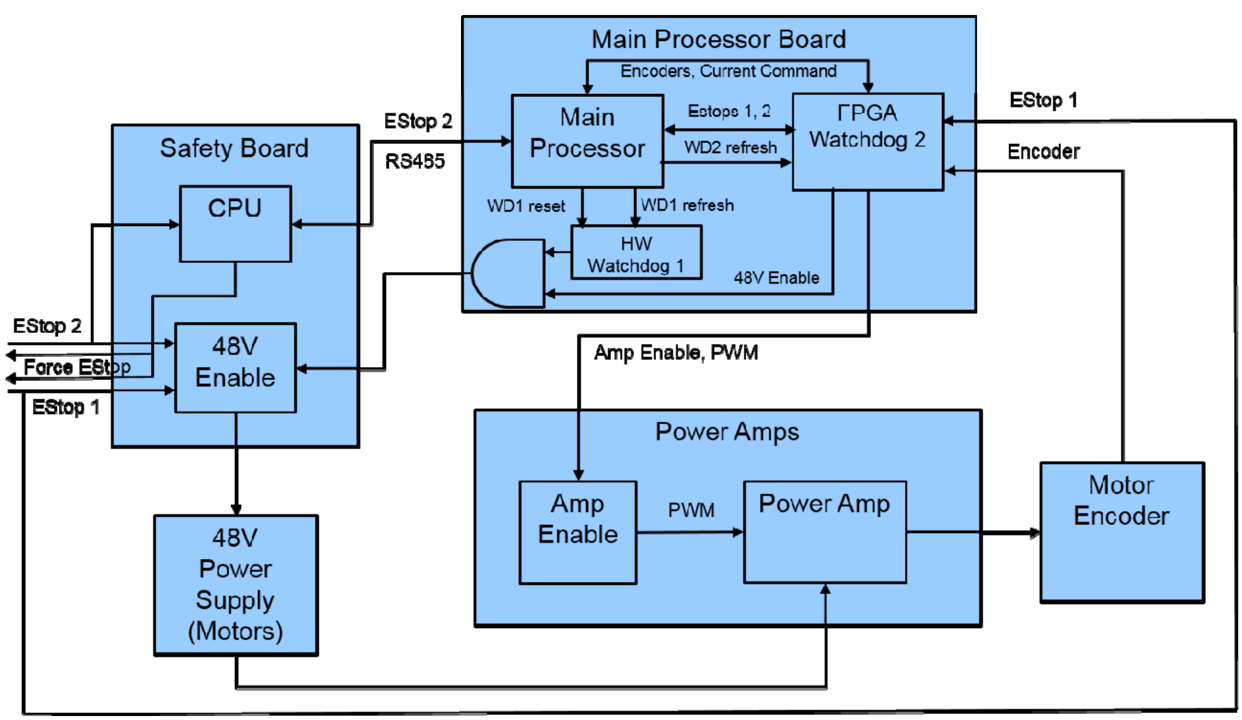
Appendix D2: Safety Circuits for PF3400 3kg Payload

14-Jun-17	PF3400								
Safety Circuit	Start up Test 1	Redundant	Continuous Test	Diagnostic Coverage	MTTFdl, Years	Power Off On Failure	PL	Category Safety	Notes (PF3400t has redundant Estop and 48V power supply enable)
Estop	Yes	Yes	No	99%	100	Yes	d	3	Startup test forces Estop, checks 48V power disable, zero amp current
									Dual Estop circuits turns off amp enable and PWM
									Dual Estop circuits turnS off 48V power
									Stopping robot with hand turns off amp enable, PWM and 48V
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
CPU Monitor	Yes	Yes	Yes	99%	100	Yes	d	3	Startup test forces CPU WD low, checks 48V power disabled
									Independent dual watchdog timers turn off amp enable, PWM and 48V
									Processor on safety board monitors main CPU. Disables 48V if failure.
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 amp enable, PWM and 48V
									Counter embedded in position word to confirm CPU read from FPGA
Power amp Fault	Yes	Yes	Yes	90%	100	Yes	d	3	Startup test confirms zero current when 48V 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
Collab Force Limit	Yes	Yes	Yes	90%	SW	Yes	d	3	Tests 2, 3, 4 above test HW. Motor driven against brake to test SW current limit.
									Position envelope error triggers fault, turns off power at amp and 48V
									Current saturation triggers separate fault, turns off power at amp and 48V
									Monitor function with WD turns off power at amp and 48V
									Monitor and CPU WD tested at startup turning off 48V
									Assymetric current limits limit Z force even with gravity load
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

PF400 500gm Safety Circuits



PF3400 3kg Safety Circuits



Installation Information

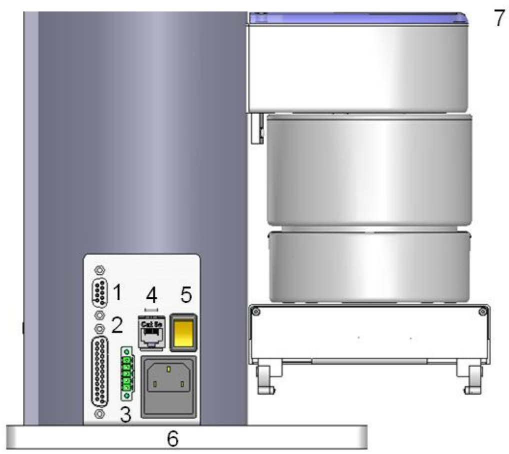
Environmental Specifications

The PreciseFlex robots must be installed in a clean, non-condensing environment. Light fluid splashing around the base of the robot is acceptable, but 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:

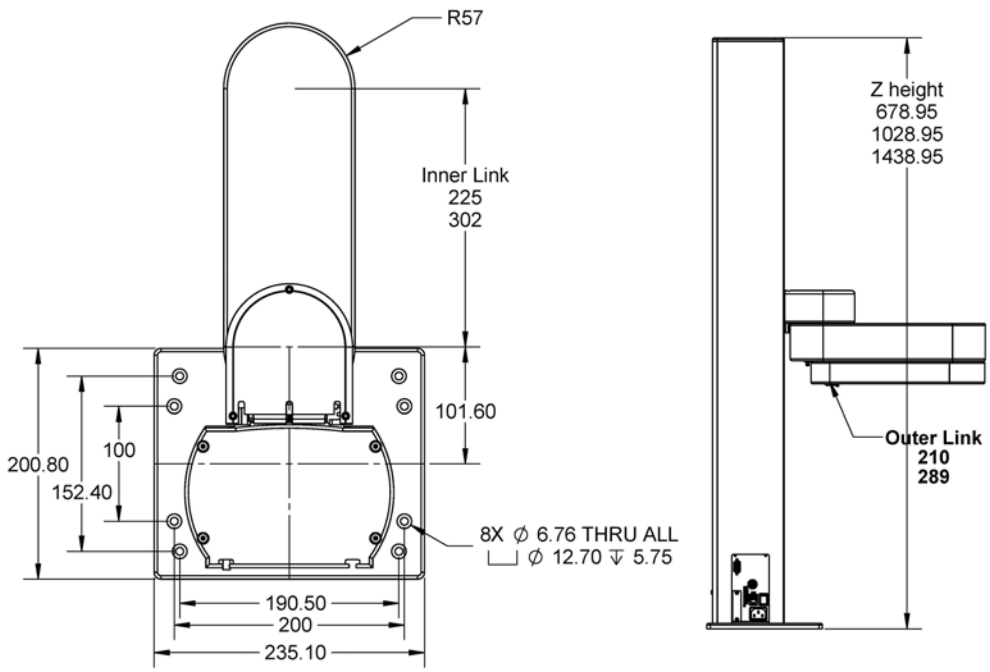
- System AC input power receptacle
- Lighted AC on/off power switch
- Connectors for controller input and output signals



Item	Name	Description
1	9 Pin D Sub Connector	Contains RS-232 Serial Port, 24 VDC, Gnd Can be used for optional teach pendant
2	25 Pin D Sub Connector	For optional DIO module, 12 inputs, 8 outputs
3	EStop Connector	EStop and Cell Interlock Signals
4	Ethernet Connector	For Ethernet to Computer Cable
5	Power Switch	Lighted Power Switch
6	Power Entry Module	For IEC plug. Contains dual fuse drawer.
7	Power Status Light	Blinks to indicate power status

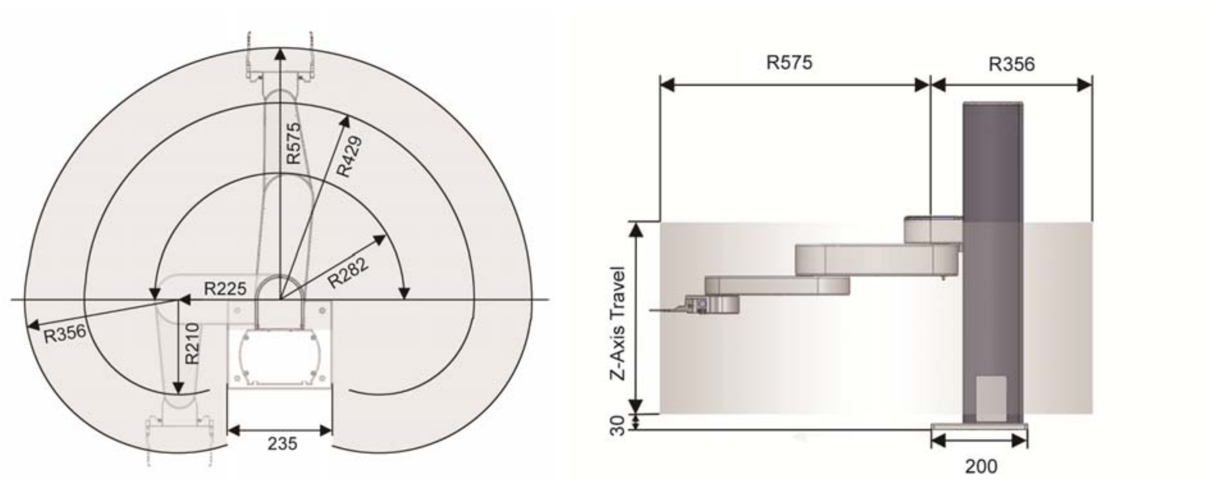
System Dimensions

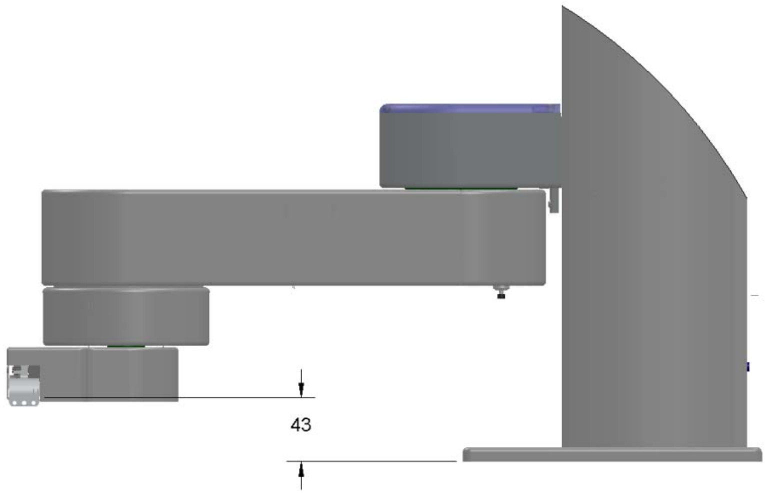
Both top and right views are shown below. All dimensions are in millimeters.



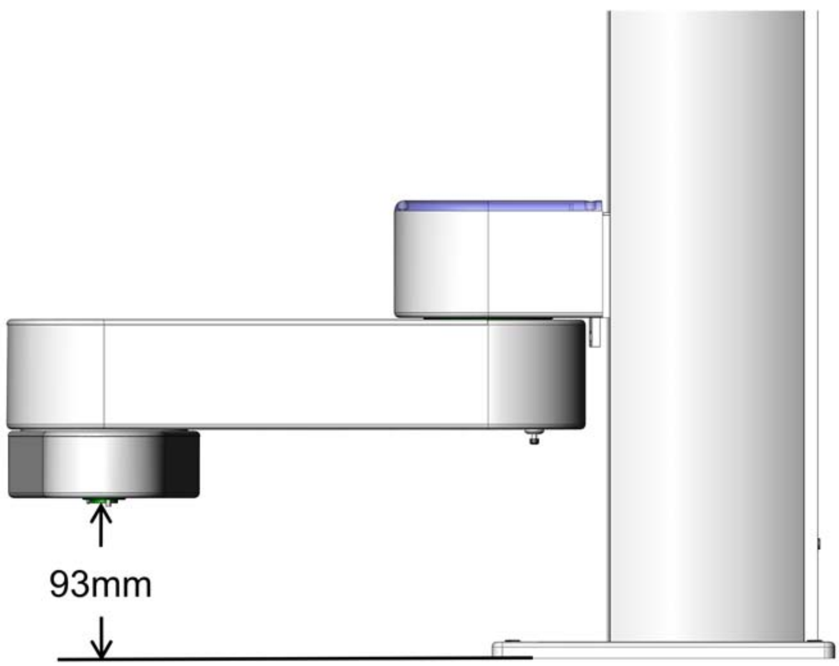
Mounting Dimensions for PF400, Standard Reach
(Increase height by 22mm for PF3400)
(For XR robot, R575 increases to R731 and inner link length increases from 225 to 302mm)

Working Volume

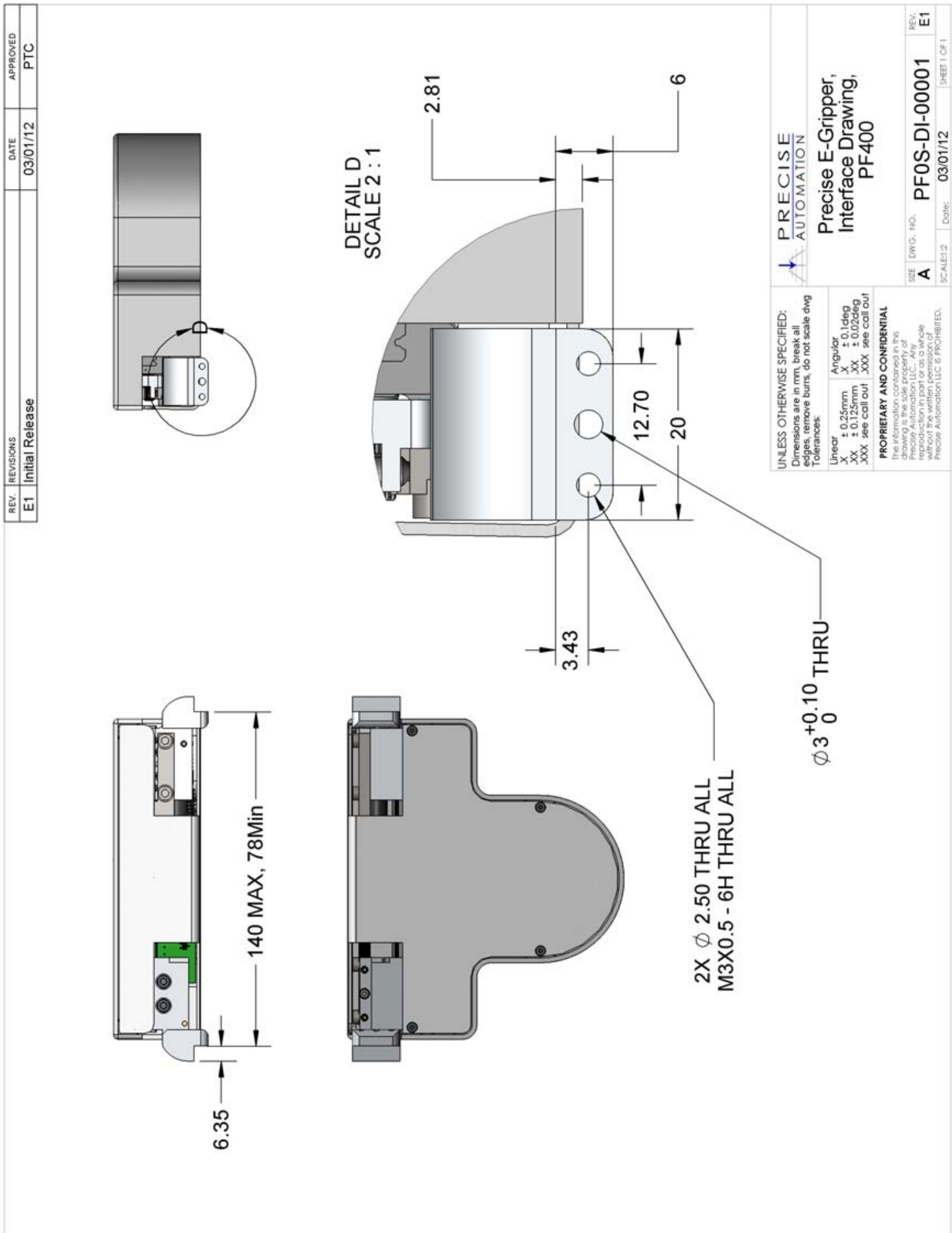


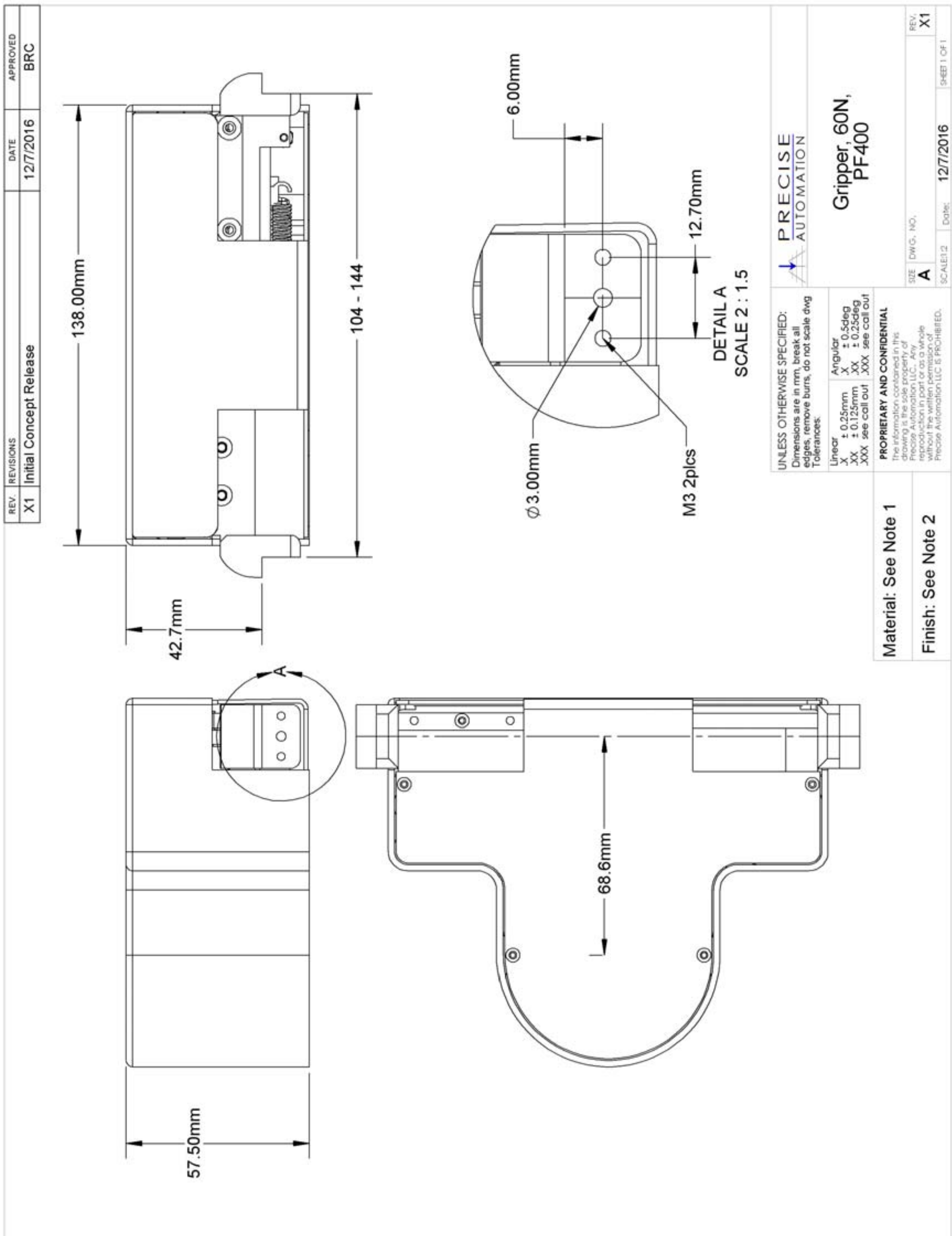


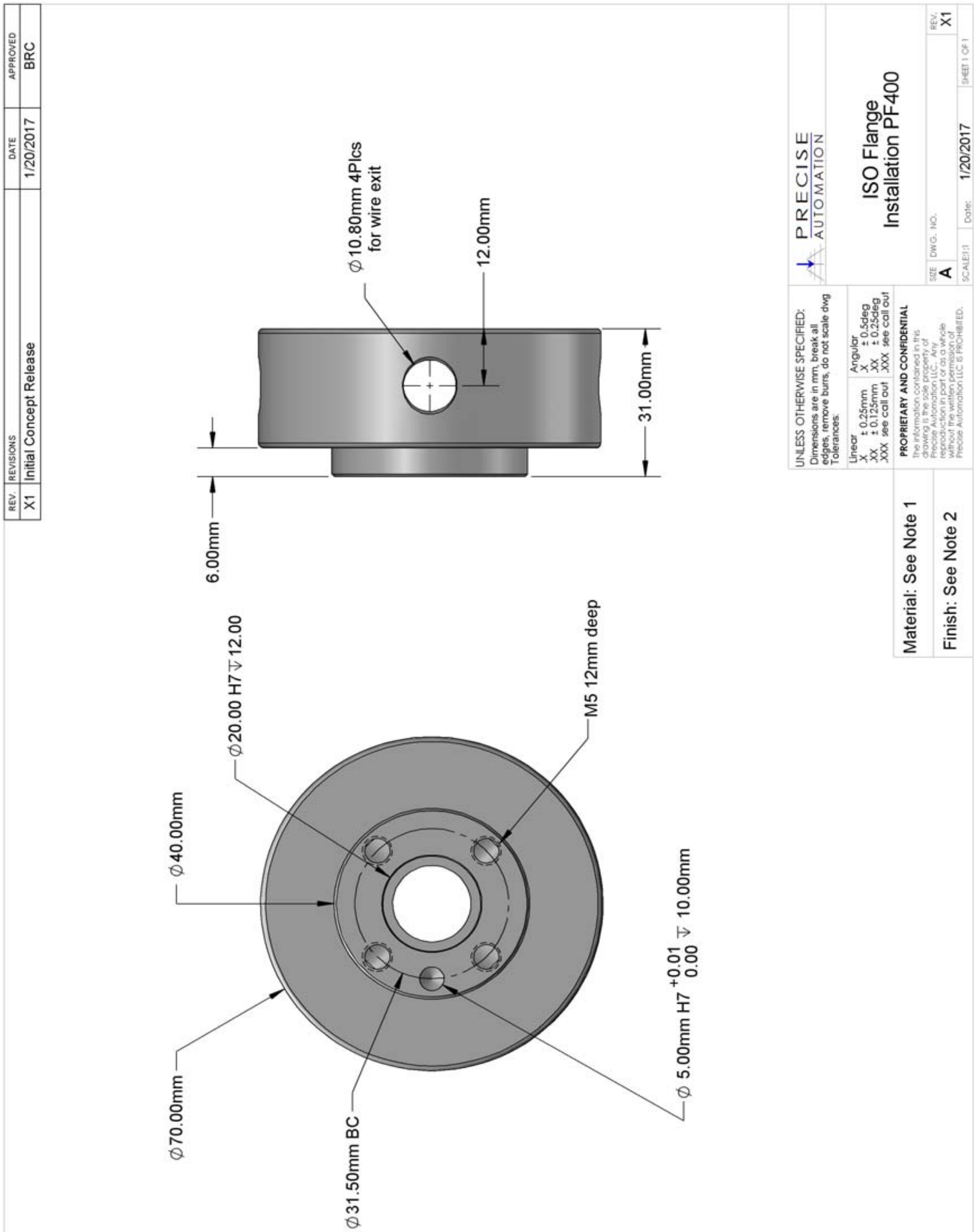
Finger Mount Height from Base PF400



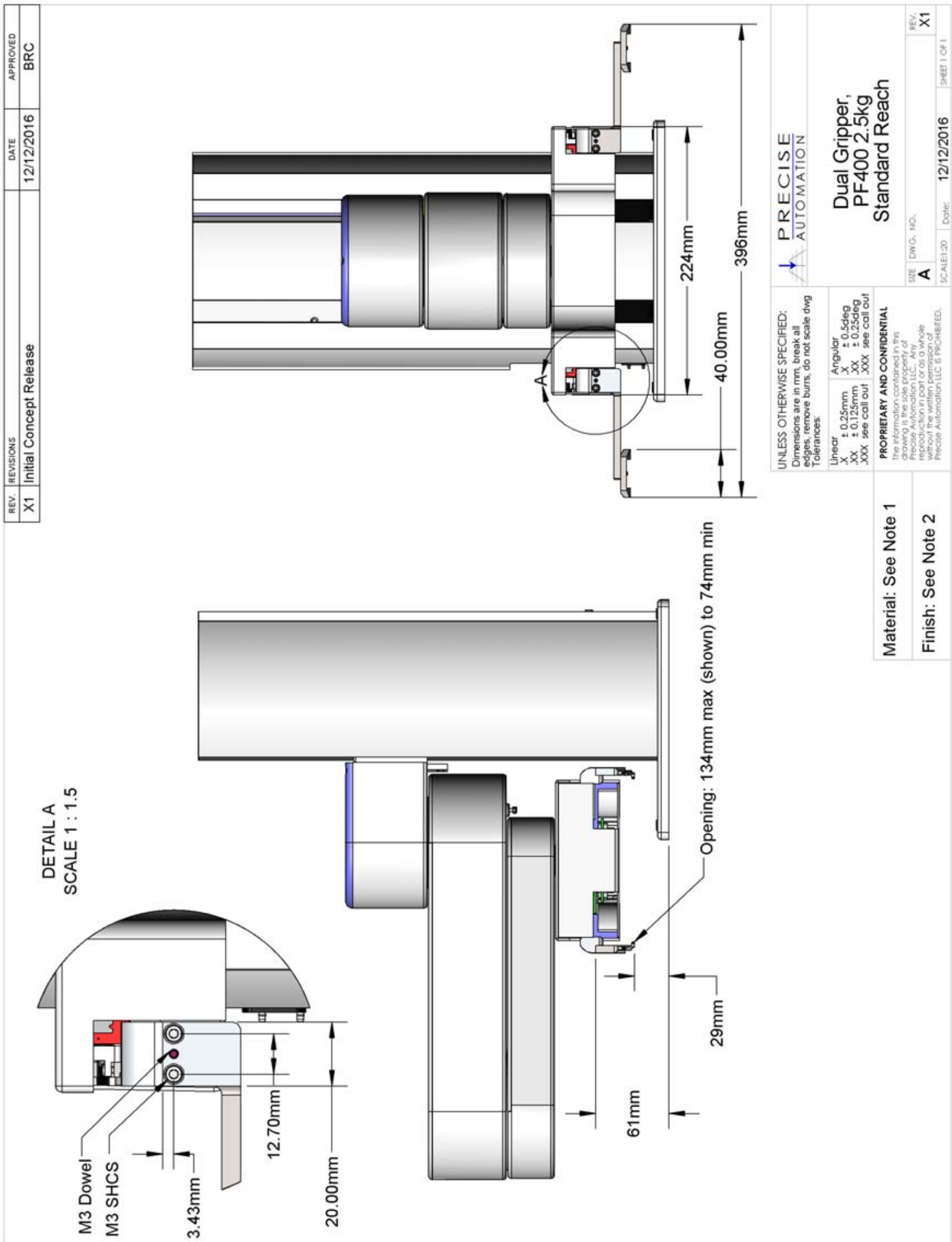
Gripper Flange Mount Height from PF3400


REV.
REVISIONS
DATE
APPROVED
E1
Initial Release
03/01/12
PTC
D
DETAIL D
SCALE 2 : 1
2.81
6
12.70
20
3.43
⌀3 +0.10 0 THRU
140 MAX, 78Min
6.35
2X ⌀ 2.50 THRU ALL
M3X0.5 - 6H THRU ALL
UNLESS OTHERWISE SPECIFIED:
Dimensions are in mm, break all edges, remove burrs, do not scale dwg
Tolerances:
Linear
.X ± 0.25mm
.XX ± 0.125mm
.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
Precise E-Gripper, Interface Drawing, PF400
SIZE
A
DWG. NO.
PF0S-DI-00001
REV.
E1
SCALE1:2
Date:
03/01/12
SHEET 1 OF 1


REV. REVISIONS DATE APPROVED
X1 Initial Concept Release 12/7/2016 BRC
138.00mm
104 - 144
42.7mm
6.00mm
12.70mm
DETAIL A
SCALE 2 : 1.5
Ø3.00mm
M3 2plcs
A
68.6mm
57.50mm
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 ± 0.25mm .XX ± 0.125mm .XXX see call out
Angular .X ± 0.5deg .XX ± 0.25deg .XXX see call out
PROPRIETARY AND CONFIDENTIAL
PRECISE AUTOMATION
Gripper, 60N, PF400
SIZE A
DWG. NO.
REV. X1
SCALE 1:2
Date: 12/7/2016
SHEET 1 OF 1

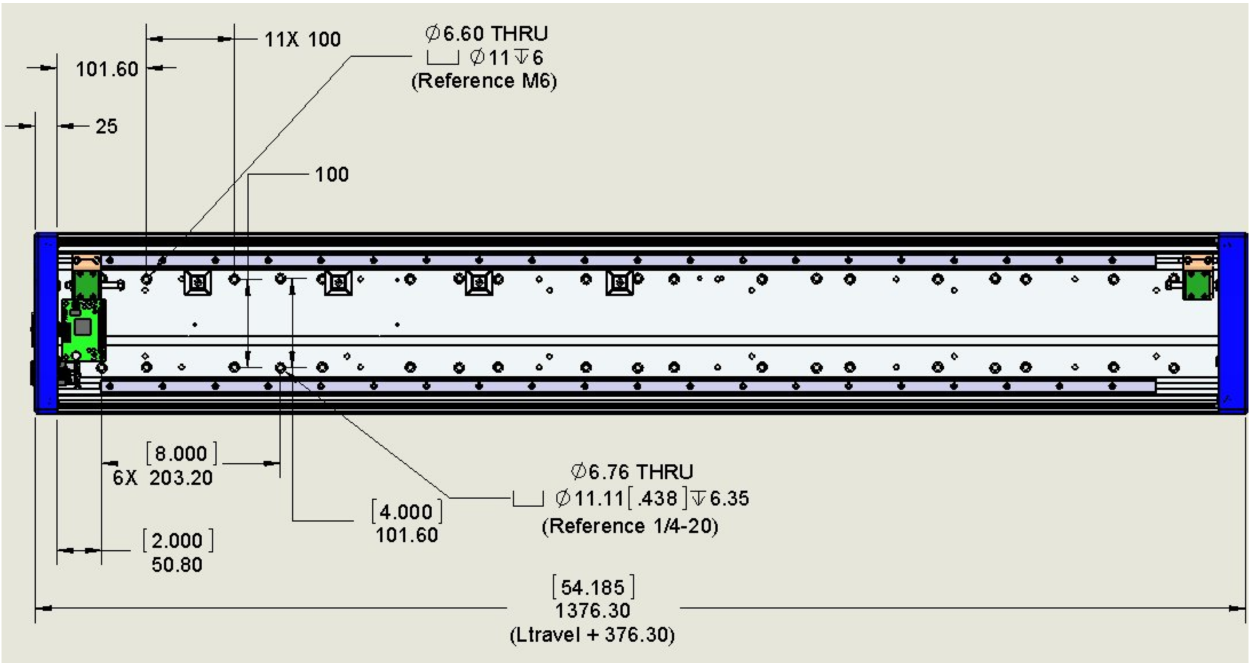


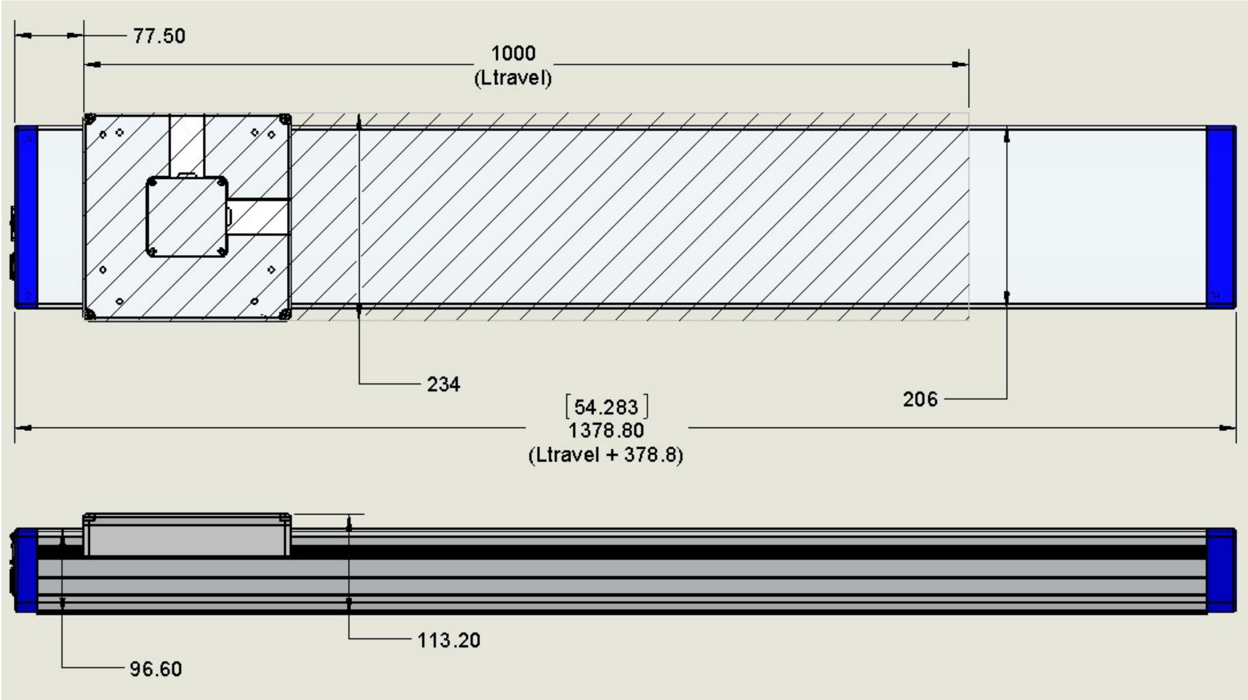
REV.
REVISIONS
DATE
APPROVED
X1
Initial Concept Release
1/20/2017
BRC
Ø70.00mm
Ø31.50mm BC
Ø40.00mm
Ø20.00 H7 ↧ 12.00
M5 12mm deep
Ø 5.00mm H7 +0.01 0.00 ↧ 10.00mm
6.00mm
Ø10.80mm 4Plcs
for wire exit
12.00mm
31.00mm
Material: See Note 1
Finish: See Note 2
UNLESS OTHERWISE SPECIFIED:
Dimensions are in mm, break all edges, remove burrs, do not scale dwg
Tolerances:
Linear
.X ± 0.25mm
.XX ± 0.125mm
.XXX see call out
Angular
.X ± 0.5deg
.XX ± 0.25deg
.XXX see call out
PROPRIETARY AND CONFIDENTIAL
PRECISE
AUTOMATION
ISO Flange
Installation PF400
SIZE
A
DWG. NO.
REV.
X1
Date:
1/20/2017


REV.
REVISIONS
DATE
APPROVED
X1
Initial Concept Release
12/12/2016
BRC
DETAIL A
SCALE 1 : 1.5
M3 Dowel
M3 SHCS
3.43mm
12.70mm
20.00mm
61mm
29mm
Opening: 134mm max (shown) to 74mm min
224mm
396mm
40.00mm
A
UNLESS OTHERWISE SPECIFIED:
Dimensions are in mm, break all edges, remove burrs, do not scale dwg
Tolerances:
Linear
.X ± 0.25mm
.XX ± 0.125mm
.XXX see call out
Angular
.X ± 0.5deg
.XX ± 0.25deg
.XXX see call out
PROPRIETARY AND CONFIDENTIAL
Material: See Note 1
Finish: See Note 2
PRECISE
AUTOMATION
Dual Gripper,
PF400 2.5kg
Standard Reach
SIZE
A
DWG. NO.
REV.
X1
SCALE1:20
Date:
12/12/2016
SHEET 1 OF 1

Linear Axis Mounting Dimensions

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

PreciseFlex robots must be attached to a rigid surface that can withstand lateral forces of 200 Newtons without moving or vibrating. The robot base has an integrated bolting pattern to accommodate 4 M6 SHCS mounting screws located as shown above.

Tool Mounting – PreciseFlex 400

The Precise Flex 400 is typically supplied with an electric gripper. In some cases, a pneumatic gripper may be supplied by Precise or by the end user. However, the standard robot does not include pneumatic lines, so if pneumatic tooling is needed, the robot must be ordered with pneumatic lines installed. The outer link has a flange for users to attach grippers or tooling. The 3kg version typically comes with 2 pneumatic lines installed, but may be ordered with optional electric grippers.

To facilitate electrical interfacing to user tooling, digital I/O signals are available in the outer link. For robots with an electric gripper, the electric gripper controller in the outer link has two extra inputs and two extra outputs available for users. However, it should be noted that all the wires in the 18 conductor slip ring are consumed by the electric gripper, so any additional IO wiring will have to be routed outside the robot wrist. For robots without the electric gripper, a ribbon cable from the G1400A controller is routed to the outer link. This ribbon cable provides 4 digital inputs and 4 digital outputs from the controller.

For robots where support for a pneumatic gripper or pneumatic tooling has been ordered, one or two (for the 3kg robot) 1/8in OD air hoses are routed from the connector plate in the base through the robot and out to the outer link. These air hoses can be connected to one or two solenoids mounted in the outer link for tooling control.

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 inner link must be removed by removing 4 M3 X 20 SHCS from the bottom of the inner link

Please see the *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. Both of these manuals are available in PDF format and are also contained in the *Precise Documentation Library*.

Power Requirements

The PreciseFlex robots contain auto-ranging power supplies that operate between 90 to 132 and 180 to 264 VAC, 50 or 60Hz. The robots are 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 green Phoenix E-Stop connector and the Manual Control 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.

Hardware Reference

System Schematics

System Diagram and Power Supplies

The robot has a 24VDC and 48VDC power supply located in the Z column. For Revisions A and B, the AC input to these power supplies is fused, with two fuses in a pull-out fuse drawer in the IEC type power entry module. For Revision C and later, these fuses have been removed. The power supplies have both over-current and over-voltage protection and are CSA, UL, and CE certified. The robot controller and electric gripper are powered by the 24VDC supply. The 4 main robot motors are powered by the 48VDC supply. The 48VDC supply is protected against over voltage bus pump up by an energy dump circuit, which connects a 25 Watt dump resistor across the 48VDC supply output when the voltage reaches 56 volts, and disconnects the dump resistor when the voltage drops to 52 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.

DC power is routed from the power supplies to an interconnect board in the base of the Z column (Z Base Motor Interface Board). From this interconnect board the power is routed in P1 and P2 flat ribbon cables. The P2 cable contains the 48VDC motor power and is connected to the power amplifier board in the controller. The P1 cable contains the 24VDC controller power and is routed to a second interconnect board (the MIDS Power Interface Board), that is mounted on the side wall inside the inner link of the robot. From this board 24VDC power is connected to the main robot controller.

Four digital input and four digital output signals from the main robot controller are also connected to the MIDS Power Interface Board through a 10 conductor ribbon cable. One digital input signal, DI3 is routed down to the base of the robot thru the P1 ribbon cable, where it is connected to the green Phoenix Estop connector. This provides a digital input for safety interlock purposes. There is a jumper on the MIDS Power Board which jumps this signal to the P1 cable. This jumper must be installed for this connection to work. The rest of the digital inputs and outputs are daisy chained to a second connector on the MIDS board for use if needed. Some of these signals are used when the pneumatic gripper option is installed.

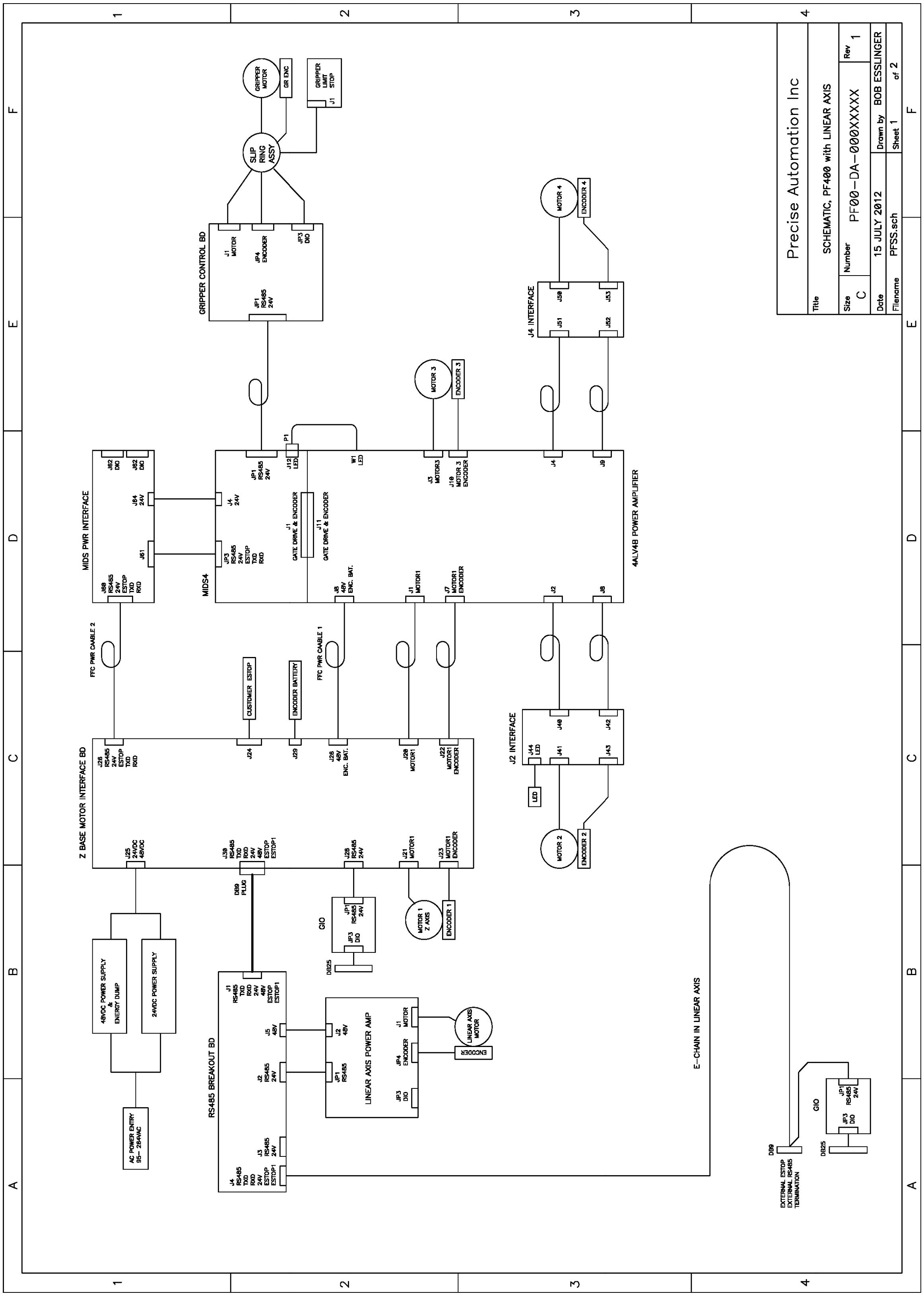
The ESTOP circuit is also connected from the controller to MIDS Power Interface Board and down through the P1 cable to two ESTOP connectors: the green Phoenix connector (J24) and the 9 pin Dsub connector (J30). The ESTOP pins on these connectors are wired in series, so that both connectors must have either a jumper or ESTOP switch installed that completes the ESTOP circuit.

The gripper controller is connected to the main controller through an RS485 cable that is routed through the elbow, along with the power and encoder cables for the J4 motor. The RS485 cable also supplies power for the gripper controller.

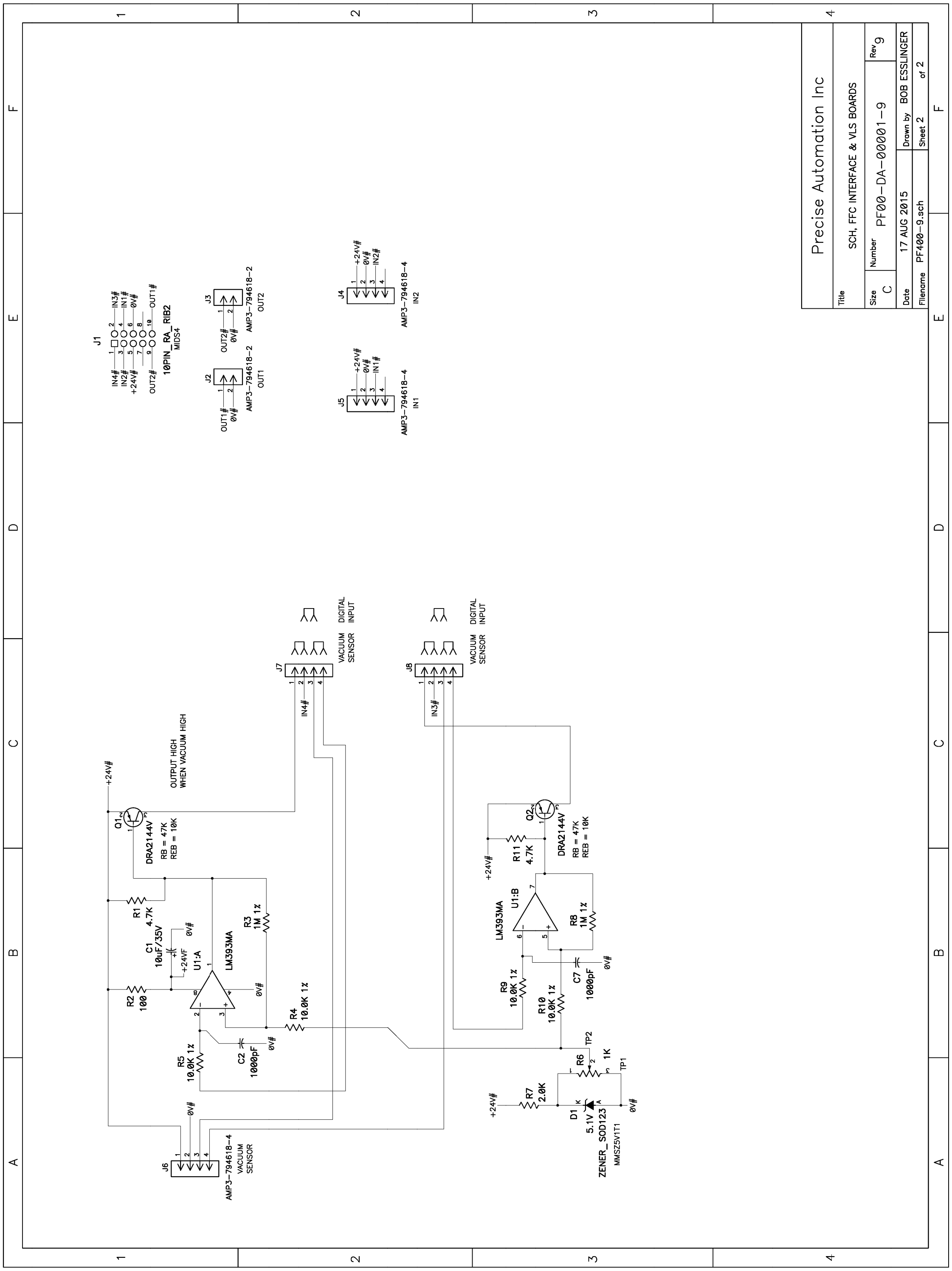
The motors for the Z column, the Shoulder and the Wrist all plug into an interconnect board which converts the signals from the motor cables to the flat ribbon cables. The motor for the elbow plugs directly into the controller amplifier board in the inner link.

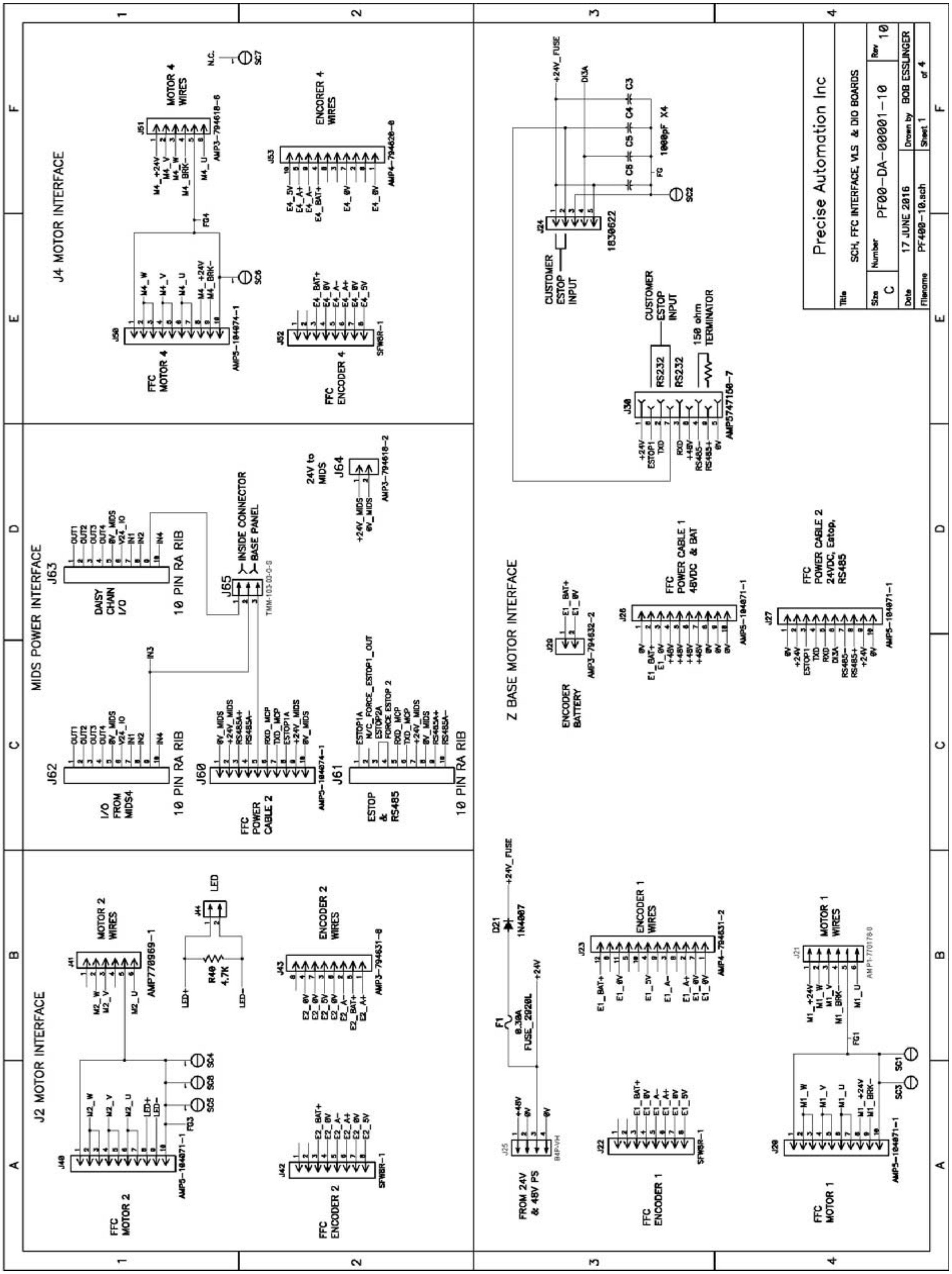
The cable from the brake release button under the Shoulder plugs into the amplifier board in the inner link. This button provides a ground return from the Z column brake to ground bypassing the transistor that performs this function under computer power so that the brake can be released manually without motor power being enabled.

Schematic: System Overview

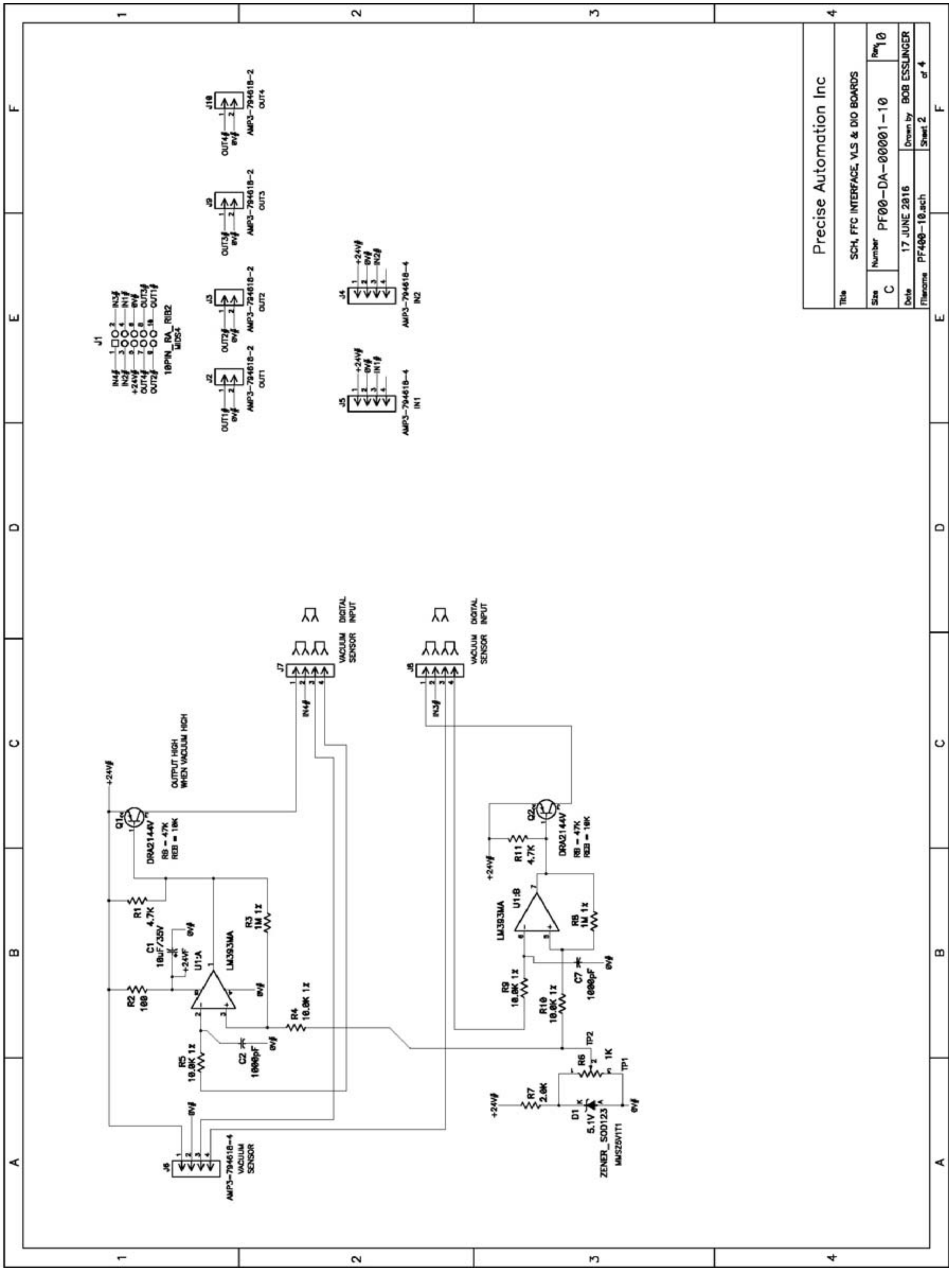


Schematic: FFC Boards Revision B PF400

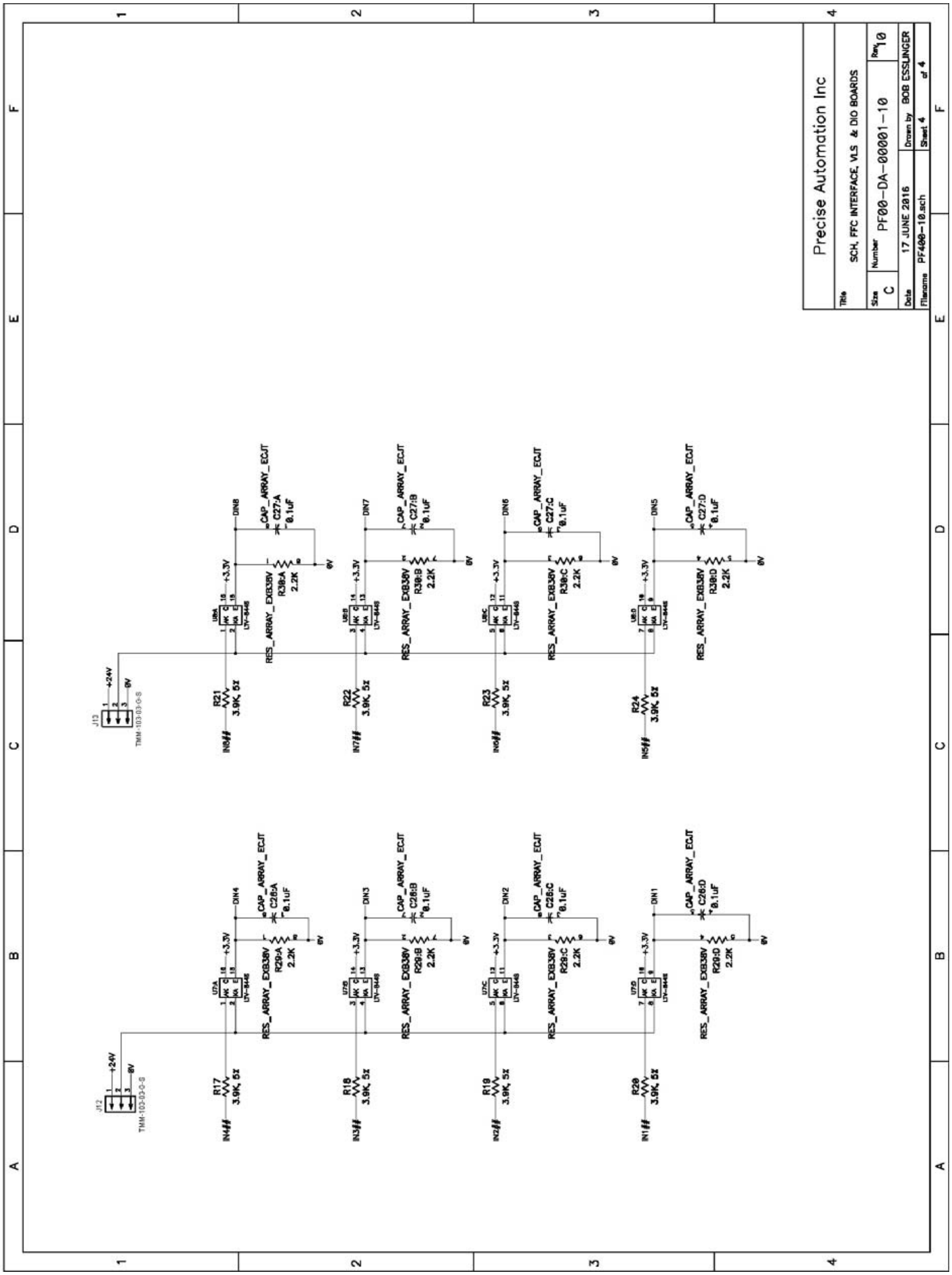


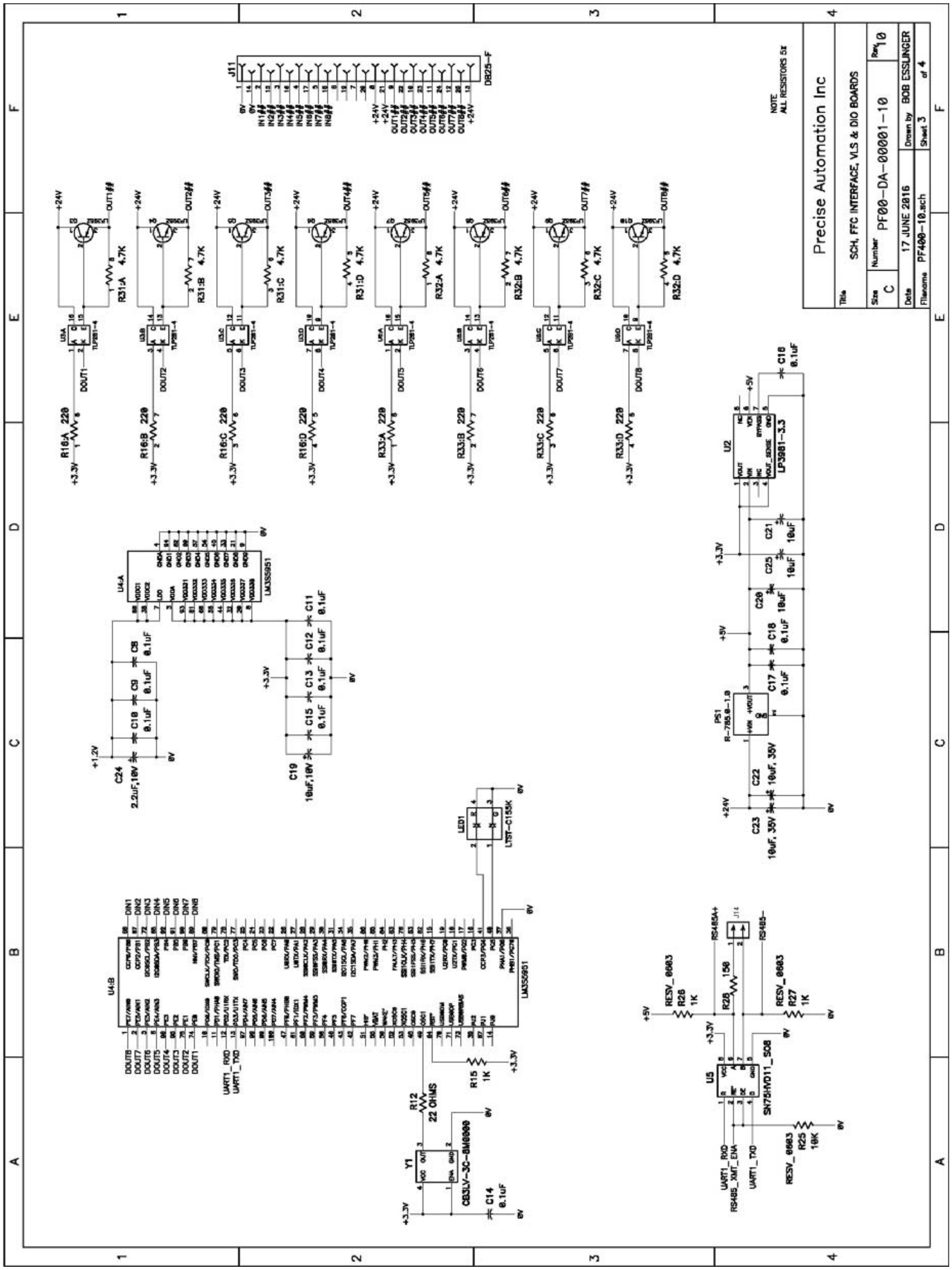

J4 MOTOR INTERFACE
MIDS POWER INTERFACE
J2 MOTOR INTERFACE
Z BASE MOTOR INTERFACE
Precise Automation Inc
Title SCH, FFC INTERFACE, VLS & DIO BOARDS
Size C
Number PF00-DA-00001-10
Rev 10
Date 17 JUNE 2016
Drawn by BOB ESSLINGER
Filename PF400-10.sch
Sheet 1 of 4

Schematic: FFC Boards Revision C PF400

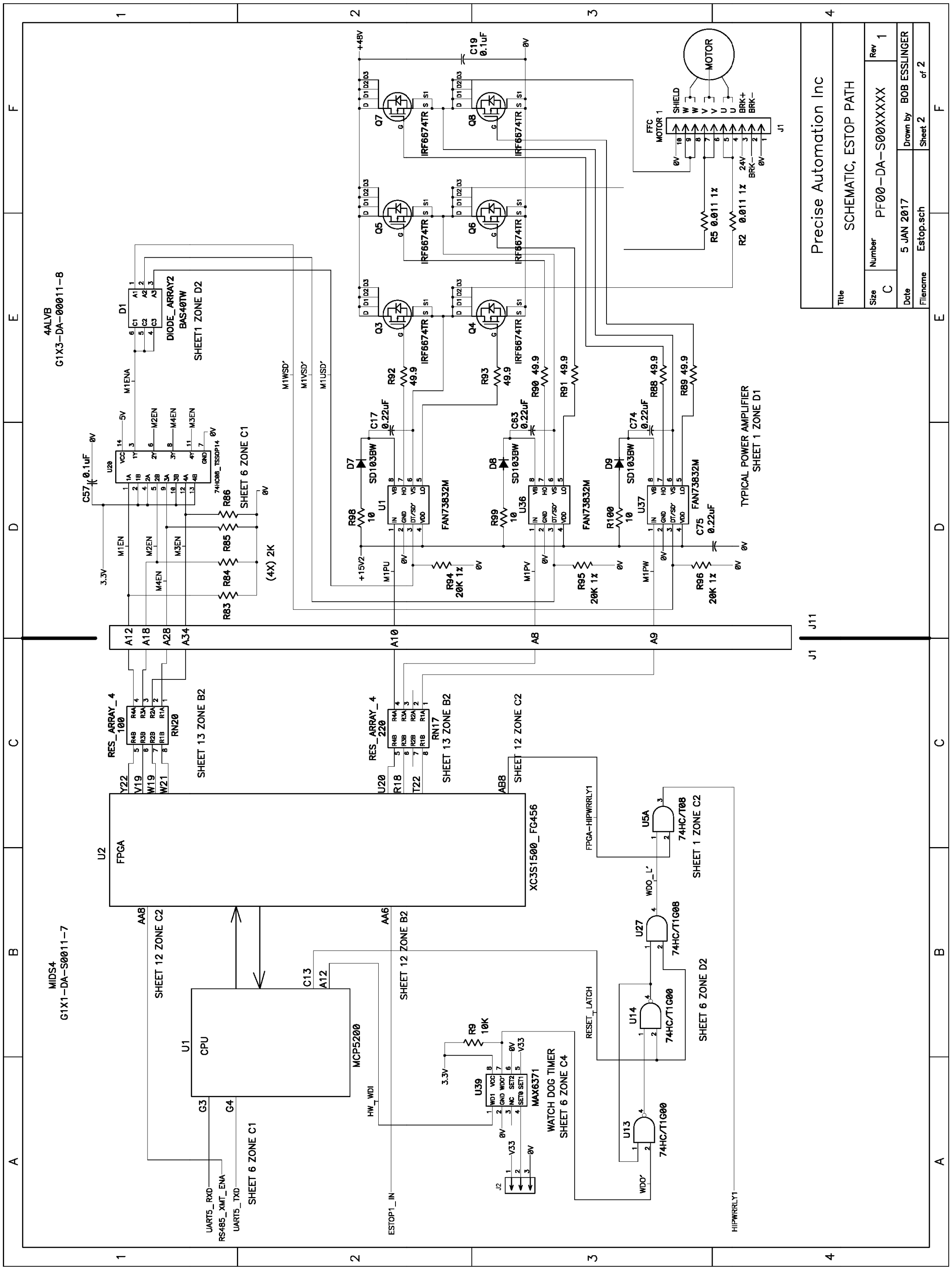


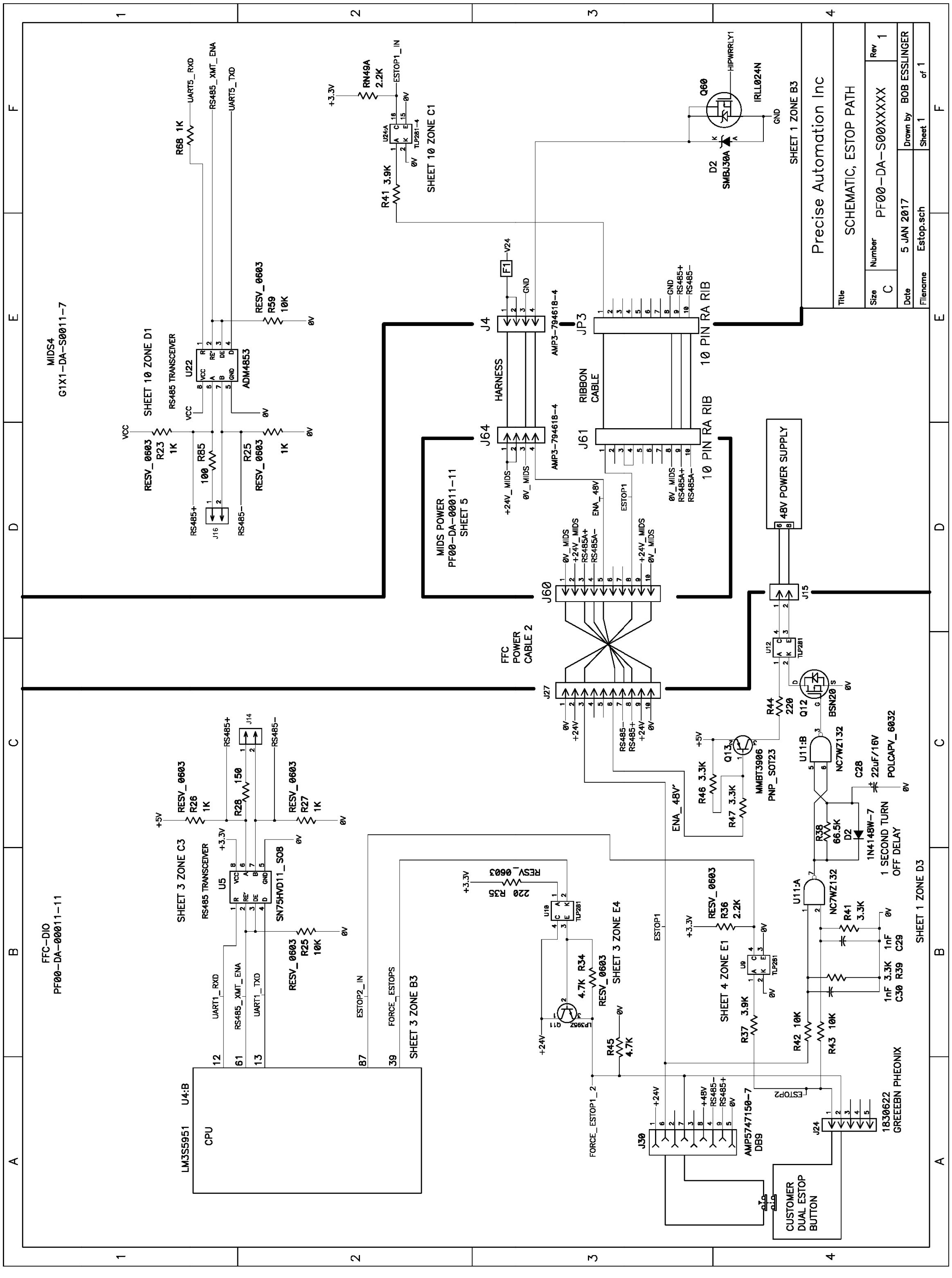
Schematic: FFC Boards 3kg PF400

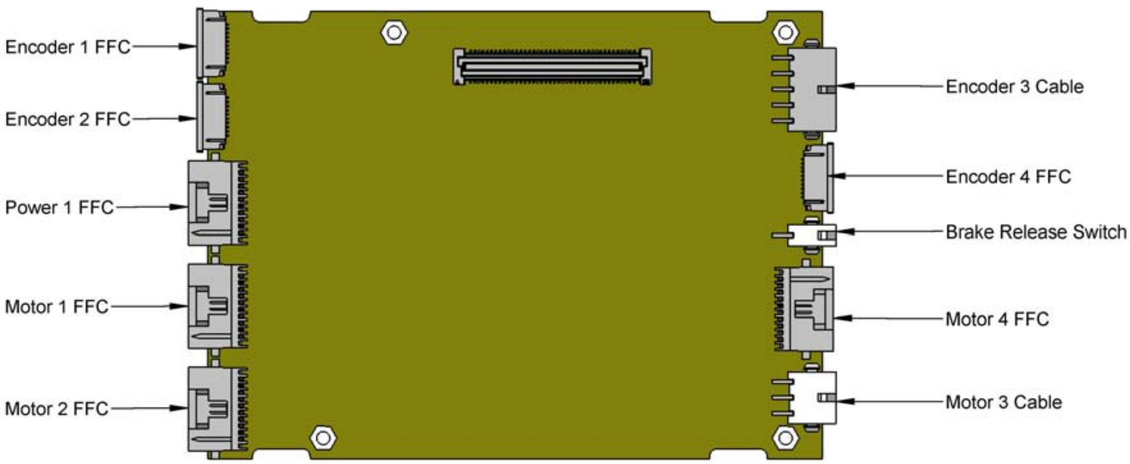



Precise Automation Inc
SCH, FFC INTERFACE, VLS & DIO BOARDS
PF00-DA-00001-10
17 JUNE 2016
BOB ESSLINGER
PF400-10.sch
NOTE
ALL RESISTORS 5%

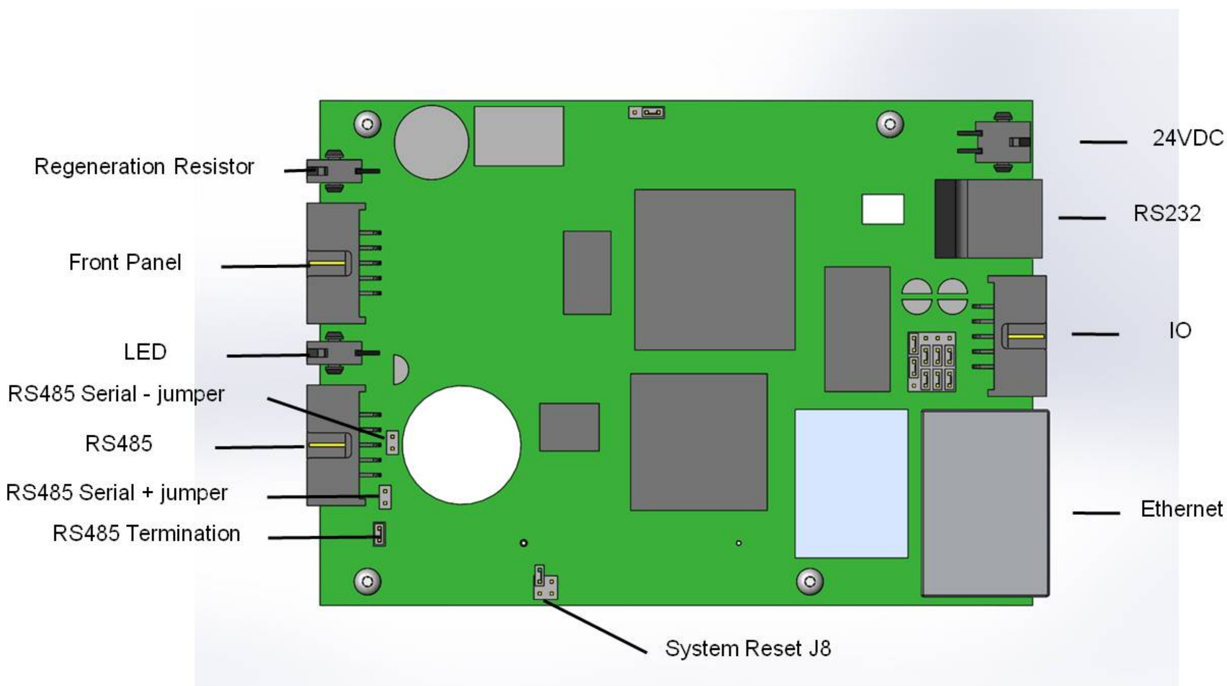
Schematic: Safety System Overview PF400 CAT3



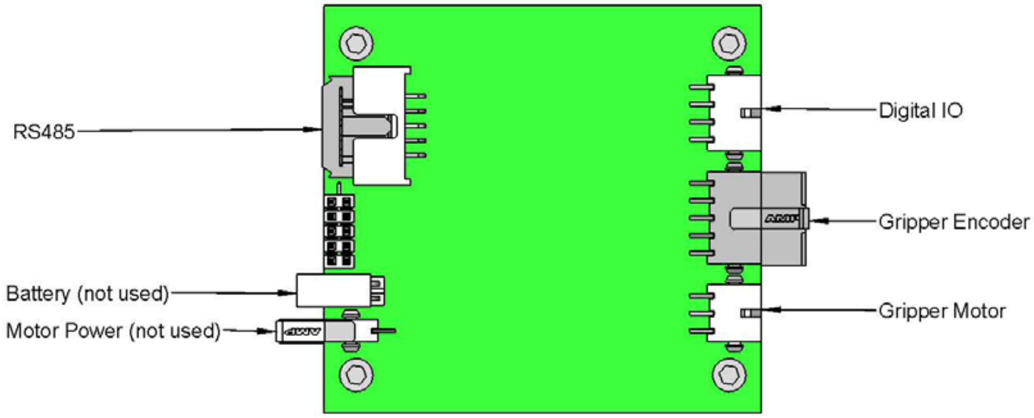

Precise Automation Inc
SCHEMATIC, ESTOP PATH
PF00-DA-S00XXXXX
5 JAN 2017
Estop.sch
BOB ESSLINGER



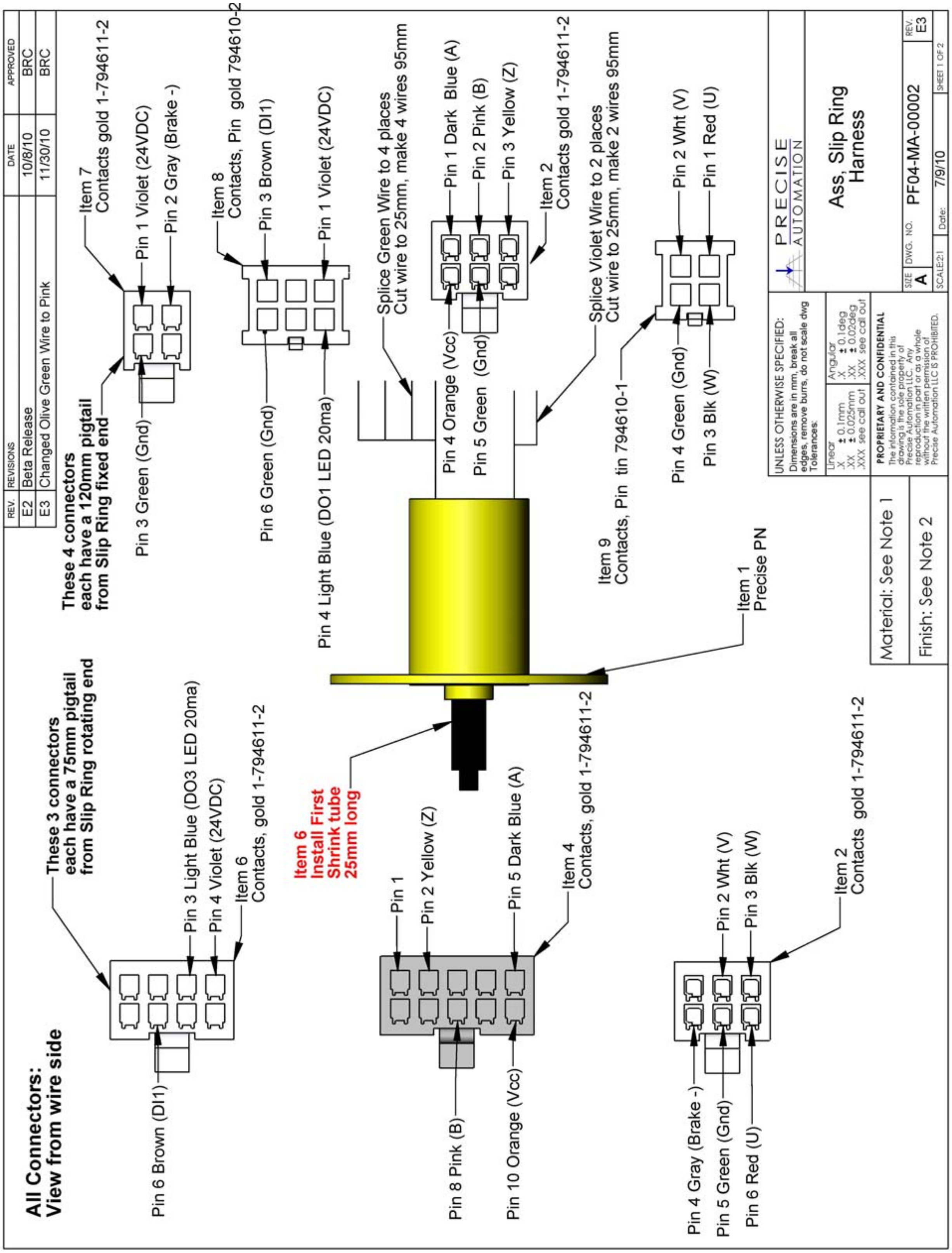
Controller Power Amplifier Connectors

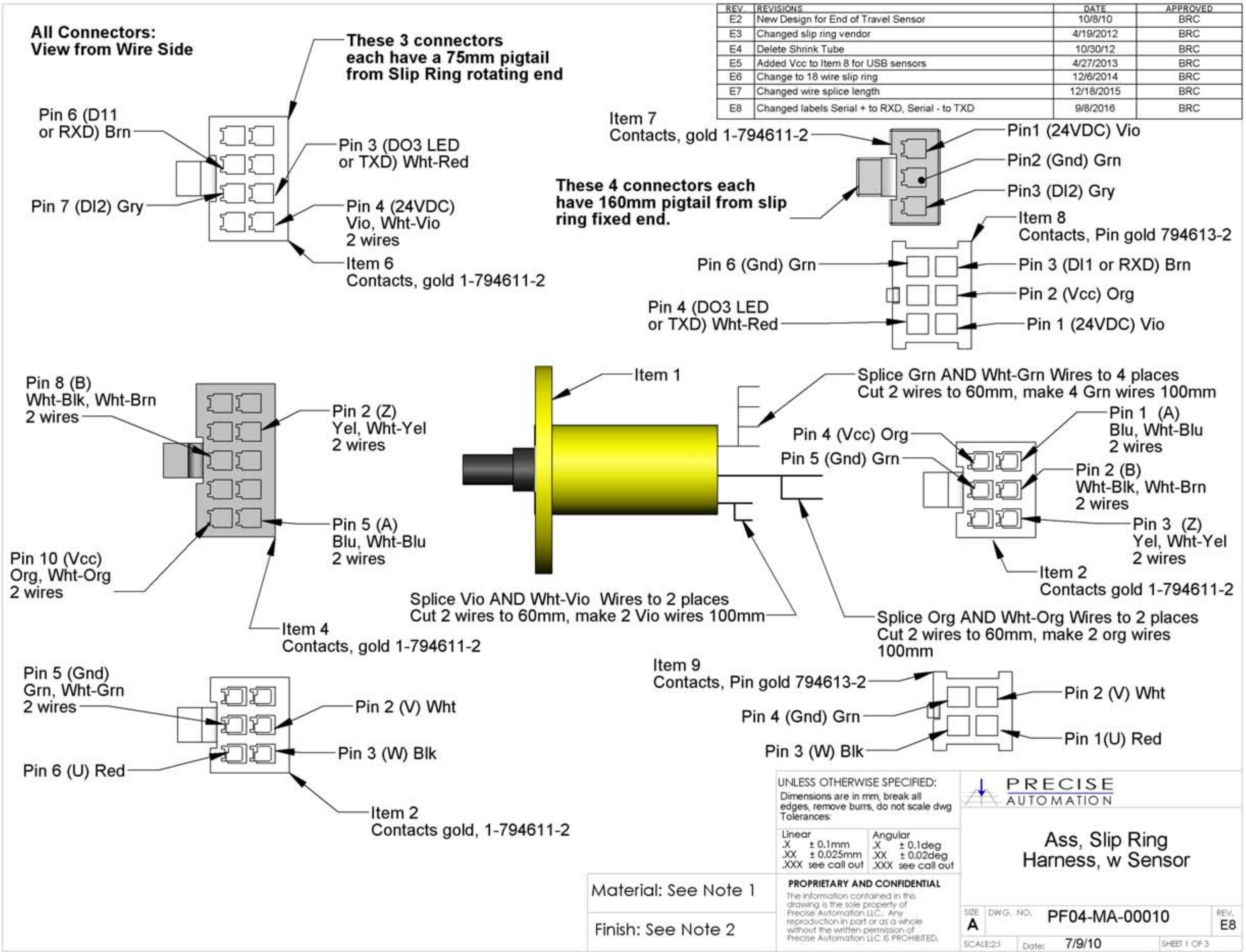


Control Board Connectors



Gripper and Linear Axis Controller Connectors


REV. | REVISIONS | DATE | APPROVED
E2 | Beta Release | 10/8/10 | BRC
E3 | Changed Olive Green Wire to Pink | 11/30/10 | BRC
All Connectors:
View from wire side
These 3 connectors each have a 75mm pigtail from Slip Ring rotating end
Pin 6 Brown (DI1)
Pin 3 Light Blue (DO3 LED 20ma)
Pin 4 Violet (24VDC)
Item 6 Contacts, gold 1-794611-2
Item 6 Install First Shrink tube 25mm long
Pin 1
Pin 2 Yellow (Z)
Pin 5 Dark Blue (A)
Item 4 Contacts, gold 1-794611-2
Pin 8 Pink (B)
Pin 10 Orange (Vcc)
Pin 2 Wht (V)
Pin 3 Blk (W)
Item 2 Contacts gold 1-794611-2
Pin 4 Gray (Brake -)
Pin 5 Green (Gnd)
Pin 6 Red (U)
These 4 connectors each have a 120mm pigtail from Slip Ring fixed end
Pin 3 Green (Gnd)
Item 7 Contacts gold 1-794611-2
Pin 1 Violet (24VDC)
Pin 2 Gray (Brake -)
Item 8 Contacts, Pin gold 794610-2
Pin 3 Brown (DI1)
Pin 1 Violet (24VDC)
Pin 6 Green (Gnd)
Pin 4 Light Blue (DO1 LED 20ma)
Splice Green Wire to 4 places Cut wire to 25mm, make 4 wires 95mm
Pin 1 Dark Blue (A)
Pin 2 Pink (B)
Pin 3 Yellow (Z)
Pin 4 Orange (Vcc)
Pin 5 Green (Gnd)
Item 2 Contacts gold 1-794611-2
Splice Violet Wire to 2 places Cut wire to 25mm, make 2 wires 95mm
Item 9 Contacts, Pin tin 794610-1
Pin 2 Wht (V)
Pin 1 Red (U)
Pin 4 Green (Gnd)
Pin 3 Blk (W)
Item 1 Precise PN
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
Material: See Note 1
Finish: See Note 2
PRECISE AUTOMATION
Ass, Slip Ring Harness
SIZE A
DWG. NO. PF04-MA-00002
REV. E3
SCALE 2:1
Date: 7/9/10
SHEET 1 OF 2


REV | REVISIONS | DATE | APPROVED
E2 | New Design for End of Travel Sensor | 10/8/10 | BRC
E3 | Changed slip ring vendor | 4/19/2012 | BRC
E4 | Delete Shrink Tube | 10/30/12 | BRC
E5 | Added Vcc to Item 8 for USB sensors | 4/27/2013 | BRC
E6 | Change to 18 wire slip ring | 12/6/2014 | BRC
E7 | Changed wire splice length | 12/18/2015 | BRC
E8 | Changed labels Serial + to RXD, Serial - to TXD | 9/8/2016 | BRC
All Connectors: View from Wire Side
These 3 connectors each have a 75mm pigtail from Slip Ring rotating end
Pin 6 (D11 or RXD) Brn
Pin 7 (DI2) Gry
Pin 3 (DO3 LED or TXD) Wht-Red
Pin 4 (24VDC) Vio, Wht-Vio 2 wires
Item 6 Contacts, gold 1-794611-2
Item 7 Contacts, gold 1-794611-2
Pin1 (24VDC) Vio
Pin2 (Gnd) Grn
Pin3 (DI2) Gry
These 4 connectors each have 160mm pigtail from slip ring fixed end.
Item 8 Contacts, Pin gold 794613-2
Pin 6 (Gnd) Grn
Pin 3 (DI1 or RXD) Brn
Pin 2 (Vcc) Org
Pin 4 (DO3 LED or TXD) Wht-Red
Pin 1 (24VDC) Vio
Pin 8 (B) Wht-Blk, Wht-Brn 2 wires
Pin 2 (Z) Yel, Wht-Yel 2 wires
Pin 5 (A) Blu, Wht-Blu 2 wires
Pin 10 (Vcc) Org, Wht-Org 2 wires
Item 4 Contacts, gold 1-794611-2
Item 1
Splice Grn AND Wht-Grn Wires to 4 places Cut 2 wires to 60mm, make 4 Grn wires 100mm
Pin 4 (Vcc) Org
Pin 5 (Gnd) Grn
Pin 1 (A) Blu, Wht-Blu 2 wires
Pin 2 (B) Wht-Blk, Wht-Brn 2 wires
Pin 3 (Z) Yel, Wht-Yel 2 wires
Item 2 Contacts gold 1-794611-2
Splice Vio AND Wht-Vio Wires to 2 places Cut 2 wires to 60mm, make 2 Vio wires 100mm
Splice Org AND Wht-Org Wires to 2 places Cut 2 wires to 60mm, make 2 org wires 100mm
Pin 5 (Gnd) Grn, Wht-Grn 2 wires
Pin 2 (V) Wht
Pin 3 (W) Blk
Pin 6 (U) Red
Item 2 Contacts gold, 1-794611-2
Item 9 Contacts, Pin gold 794613-2
Pin 4 (Gnd) Grn
Pin 3 (W) Blk
Pin 2 (V) Wht
Pin 1(U) Red
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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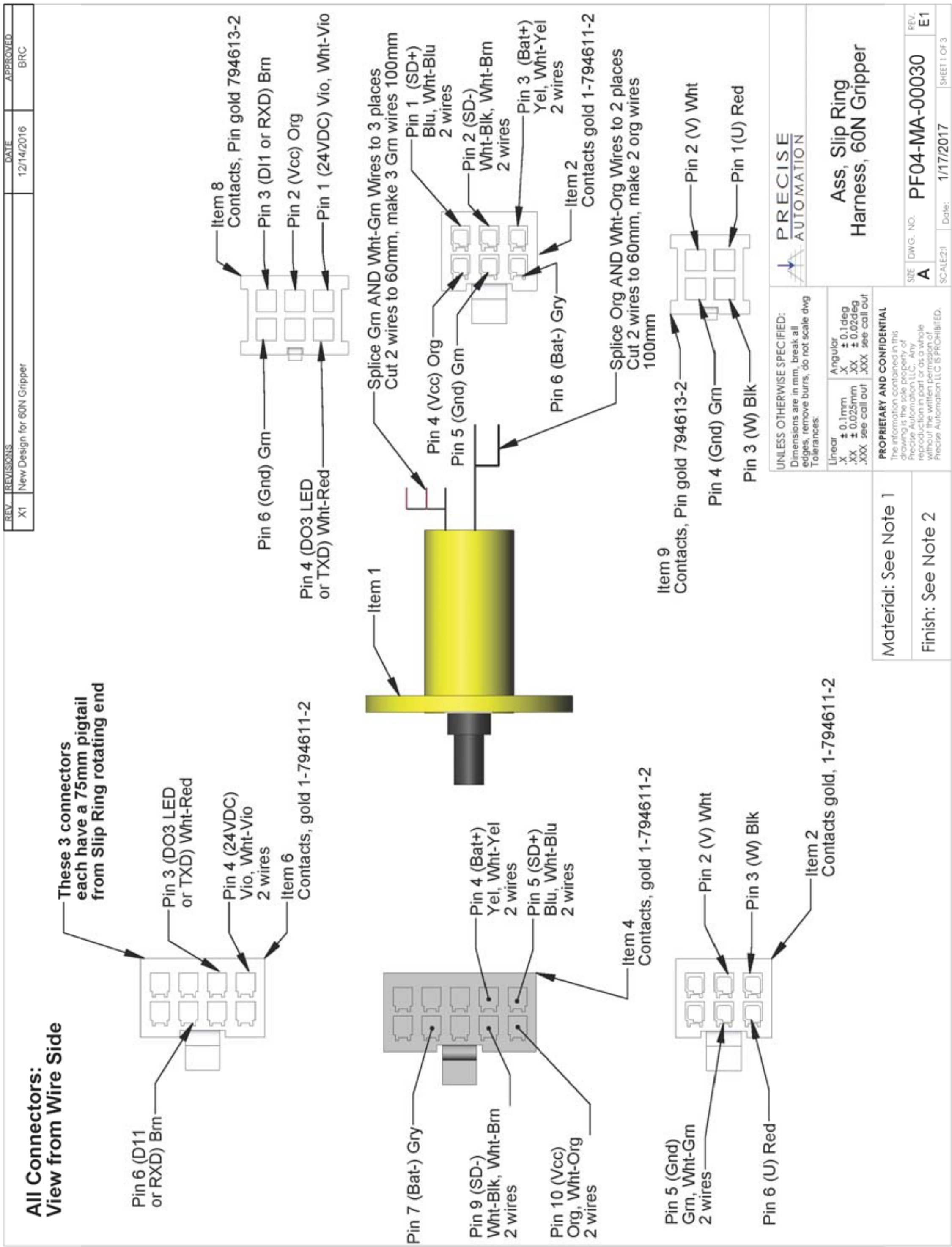
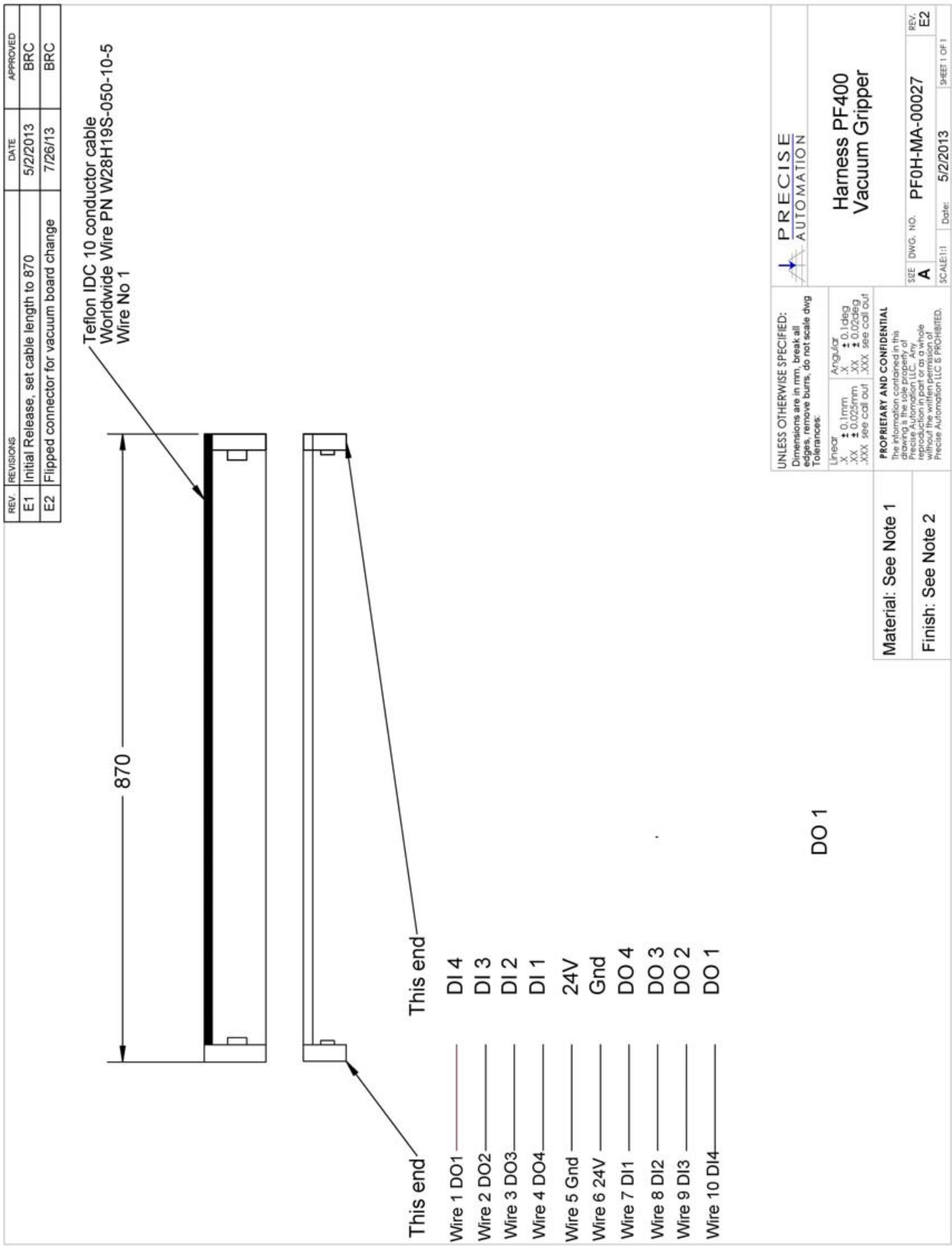
Material: See Note 1
Finish: See Note 2
PRECISE AUTOMATION
Ass, Slip Ring Harness, w Sensor
SIZE A
DWG. NO. PF04-MA-00010
REV. E8
SCALE:2:1
Date: 7/9/10
SHEET 1 OF 3

Schematic: Slip Ring for 60N Gripper




REV. REVISIONS DATE APPROVED
E1 Initial Release, set cable length to 870 5/2/2013 BRC
E2 Flipped connector for vacuum board change 7/26/13 BRC
Teflon IDC 10 conductor cable
Worldwide Wire PN W28H19S-050-10-5
Wire No 1
870
This end
This end
DI 4
DI 3
DI 2
DI 1
24V
Gnd
DO 4
DO 3
DO 2
DO 1
Wire 1 DO1
Wire 2 DO2
Wire 3 DO3
Wire 4 DO4
Wire 5 Gnd
Wire 6 24V
Wire 7 DI1
Wire 8 DI2
Wire 9 DI3
Wire 10 DI4
DO 1
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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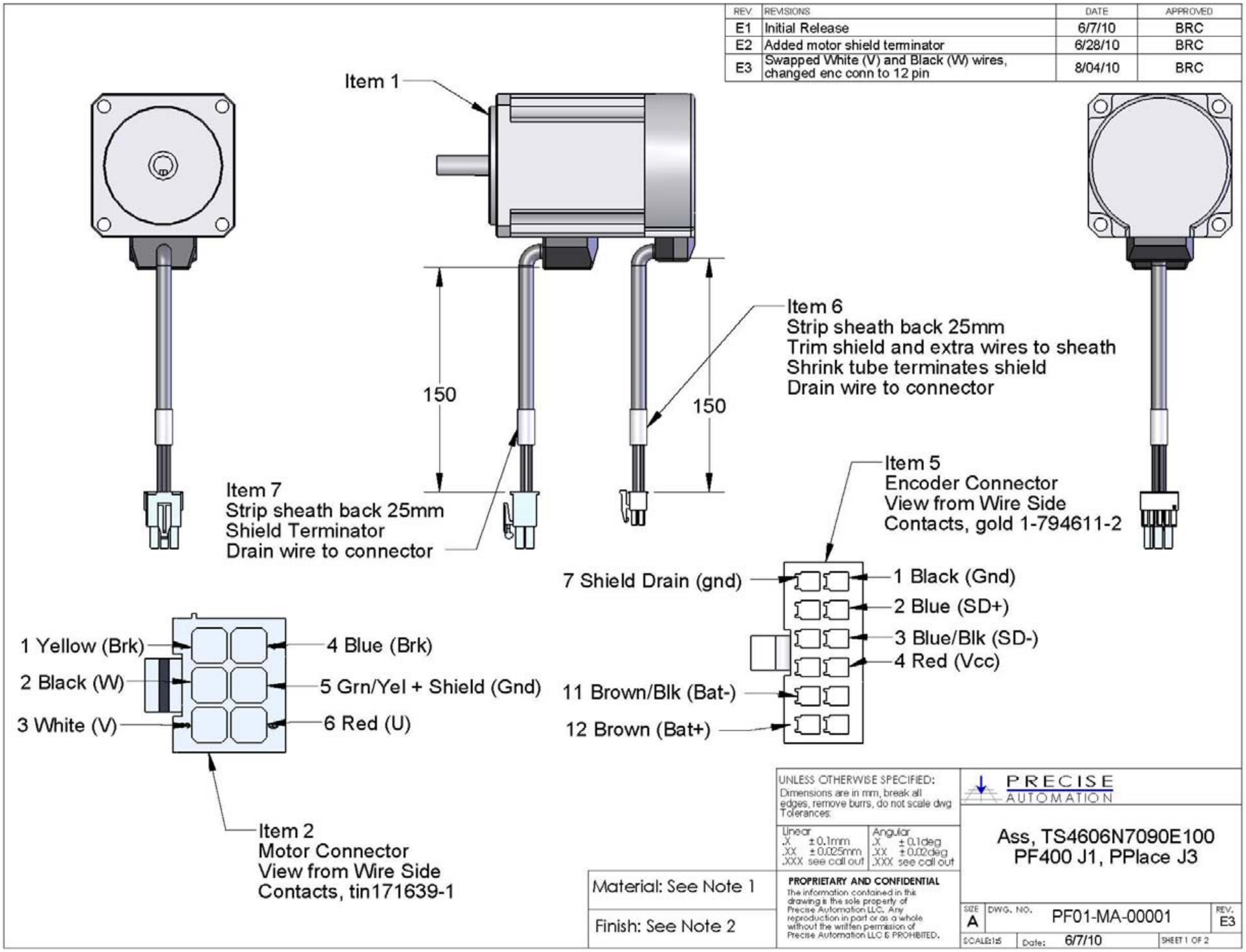
PRECISE AUTOMATION
Harness PF400
Vacuum Gripper
SIZE A
DWG. NO. PF0H-MA-00027
REV. E2
SCALE 1:1
Date: 5/2/2013
SHEET 1 OF 1


REV. | REVISIONS | DATE | APPROVED
E1 | Initial Release | 6/7/10 | BRC
E2 | Added motor shield terminator | 6/28/10 | BRC
E3 | Swapped White (V) and Black (W) wires, changed enc conn to 12 pin | 8/04/10 | BRC
Item 1
150
150
Item 6
Strip sheath back 25mm
Trim shield and extra wires to sheath
Shrink tube terminates shield
Drain wire to connector
Item 7
Strip sheath back 25mm
Shield Terminator
Drain wire to connector
Item 5
Encoder Connector
View from Wire Side
Contacts, gold 1-794611-2
7 Shield Drain (gnd)
1 Black (Gnd)
2 Blue (SD+)
3 Blue/Blk (SD-)
4 Red (Vcc)
11 Brown/Blk (Bat-)
12 Brown (Bat+)
1 Yellow (Brk)
2 Black (W)
3 White (V)
4 Blue (Brk)
5 Grn/Yel + Shield (Gnd)
6 Red (U)
Item 2
Motor Connector
View from Wire Side
Contacts, tin171639-1
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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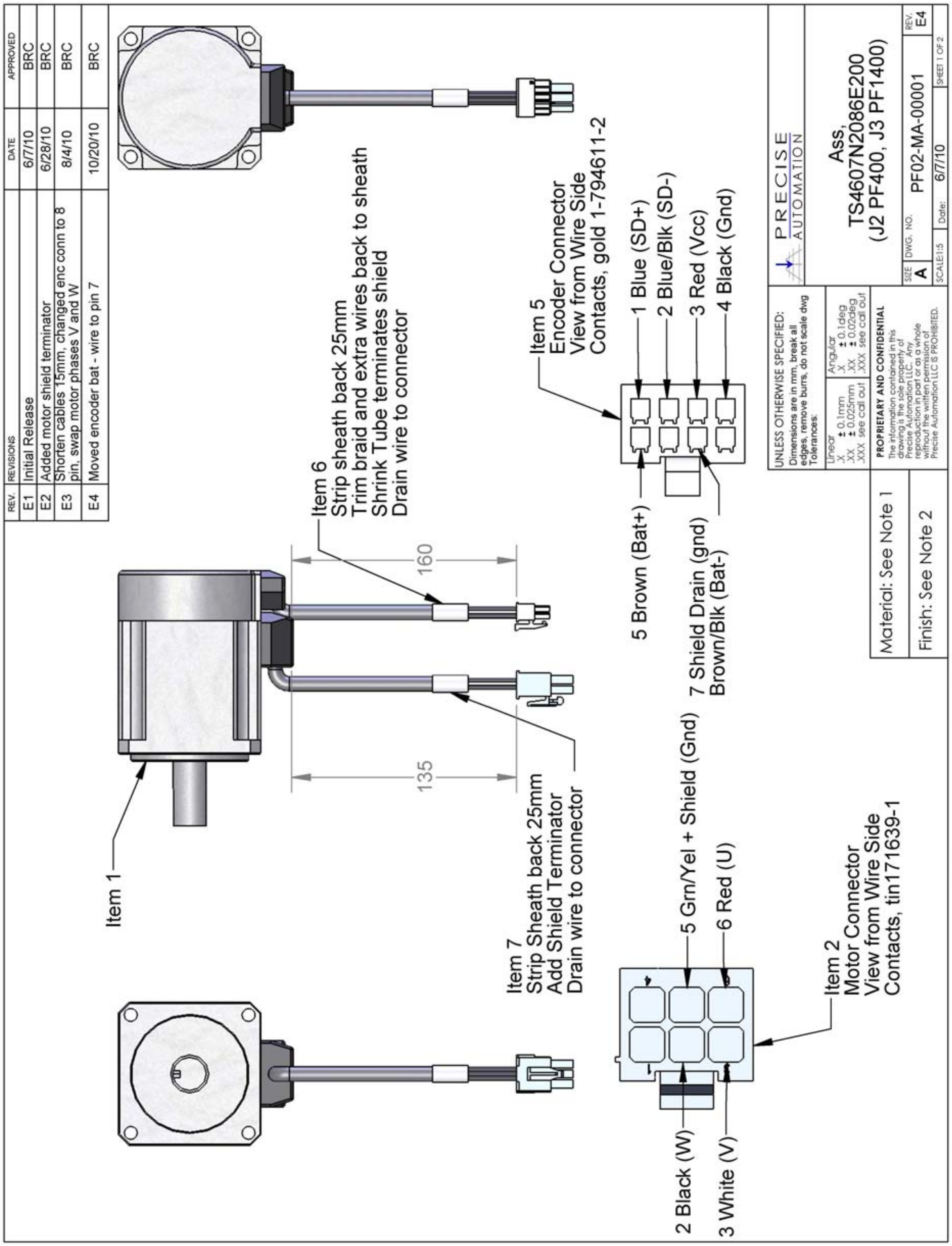
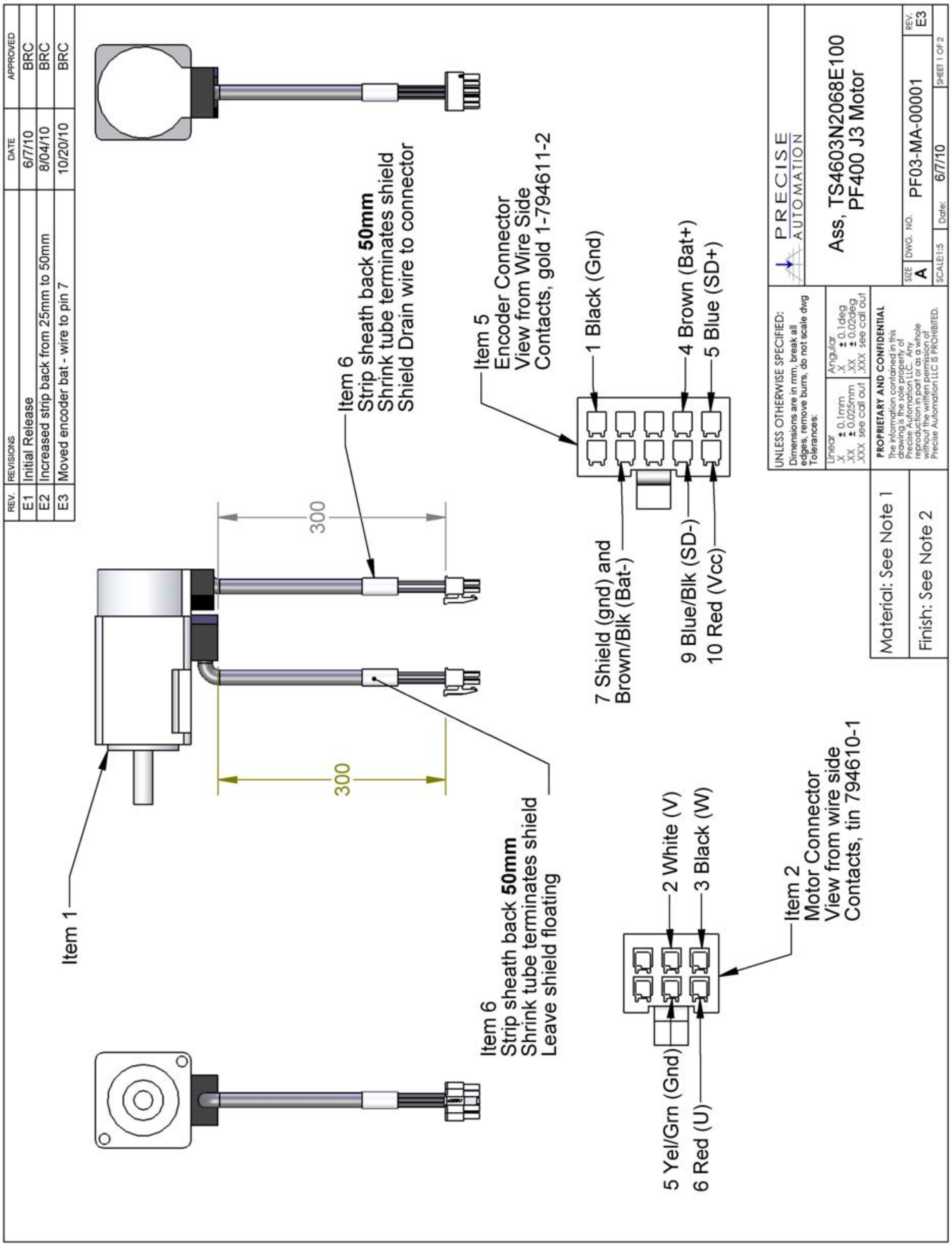
Material: See Note 1
Finish: See Note 2
PRECISE AUTOMATION
Ass, TS4606N7090E100
PF400 J1, PPlace J3
SIZE A
DWG. NO. PF01-MA-00001
REV. E3
SCALE:1:5
Date: 6/7/10
SHEET 1 OF 2



REV. | REVISIONS | DATE | APPROVED
E1 | Initial Release | 6/7/10 | BRC
E2 | Added motor shield terminator | 6/28/10 | BRC
E3 | Shorten cables 15mm, changed enc conn to 8 pin, swap motor phases V and W | 8/4/10 | BRC
E4 | Moved encoder bat - wire to pin 7 | 10/20/10 | BRC
Item 1
Item 7
Strip Sheath back 25mm
Add Shield Terminator
Drain wire to connector
135
160
Item 6
Strip sheath back 25mm
Trim braid and extra wires back to sheath
Shrink Tube terminates shield
Drain wire to connector
Item 5
Encoder Connector
View from Wire Side
Contacts, gold 1-794611-2
1 Blue (SD+)
2 Blue/Blk (SD-)
3 Red (Vcc)
4 Black (Gnd)
5 Brown (Bat+)
7 Shield Drain (gnd)
Brown/Blk (Bat-)
5 Grn/Yel + Shield (Gnd)
6 Red (U)
2 Black (W)
3 White (V)
Item 2
Motor Connector
View from Wire Side
Contacts, tin171639-1
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:
PROPRIETARY AND CONFIDENTIAL
PRECISE AUTOMATION
Ass,
TS4607N2086E200
(J2 PF400, J3 PF1400)
SIZE A
DWG. NO. PF02-MA-00001
REV. E4
SCALE1:5
Date: 6/7/10
SHEET 1 OF 2


REV. | REVISIONS | DATE | APPROVED
E1 | Initial Release | 6/7/10 | BRC
E2 | Increased strip back from 25mm to 50mm | 8/04/10 | BRC
E3 | Moved encoder bat - wire to pin 7 | 10/20/10 | BRC
Item 1
300
300
Item 6
Strip sheath back 50mm
Shrink tube terminates shield
Shield Drain wire to connector
Item 6
Strip sheath back 50mm
Shrink tube terminates shield
Leave shield floating
Item 5
Encoder Connector
View from Wire Side
Contacts, gold 1-794611-2
1 Black (Gnd)
4 Brown (Bat+)
5 Blue (SD+)
7 Shield (gnd) and
Brown/Blk (Bat-)
9 Blue/Blk (SD-)
10 Red (Vcc)
Item 2
Motor Connector
View from wire side
Contacts, tin 794610-1
2 White (V)
3 Black (W)
5 Yel/Grn (Gnd)
6 Red (U)
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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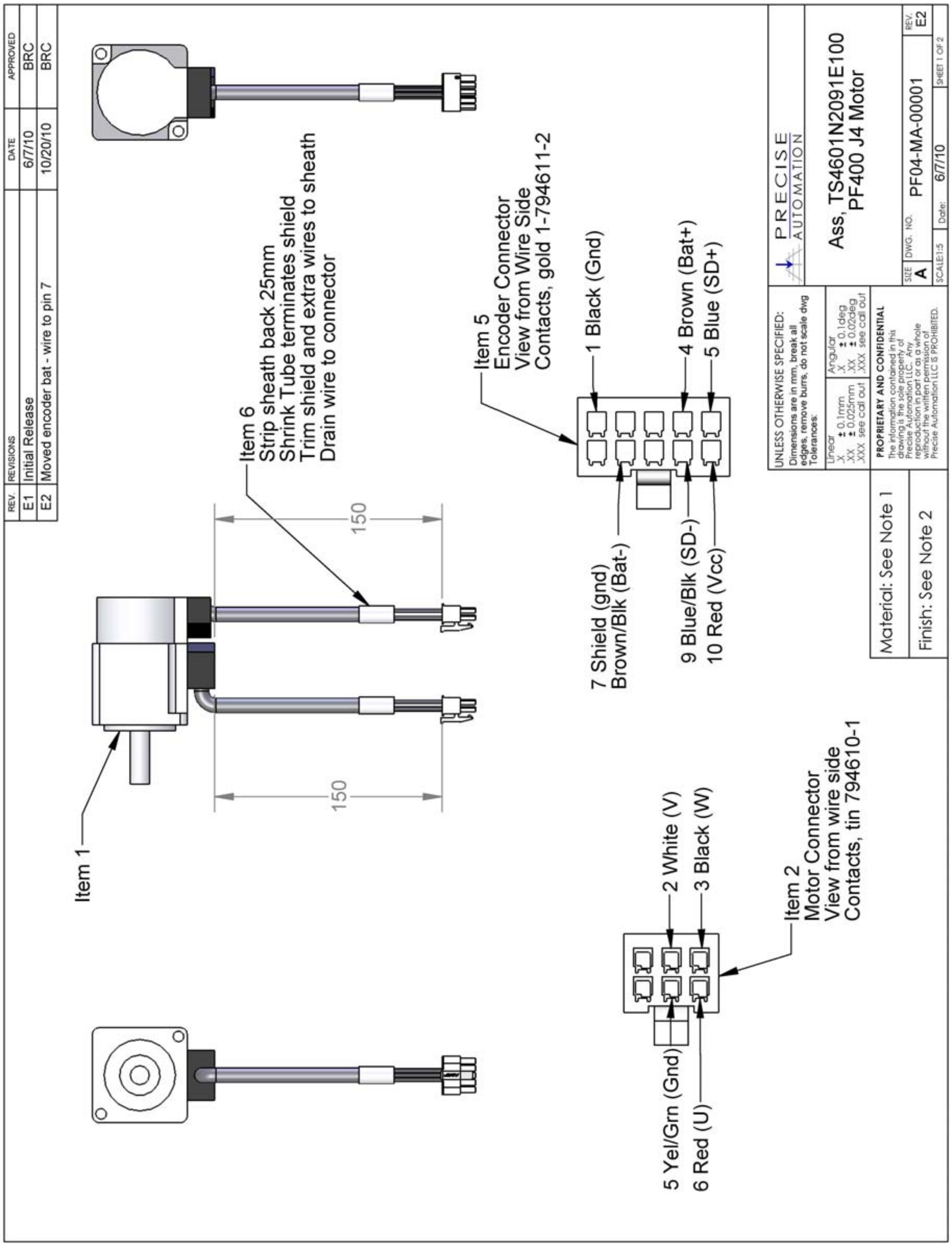
PRECISE AUTOMATION
Ass, TS4603N2068E100
PF400 J3 Motor
SIZE A
DWG. NO. PF03-MA-00001
REV. E3
SCALE:1:5
Date: 6/7/10
SHEET 1 OF 2



REV. | REVISIONS | DATE | APPROVED
E1 | Initial Release | 6/7/10 | BRC
E2 | Moved encoder bat - wire to pin 7 | 10/20/10 | BRC
Item 1
150
150
Item 6
Strip sheath back 25mm
Shrink Tube terminates shield
Trim shield and extra wires to sheath
Drain wire to connector
Item 5
Encoder Connector
View from Wire Side
Contacts, gold 1-794611-2
1 Black (Gnd)
4 Brown (Bat+)
5 Blue (SD+)
7 Shield (gnd)
Brown/Blk (Bat-)
9 Blue/Blk (SD-)
10 Red (Vcc)
2 White (V)
3 Black (W)
5 Yel/Grn (Gnd)
6 Red (U)
Item 2
Motor Connector
View from wire side
Contacts, tin 794610-1
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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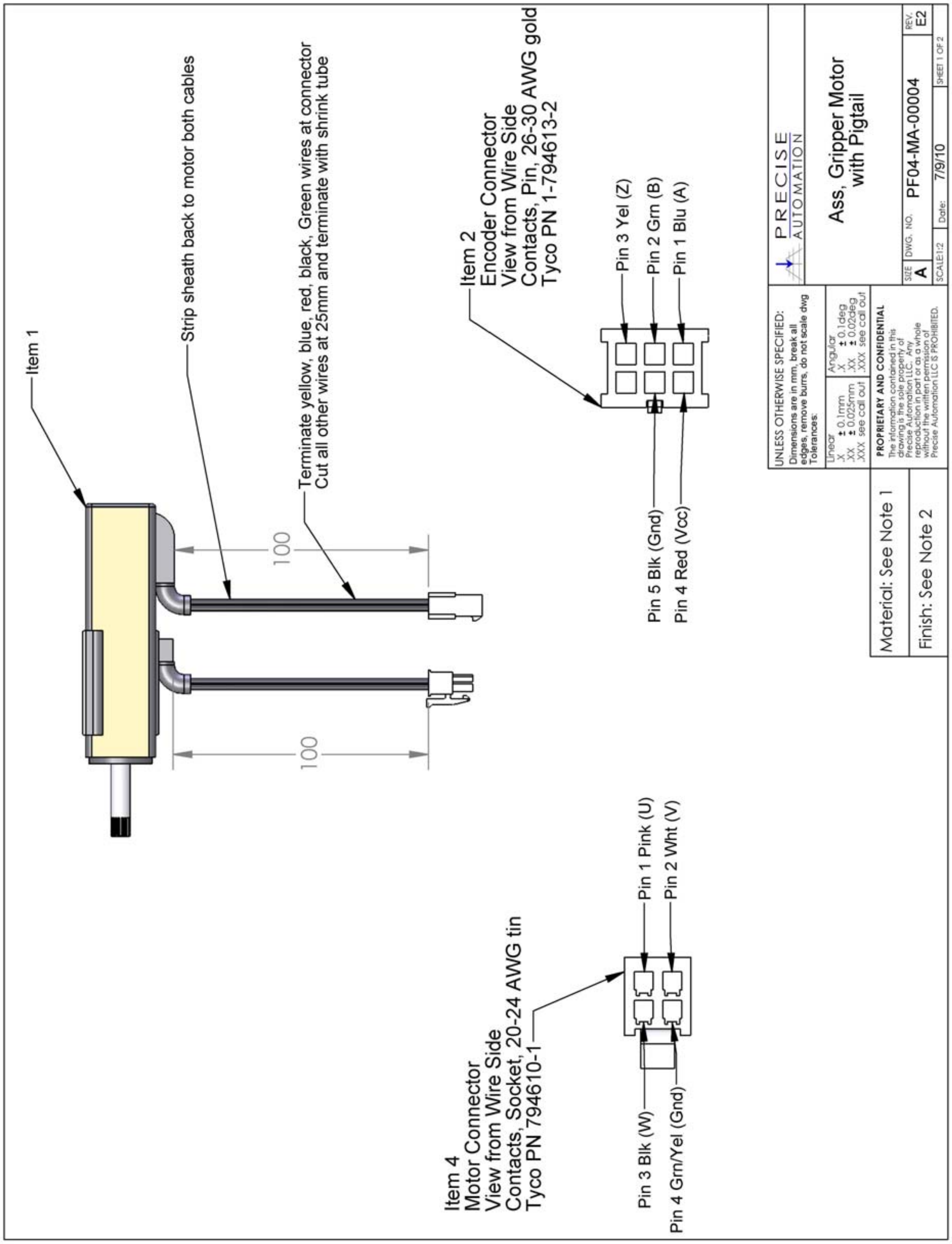
PRECISE AUTOMATION
Ass, TS4601N2091E100
PF400 J4 Motor
SIZE A
DWG. NO. PF04-MA-00001
REV. E2
SCALE: 1:5
Date: 6/7/10
SHEET 1 OF 2



Item 1
Strip sheath back to motor both cables
Terminate yellow, blue, red, black, Green wires at connector
Cut all other wires at 25mm and terminate with shrink tube
100
100
Item 2
Encoder Connector
View from Wire Side
Contacts, Pin, 26-30 AWG gold
Tyco PN 1-794613-2
Pin 3 Yel (Z)
Pin 2 Grn (B)
Pin 1 Blu (A)
Pin 5 Blk (Gnd)
Pin 4 Red (Vcc)
Item 4
Motor Connector
View from Wire Side
Contacts, Socket, 20-24 AWG tin
Tyco PN 794610-1
Pin 1 Pink (U)
Pin 2 Wht (V)
Pin 3 Blk (W)
Pin 4 Grn/Yel (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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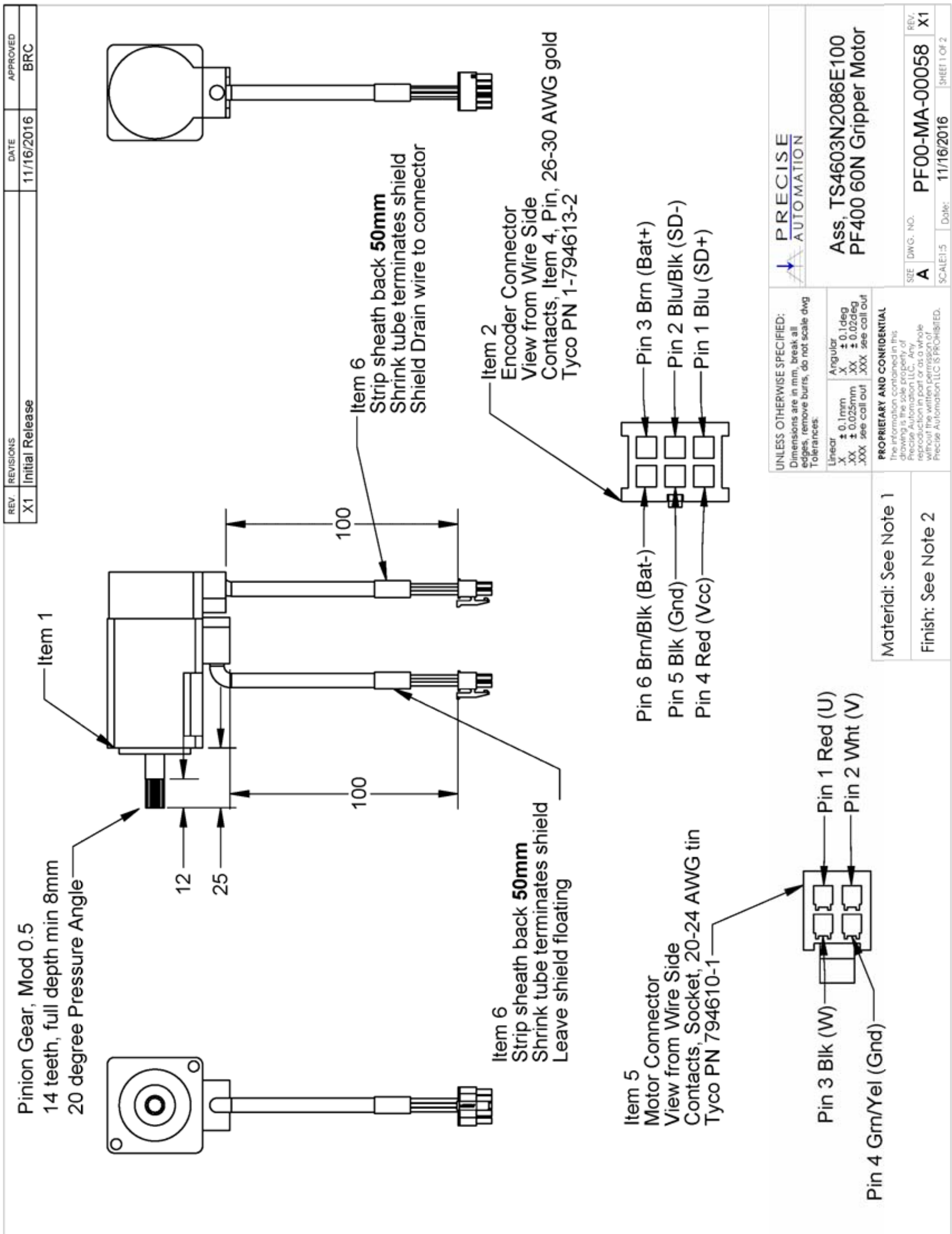
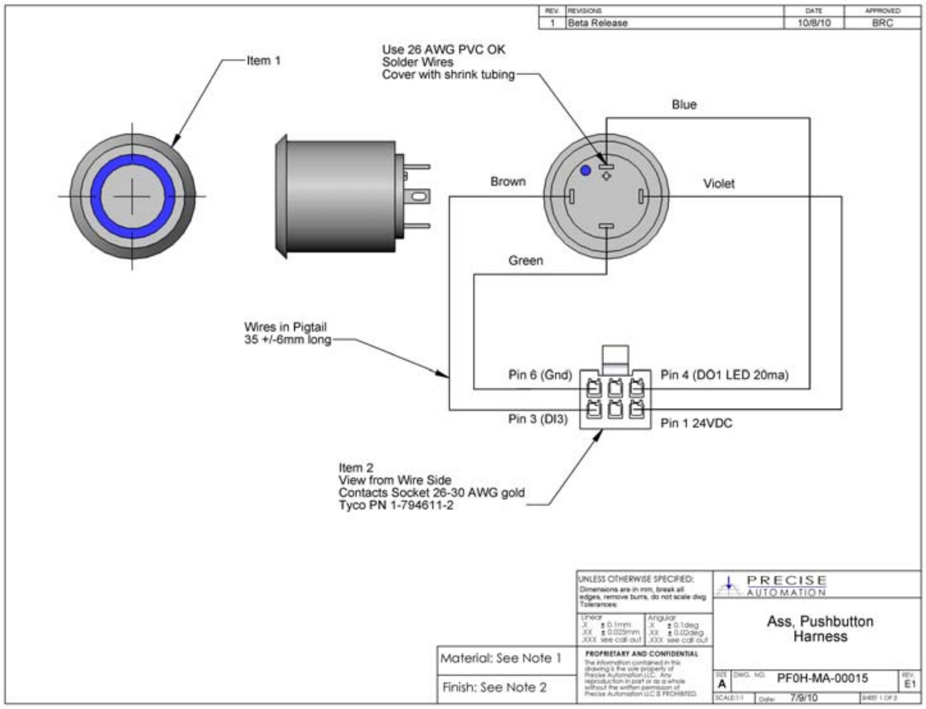
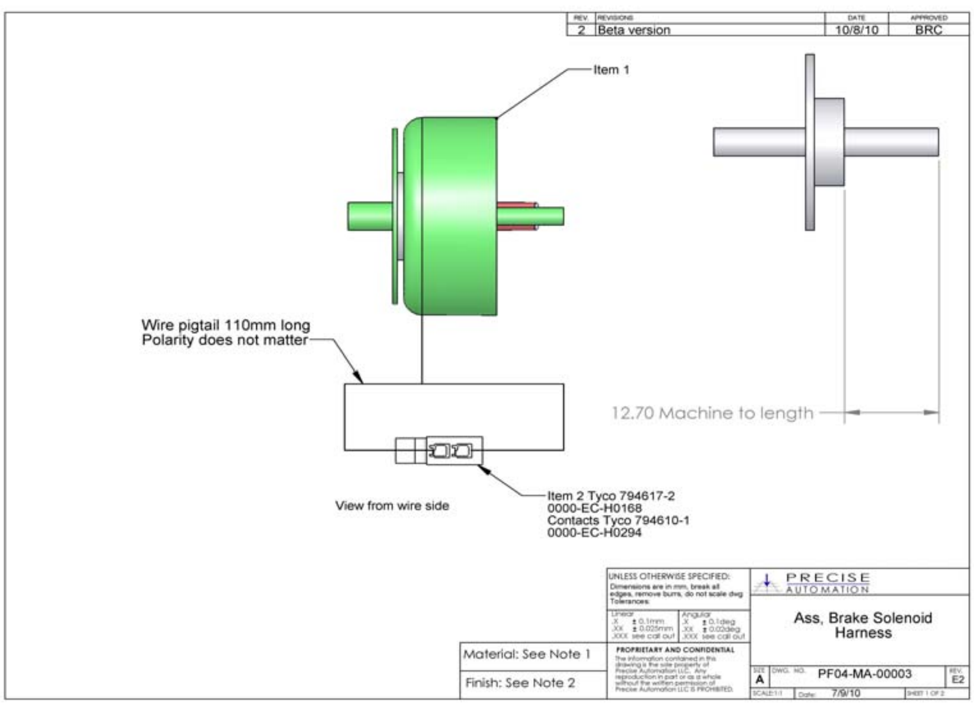
PRECISE AUTOMATION
Ass, Gripper Motor with Pigtail
Material: See Note 1
Finish: See Note 2
SIZE A
DWG. NO. PF04-MA-00004
REV. E2
SCALE1:2
Date: 7/9/10
SHEET 1 OF 2

Motor 60N Gripper





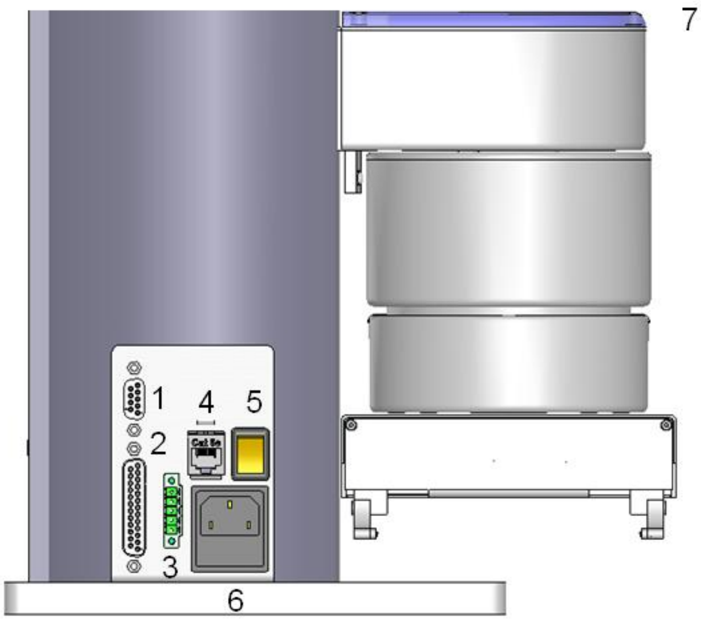
REV. REVISIONS DATE APPROVED
1 Beta Release 10/8/10 BRC
Item 1
Use 26 AWG PVC OK
Solder Wires
Cover with shrink tubing
Blue
Brown
Violet
Green
Wires in Pigtail
35 +/-6mm long
Pin 6 (Gnd)
Pin 4 (DO1 LED 20ma)
Pin 3 (DI3)
Pin 1 24VDC
Item 2
View from Wire Side
Contacts Socket 26-30 AWG gold
Tyco PN 1-794611-2
UNLESS OTHERWISE SPECIFIED:
PRECISE AUTOMATION
Ass, Pushbutton Harness
PROPRIETARY AND CONFIDENTIAL
Material: See Note 1
Finish: See Note 2
PF0H-MA-00015
E1
7/9/10



REV. REVISIONS DATE APPROVED
2 Beta version 10/8/10 BRC
Item 1
Wire pigtail 110mm long
Polarity does not matter
12.70 Machine to length
View from wire side
Item 2 Tyco 794617-2
0000-EC-H0168
Contacts Tyco 794610-1
0000-EC-H0294
UNLESS OTHERWISE SPECIFIED:
PRECISE AUTOMATION
Ass, Brake Solenoid Harness
PROPRIETARY AND CONFIDENTIAL
Material: See Note 1
Finish: See Note 2
PF04-MA-00003
E2
7/9/10

Facilities Panel

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



Item	Name	Description
1	9 Pin D Sub Connector	Contains RS-232 Serial Port, 24 VDC, Gnd Can be used for optional teach pendant
2	25 Pin D Sub Connector	For optional DIO module, 12 inputs, 8 outputs
3	EStop Connector	EStop and Cell Interlock Signals
4	Ethernet Connector	For Ethernet to Computer Cable
5	Power Switch	Lighted Power Switch
6	Power Entry Module	For IEC plug. Contains dual fuse drawer.
7	Power Status Light	Blinks to indicate power status

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

Each of these interfaces is described in detail in the following sections. In addition, the robot's controller, which is mounted in the inner link of the robot, may contain additional interfaces (e.g. inputs or outputs). Please refer to the *Guidance 1000A/B Controllers, Hardware Introduction and Reference Manual* for additional information.

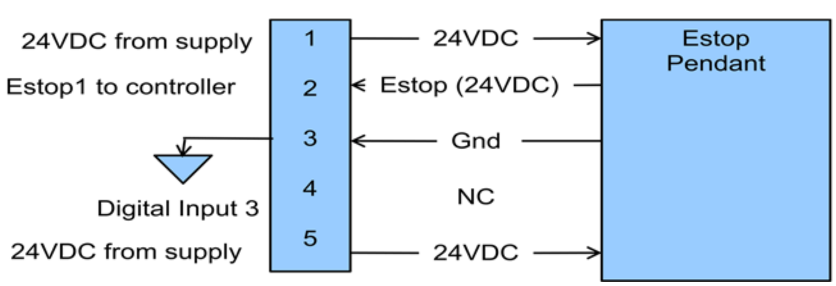
> **DANGER:** The Guidance 1400B controller, and the 24 VDC and 48 VDC power supplies are all open frame electrical devices that contain unshielded high voltage pins, components and surfaces. . **The main AC power should always be disconnected before the Facilities Panel is removed.**

If the pneumatic gripper option is ordered one air line is routed through the interior of the robot. At the Facilities Panel, this air line is presented in a fitting on a sub plate mounted to the facilities panel. The other end of this line exits at the Outer Link. When using this line, clean, dry external air should be provided.

> **CAUTION:** The maximum air pressure that can be conveyed by the air lines through the robot is **75 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.

E-Stop Connector

The standard E-Stop connector is the green Phoenix connector on the Facilities Panel. Note the E-Stop pins on the MCP Interface (below) are in series with the E-Stop signals on the Phoenix E-Stop connector. An E-Stop box or circuit can be plugged into either one of these two connectors. However in order for the robot to allow motor power to be enabled the E-Stop circuit must connect 24 VDC to E-Stop1 in both of these two connectors. If no E-Stop box or circuit is connected, then the circuit must be completed with a jumper from pin 1 to pin 2 on the Phoenix connector or from pin 1 to pin 6 on the MCP connector. The robot is shipped with a Phoenix jumper plug PN 1851070 and a jumper plug in the 9 pin Dsub connector that satisfy these requirements. Unlike the Digital IO circuits, the E-Stop circuit cannot be configured as “Sourcing” or “Sinking”. If a remote signal (for example from a PLC) is used to trigger E-Stop, it should be wired to a relay that closes the circuit between pins 1 and 2. When the robot is mounted on a Linear Axis, the MCP Interface is extended to the end cap of the Linear Axis.



MCP / E-Stop Interface

The MCP interface includes the signals necessary to connect a Manual Control Pendant, secondary E-Stop circuit, or an external RS485 Remote IO Module. 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.

Note the E-Stop pins on the MCP Interface are in series with the E-Stop signals on the Phoenix E-Stop connector. An E-Stop box or circuit can be plugged into either one of these two connectors. However in order for the robot to allow motor power to be enabled the E-Stop circuit must connect 24 VDC to E-Stop1 in one of these two connectors. If no E-Stop box or circuit is connected, then both circuits must be completed with jumper plugs. (The robot is shipped with a Phoenix jumper plug PN 1851070 and a Dsub jumper plug that satisfy these requirements.)

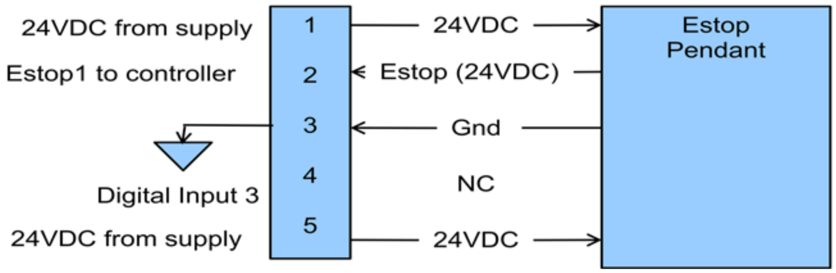
If a Manual Control Pendant is not connected to the secondary RS-232 port provided in this connector, this serial interface can be accessed via a GPL procedure as device "/dev/com2" for general communications purposes. Please note that unlike the primary serial interface, THIS SECONDARY SERIAL INTERFACE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

The RS485 port is used internally to communicate with the gripper controller and is also be used for the Remote IO option. As such it has a dedicated protocol and is not available for general use.

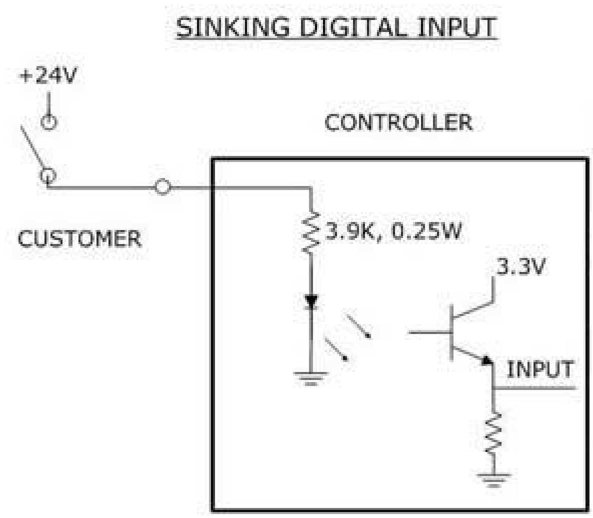
Pin	Description
1	24VDC
2	RS232 TXD
3	RS232 RXD
4	RS485-
5	Gnd
6	E-Stop1
7	E-Stop Daisy Chain
8	48VDC
9	RS485+
Interface Panel Connector Part No	DB9 Female Connector AMP 5747150-7
User Plug Part No	DB9 Male Plug Amp 1658655-1 (crimp) Pins 22-26AWG 745254-6

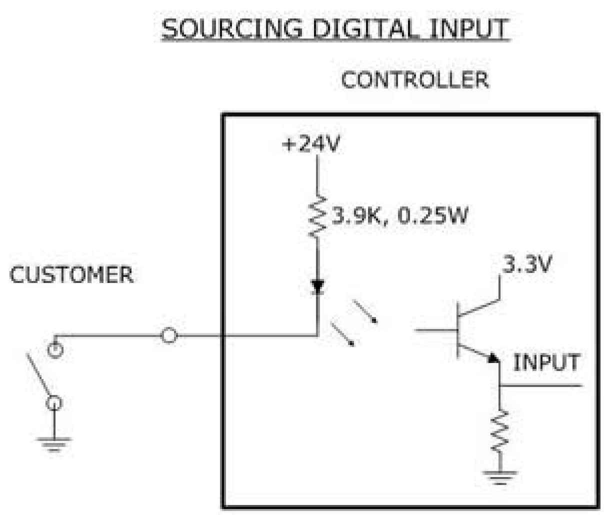
Digital Input Signals

The standard PreciseFlex 400 robot provides 1 general purpose optically isolated digital input signal at the Facilities Panel (in addition to those signals that are available at the Gripper Control Board). This line is accessed in the Phoenix 5 pin E-Stop connector and is connected to Digital Input 3 in the controller.



This input signal 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”.



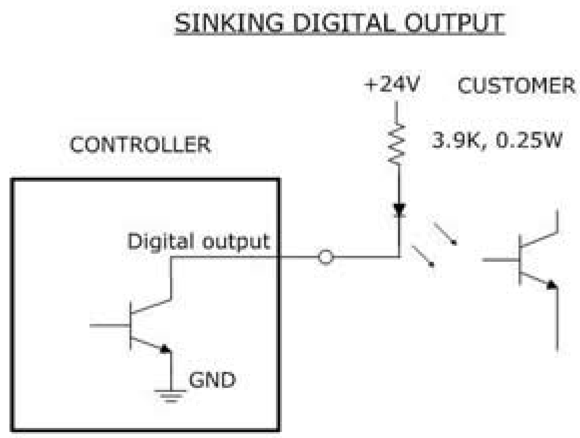


By setting Jumpers on the CPU (MIDS4) board, the four output signals can be individually configured as "sinking" or "sourcing" and the four digital inputs can be configured as a group to all operate as either sinking or sourcing. For more information on configuring the jumpers, please see the *Guidance 1000A/B Controllers, Hardware Introduction and Reference Manual.*

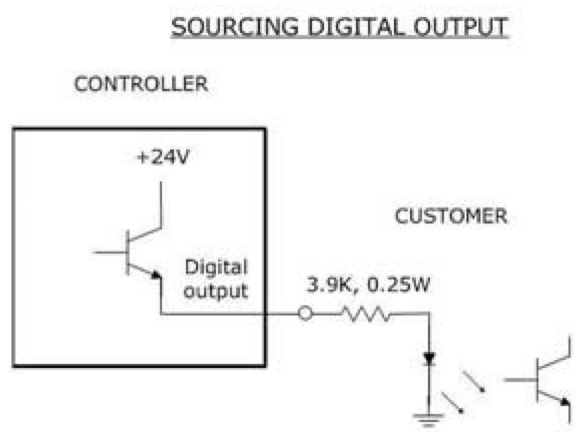
Digital Output Signals

The PreciseFlex robot provides 4 general-purpose optically isolated digital output signals at the G1400B controller.

These output signals can be configured as "sinking" or "sourcing". ***As shipped from the factory, the output signals are configured as "sinking"***, i.e. the external equipment must provide a 5VDC to 24VDC pull up voltage on an output pin and the controller pulls this pin to ground when the signal is asserted as true.



Alternately, the output signals can be configured as "sourcing", i.e. the external equipment must pull down an output pin to ground and the controller pulls this pin to 24VDC when the signal is asserted as true.



Outputs can be individually configured as sinking or sourcing signals. For more information on configuring the jumpers, please see the *Guidance Controller, 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	Description
1	13	Digital Output 1
2	14	Digital Output 2
3	15	Digital Output 3
4	16	Digital Output 4
5		GND
6		24 VDC output
7	10001	Digital Input 1
8	10002	Digital Input 2
9	10003	Digital Input 3
10	10004	Digital Input 4
User Plug Part No		AMP 1658622-1 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.

Gripper Controller Digital Inputs and Outputs

If the robot is equipped with an electric gripper, the gripper controller includes 3 sinking digital inputs and 3 sourcing digital outputs. One digital input and one digital output are dedicated for a lighted teach button on some electric grippers. The other two inputs and outputs are available in the outer link for application use.

Pin	GPL Signal Number	Description
1	200013	Digital Output 1/LED driver
2	200014	Digital Output 2
3	200015	Digital Output 3
4		24 VDC output
5		GND
6	210001	Digital Input 1
7	210002	Digital Input 2
8	210003	Digital Input 3
User Plug Part No		Amp 794617-8, crimp contacts 1-794611-2

RS485 Remote IO Module (GIO)

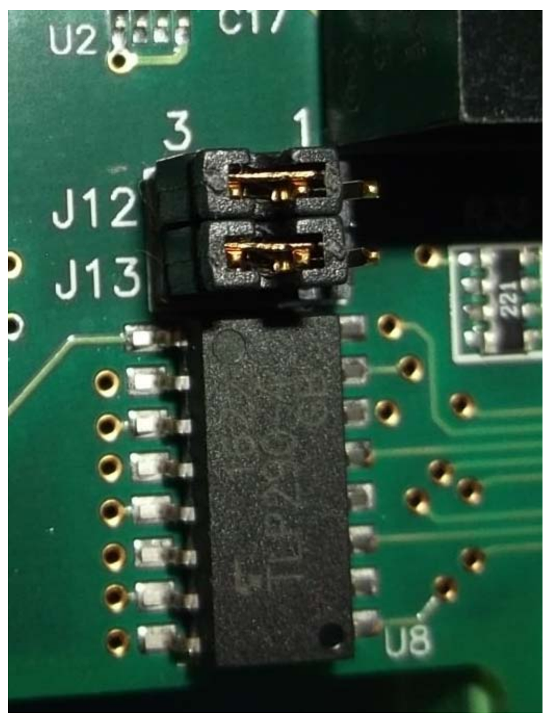
Customers who need additional digital IO may order the RS485 Remote IO Module. This module installs in the base of the robot and provides 12 Digital Inputs and 8 Digital Outputs in a 25 pin Dsub connector.

The RS485 Remote IO Module (GIO) provides 12 general purpose optically isolated digital input signals and 8 general purpose optically isolated digital output signals. 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 ordered). 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 signals are accessible via the DB25 female connector that is mounted on the facilities panel when this option is ordered. The DIO signals addresses are determined by a base address set by a DIP switch on the DIO board. For the PF400 robot without the linear axis option the DIO option is located at the robot connector panel and for both this location and also for the location at the end of the optional linear axis, 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 gripper and optional linear axis. See “Installing the optional G IO Board” under Service Procedures for details on installing this module.

PF3400 3kg IO in Base of Robot (GIO)

For the 3kg PF400, the GIO function is integrated as a standard feature in the base of the robot, however only inputs 1-8 are supported. All outputs are sourcing and cannot be changed. Inputs are set to sinking in the factory and can be changed in blocks of 4 by moving J12 and J13 to connect pins 1 and 2, instead of 2 and 3.



The software addresses will then be as follows.

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 (Not available PF3400)
7	810011	Digital Input 11 (Not available PF3400)
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 (Not available PF3400)
20	810012	Digital Input 12 (Not available PF3400)
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

Digital Outputs in the Outer Link

In the Revision C and 3kg versions of the PF400 the motor interface board in the outer link can be connected by means of a flat ribbon cable to the controller digital inputs and digital outputs, providing support for both pneumatic and vacuum grippers where desired. The schematic for this interconnect board can be found in the schematics section labeled Schematic: Revision C of FFC Boards.

For the 3kg version of the FFC boards, a jumper has been added to the MIDS4 power interface board located on the vertical wall of the inner link. This jumper connects the signals in the IO cable running to the outer link to either the IO port of the controller OR the RS485 port of the controller. When this jumper is placed in the "IO" position the innermost connector on the IO cable should be plugged into the J4 motor interface board in the outer link which connects the IO signals. These signals are then available to control solenoids for both air and vacuum grippers. When the jumper is placed in the "RS485" position, the outermost connector on the IO cable in the outer link should be plugged into the GSB gripper controller board.

<Insert images of J4 motor interface board in 2 solenoid config and RS485 config>

Ethernet Interface

PreciseFlex 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.

Due to limited space on the Facilities Panel, only one of the two Ethernet ports is available via an external RJ45 connector. This external Ethernet port is typically used to interface the robot to a PC. The second Ethernet port is only available inside the inner link of the robot. In some cases it may be used to connect an Ethernet camera that is mounted on the robot.

In this case, a PC that is connected to the Ethernet plug on the Facilities Panel can communicate with the robot's controller as well as receive images from an arm-mounted camera. (For the initial release of this robot, arm mounted cameras are not supported.)

If a camera is mounted in the workcell, an external Ethernet switch must be added to connect these cameras and the robot to a PC.

See the *Setup and Operation Quick Start Guide* for instructions on setting the IP address for the controller.

RS-232 Serial Interface

The PreciseFlex robot includes a standard RS-232 serial line equipped with hardware or software flow control. However this port is only available on the G1400B controller in the inner link of the robot and is not brought out to any outside connector on this robot. This port can be used to communicate to the system serial console or can be connected to external equipment for general communication purposes. When used for general communications, this port is referenced as device "/dev/com1" within the Guidance Programming Language (GPL).

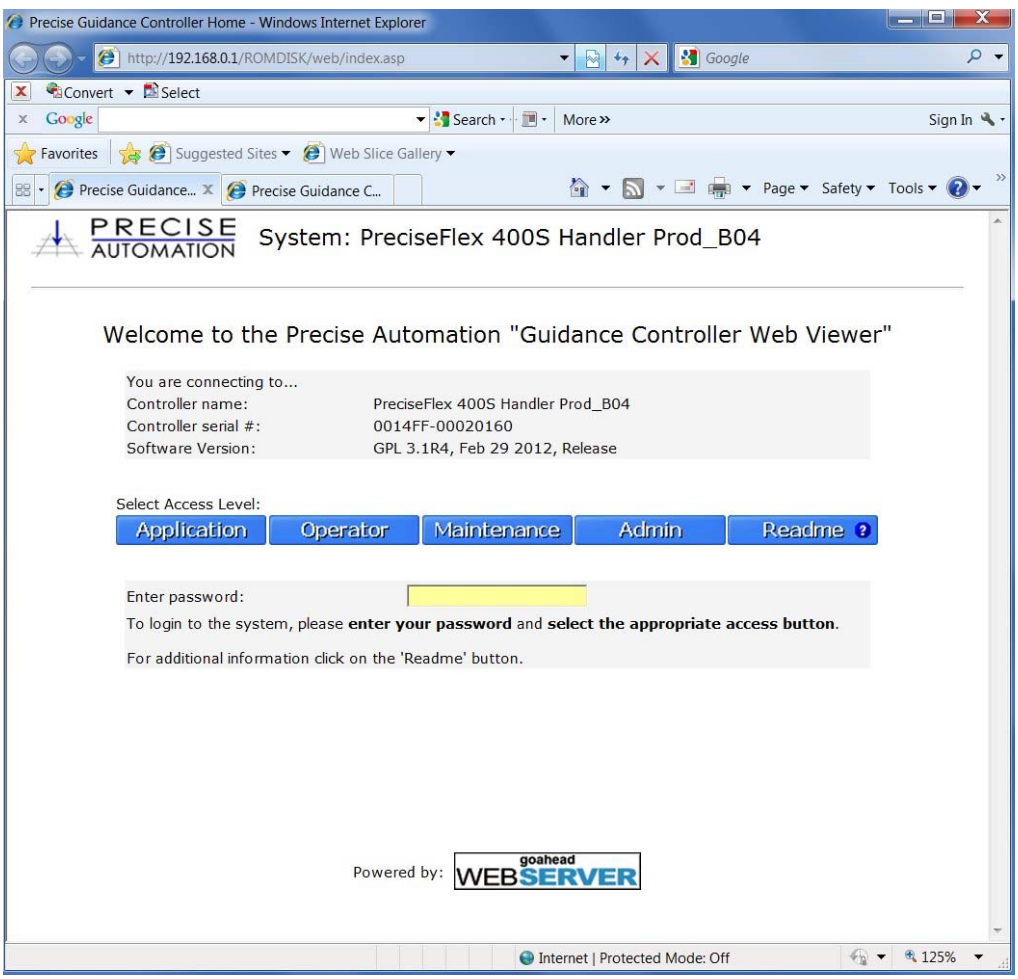
The connector for this interface is a standard RJ11 serial interface connector that has pin assignments compatible with standard PC "com" ports. For this robot it is only used for debugging and special service procedures.

Software Reference

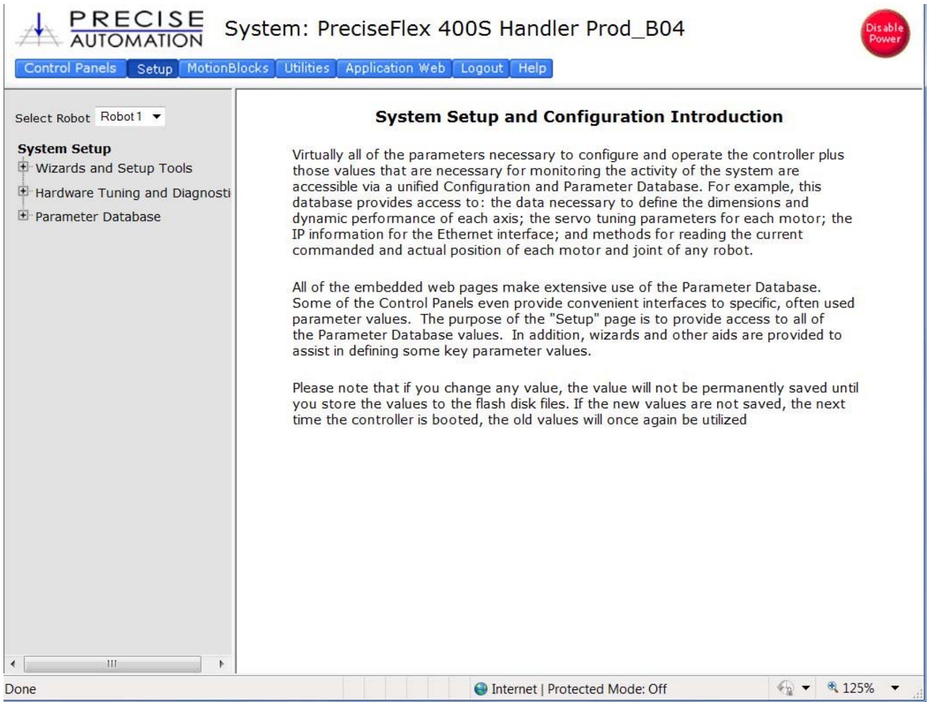
Accessing the Web Server

Many OEM customers run the PF400 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.

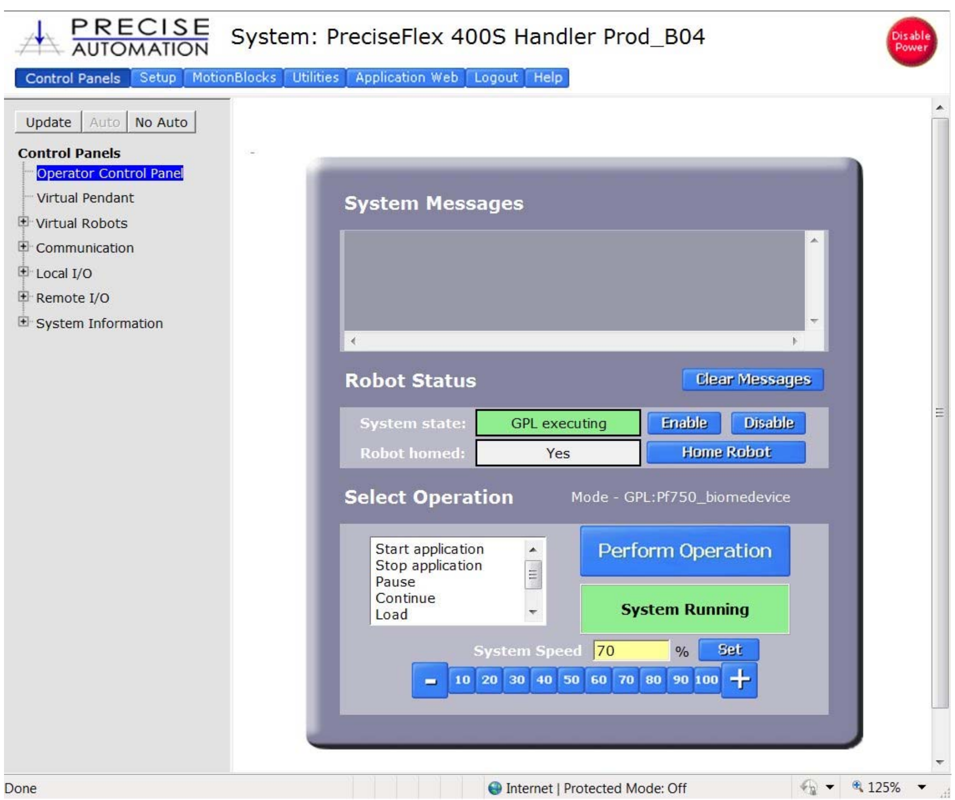
The Web Server Interface may be addressed by opening a browser (such as Internet Explorer) in a PC that is connected to the robot via Ethernet. You must know the IP address of the robot controller. Two common IP addresses are 192.168.0.1 and 192.168.0.10. The PC LAN interface address must be configured 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.



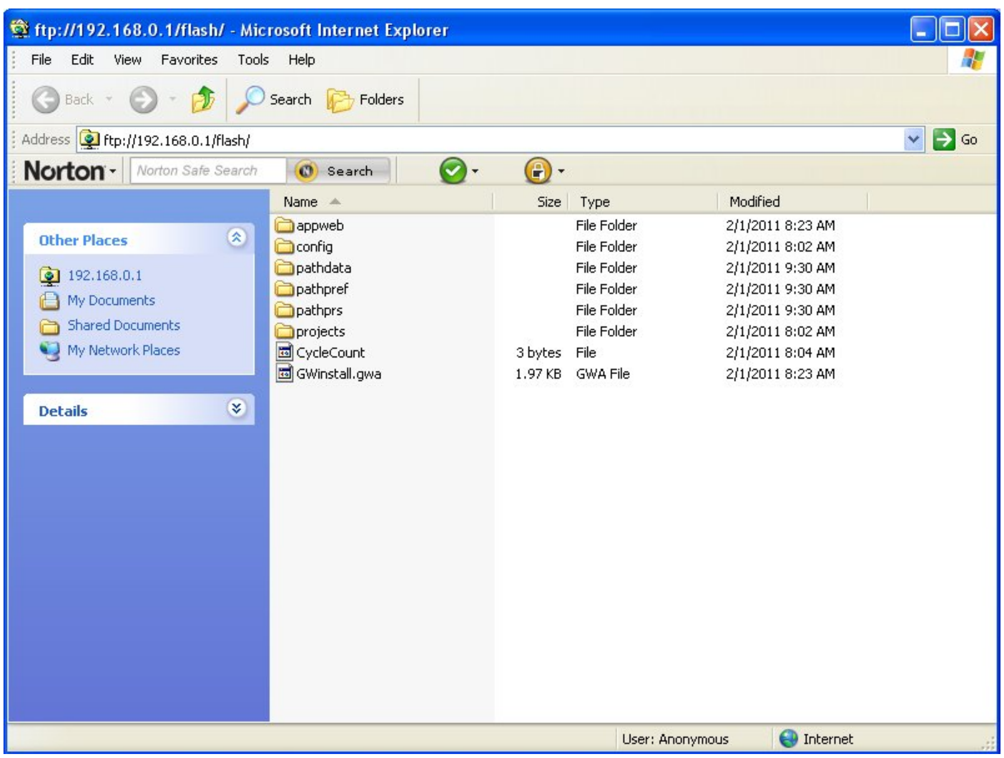
If an application is running, the “System Running” panel will display in green. In order to run diagnostics, you must stop the application from running. Click “Stop Application” and then “Perform Operation”. This will stop the application from running. You should click the “Disable Power” button to be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



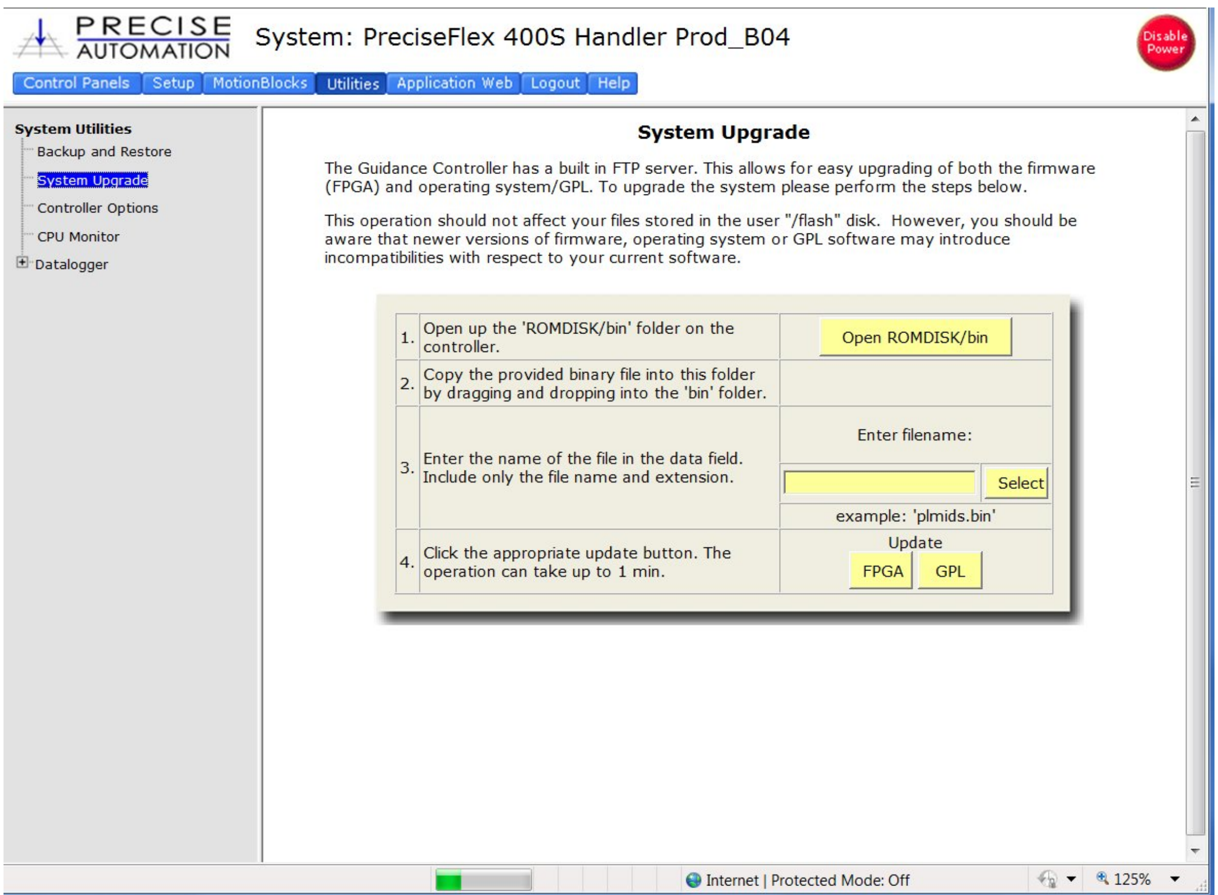
3. To load a Project, Open the “Projects” folder and paste the Project folder into this area. There may be several other projects (programs) loaded into this folder, which is stored in flash ram in the controller. A project folder is a software folder than may have several files inside it. You must load 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

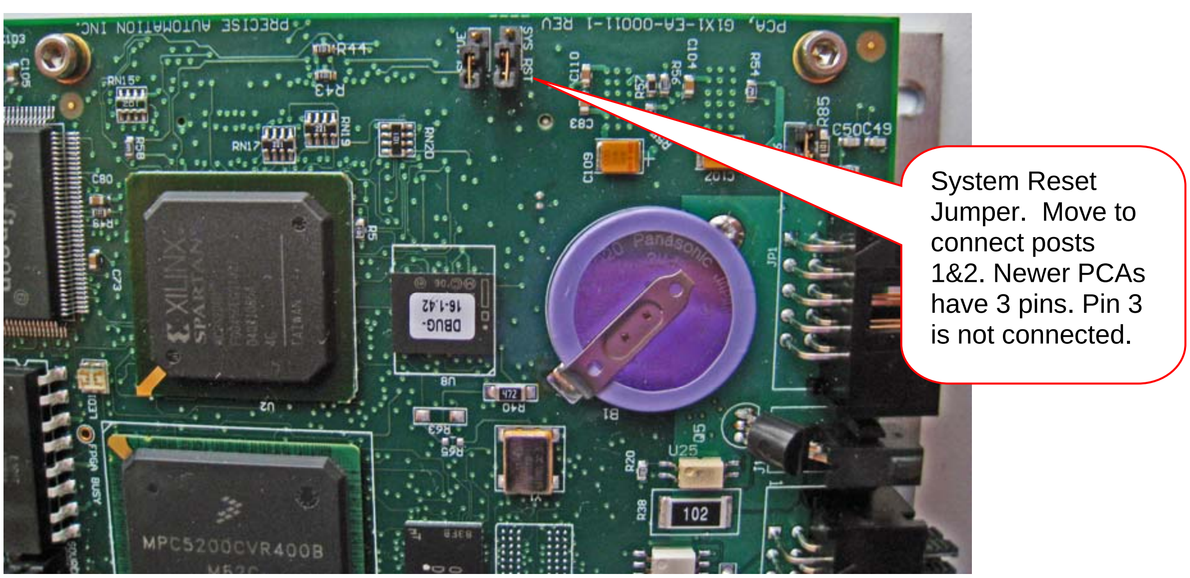
PAC files are configuration files that determine the configuration of the robot for the software, including the robot factory calibration data. These files are stored in Flash RAM. Flash RAM is also used to store robot programs. The Flash RAM requires some time for a complete write cycle. During the 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.

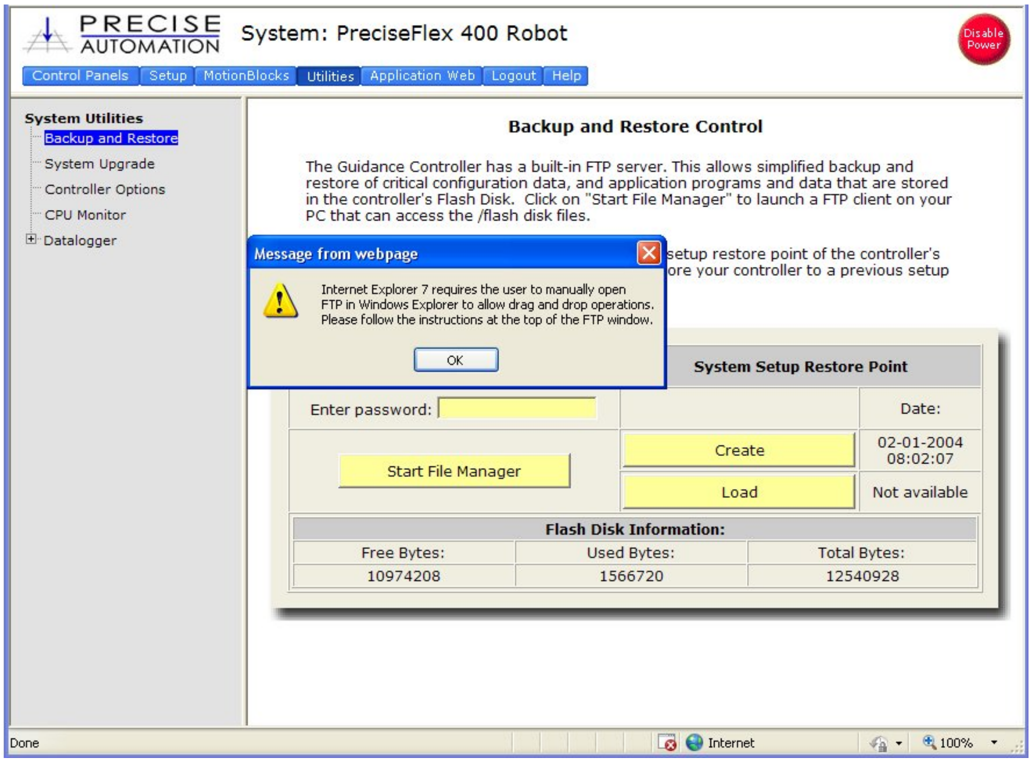
In order to allow the controller to recover from corrupted PAC files, a set of recovery boot up PAC files is loaded in a the system area of the Flash.

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

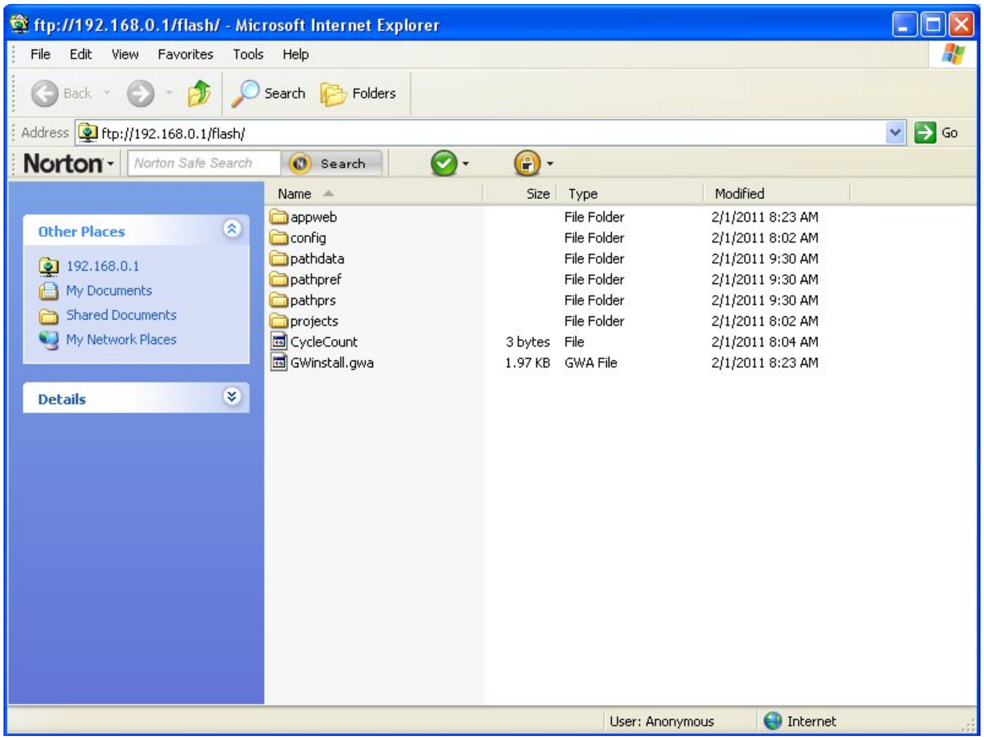
1. Obtain a set of backup PAC Files from Precise or local backup.
2. Remove the Inner Link Cover of the robot.
3. Move Jumper J8 (see figure below) so that it connects the two jumper posts. This will cause the factory default configuration files to be loaded at controller boot up.



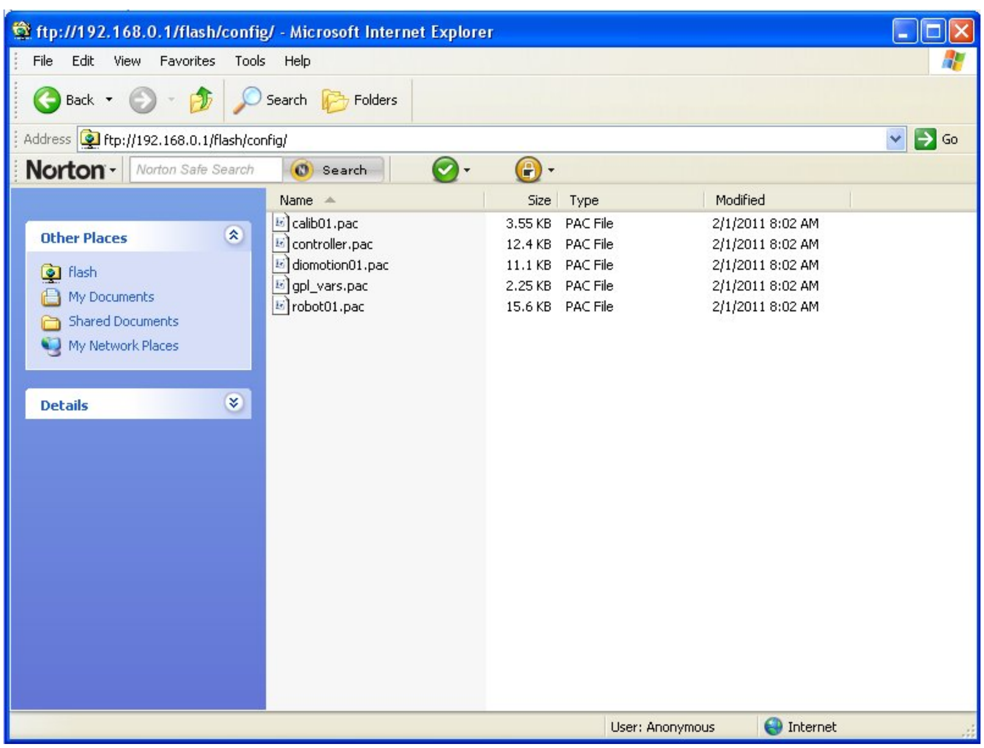
4. Cycle robot power to reboot the controller.
5. In the Web Based Operator Interface, select "Utilities/Backup and Restore



6. 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".



7. Open the "Config" folder and paste the backup copy of the PAC files into this folder.



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

10. Restore Jumper J8 to its previous position.
11. Reboot the robot. The PAC files should be restored and the robot should run.
12. 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.
13. Replace the Inner Link Cover.

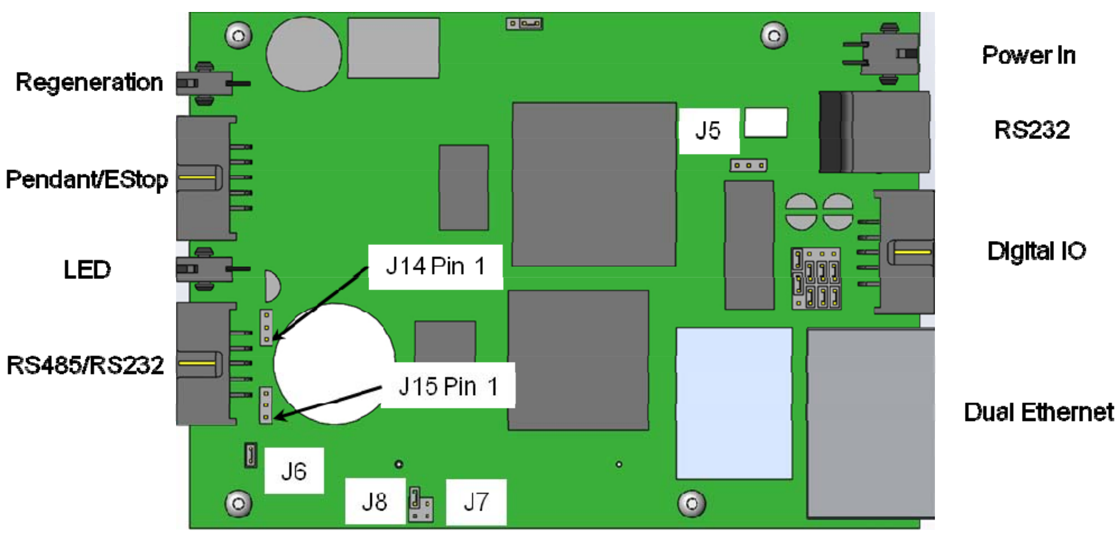
Controller Software Extensions

This section discusses extensions to the standard Guidance Controller software that are specific to the PreciseFlex 400 Robot. Precise offers a Command Server software package that allows a PC to send high level commands to the PF400 robot. This package is available upon request.

Adding or Removing the Optional Linear Axis

The optional Linear Axis may be added to existing PF400 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 3.2.H4 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_Rev21 or later.

In addition, when adding a linear axis to a robot with a servo gripper for the first time, the J6 RS485 termination jumper on the robot controller in the inner link of the robot must be removed, as the RS485 bus is now extended to the end of the linear rail, where an RS485 jumper is installed. Failing to remove this jumper can result in RS485 communication errors as there will be too many loads on the RS485 bus. Note however that for robots with a pneumatic gripper, this jumper should not be removed as the controller will form one end of the RS485 chain and the GSB controller in the linear rail or the GIO IO board in the end of the linear rail should provide the second termination. If the GIO is installed, J6 should be installed on the GIO and J6 should be removed from the GSB on the linear rail carriage. (See sections on replacing the Linear Axis Controller and Installing the Optional GIO Board for pictures.)



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.

The factory test program which is shipped with each robot includes sample code to move the Linear Axis.

Controlling the Precise Servo Grippers

Overview

The 23 Newton Precise Servo Gripper with spring return contains a brushless servo motor with an incremental encoder with both counting and motor phase tracks. At power up the encoder provides motor commutation information for a brief period, and then switches the incremental encoder A, B and Z signals onto the same set of wires. This allows the motor commutation to be initialized at startup without any motion.

The motor has a 12 tooth pinion gear cut directly on the motor shaft. This pinion drives a pair of opposing racks to open and close a set of finger mounts which are attached to linear ball slides. Various fingers can be attached to the finger mounts.

One finger mount is also attached to a spring return, which applies a continuous closing force to the finger mounts as they are coupled together by the pinion. So if power is lost the gripper will close and maintain a closing force so that it does not drop parts.

In order to avoid the gripper slamming closed from the spring force when motor power is disabled, there is a 500ms delay after an EStop or power disable command is sent before the motor power is cut off. During this period, the servo slowly closes the gripper.

In order to support “free” mode, in which the fingers can be moved back and forth freely by hand, in free mode the servo counterbalances the spring by applying an opposing force based on finger position.

For the 3kg PF3400 users may order an optional 60 Newton servo gripper.

Software Revision

The Spring Gripper functionality is fully supported by GPL version 3.1.P11 or later and PAC files PFlex400S_Prod_B03 110913 or later. Some slightly earlier software versions were delivered to beta customers.

Controlling the Gripper

Precise has created a GPL software routine that controls the spring gripper. This routine includes features for controlling the gripper squeeze force and detecting if a plate is present during a grip. Precise makes this routine available to customers upon request. This routine is also available in the Precise Command Server Software for the PF400.

Gripper Squeeze (Simple Method)

The spring applies a closing force of approximately 7 Newtons at a finger opening of 103mm, which is halfway between a portrait titer plate grip at 83mm and a landscape titer plate grip at 123mm. The force is closer to 6N in portrait mode and 8N in landscape mode and 9-10N at the full open homing position. These closing forces appear adequate to prevent dropping titer plates weighing up to 200 gms, and are selected to allow enough motor torque to overcome the spring and still provide reasonable opening force for inside grips.

The motor for the 23N gripper can apply about 18N of force at its rated current of 1.26A. When closing the fingers the motor adds its force to the spring force, so a maximum closing force of about 24-26N is possible, depending on portrait or landscape gripping. When opening, the motor must oppose the spring force, so a maximum opening force of about 8- 12N is possible, depending on the opening of the fingers.

The motor squeeze force can be limited by modifying the rated current of the motor. This can be done by writing into the 5th field in Parameter Data Base # 10611. The motor current can be set once and saved into flash or modified dynamically by a GPL program using the Controller.PDbNum instruction.

For the 23N gripper the formula for determining the approximate gripper squeeze is 7N +(Rated Current/1.26Amps)X18N for squeeze and (Rated Current/1.26Amps)X18N –9N for gripper opening force.

For the 60N gripper the formula for determining the approximate gripper squeeze is 7N +(Rated Current/2.0Amps)X53N for squeeze and (Rated Current/2.0Amps)X53N –9N for gripper opening force.

Note that in order to home the gripper must open all the way its maximum hard stop. The spring force at this point is about 10N. So the motor current should not be set below about 12N/18NX1.26A or 0.8A for the simple method of controlling gripper squeeze, giving a range of about 18N minimum to 24N maximum squeeze for the 23N gripper.

Gripper Squeeze (Asymmetric Method)

There may be cases where 18N of squeeze is too much. In this case there is a more sophisticated method to control squeeze.

There are two parameters in the database, 10351 and 10352 that can be used to limit the torque from the PID loop in the positive and negative directions. These parameters were developed to limit the downwards force of a robot running with dynamic feedforward, where the dynamic feedforward compensates for the gravity torque of the robot. The feedforward torque is NOT limited by these parameters, only the PID torque. So for a perfectly balanced robot, setting these parameters to a low value for a gravity loaded axis limits the maximum force the axis can apply from any position error. So if the axis crashes into a hard stop, the downwards or upwards force can be limited to a small value.

These same parameters can be used to limit the gripper squeeze in an asymmetric manner. Parameter 10352 can be set to a negative value of torque counts (tcnts) to limit the torque from the PID loop in the controller in the negative direction only. Parameter 10351 can similarly be set to limit tcnts from the PID loop in the positive direction. Since the spring compensation in the gripper is treated as a feedforward torque, these parameters do not affect the spring compensation torque.

For this case it is more exact to know the exact number of tcnts to oppose the spring at various openings. For the portrait mode opening of 83mm it takes 1600 tcnts to oppose the spring. For the landscape mode opening of 123mm it takes 2200 tcnts to oppose the spring.

If the rated torque of the motor has been set to its maximum value of 1.26A, the formula for setting parameter 10352 is (Spring force at position) +((-<Contents of 10352>-<tcnts to oppose spring force>)/4378)X18N, where 4378 is the number of tcnts corresponding to 1.26A or the rated torque of the motor. For example, for portrait mode the spring force is about 6N, and if the contents of 10352 are -3200, this value will be 6N + (3200-1600)/4378)X18N or about 12.5N. If the value of 10352 is -1600, the squeeze will be 6N which is the spring force only.

In a similar manner parameter 10351 can be used to limit the gripper opening force. In this case the value for the opening force is ((<Contents of 10351>-<tcnts to oppose spring force>)/4378)X18N – (Spring force at position). For example, in landscape mode the spring force is about 8N, and if the contents of 10351 are 5200, this value will be (5200-2200)/4378X18N -8N or 4.3N. Note that 5200 is about as low a value as you would want to use in landscape mode for parameter 10351, to ensure there is enough force to oppose the spring and open the gripper all the way to the homing position. For many cases, 10351 can be left at its default value of 0, in which case it is disabled.

End of Travel Sensor

The Precise 23N EGripper includes a sensor to detect the gripper closed to hard stop position. The spring will return the gripper to this position if power is off and there is no plate in the gripper. This sensor is wired to Digital Input 2 on the Gripper Controller Board which can be read at Digital Input 210002. This input can be viewed in the Web Browser under Control Panels/Remote IO/Network Node 2 IO. At power up this sensor can be checked to determine if the gripper is fully closed, and thus not holding a plate. If the gripper is not fully closed it will be holding a plate, and the operator should be directed to remove the plate before homing the robot, which will open the gripper to the maximum hard stop. The 60N servo gripper has an absolute encoder and position can be checked after homing, which does not move the gripper fingers.

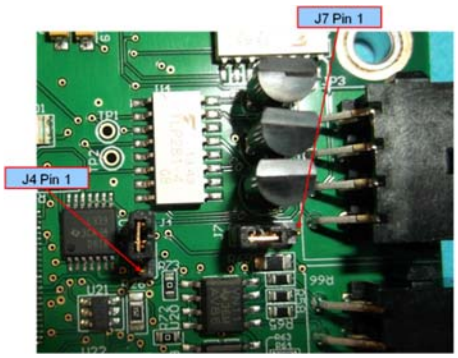
Grip Test and Squeeze Check

It may be desirable to check if a plate is gripped by checking the gripping torque value. The output torque to the motor is available in Parameter 12304, value 5 in the parameter data base. For a non-spring gripper, this value varies between 0 and 4378 tcnts for a maximum gripper force of 18N. For a spring gripper, per above, for a portrait grip, the spring adds about 1600 tcnts to the squeeze and for a landscape grip, it adds about 2200 torque counts to the squeeze. Since this value is taken into account by the spring compensation and is offset from the torque commanded to the motor in Parameter 12304, when checking Parameter 12304 to determine squeeze the spring compensation must be subtracted from the torque value in Parameter 12304. For example, if the gripper is at the portrait position and not holding a plate, it must servo against the spring. In this case the value in Parameter 12304 will be about 1600 tcnts. To determine the effective squeeze torque, subtract 1600 tcnts from this value, which results in zero tcnts of squeeze force. If the value in 12304 is -2700, then the gripper motor is squeezing with -2700 tcnts, and the spring is adding -1600 tcnts, and the effective squeeze is -4300 tncts, or about 18N. The exact spring compensation value is stored in field 5 of Parameter 12331. For the best accuracy in determining effective squeeze force at any gripper opening, subtract this value from the value in 12304.

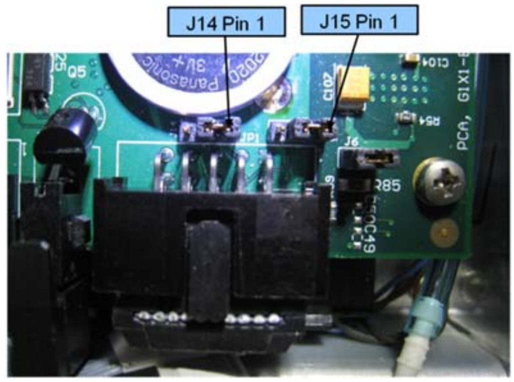
Servo Gripper Controller Digital Inputs and Outputs

The Servo Gripper Controller PCA (GSB) adds 3 general optically isolated digital outputs and 3 general optically isolated digital inputs to the standard digital I/O found on the Guidance Controller. Like the other general inputs and outputs, they can be assigned for various control purposes during system setup, or they can be used directly by a GPL procedure.

Unlike the controller's standard digital I/O that are directly accessed on demand, these I/O are scanned by the controller. The scanning period is nominally 4 milliseconds, so your application must be able to handle a delay of up to 4 milliseconds for signal changes to propagate through the system. Note that effective with Rev 4 of the GSB board, two IO pins have optional assignments based on jumpers. J4 is connected to pins 2 and 3 to connect Digital Input 1 to pin 6 and is connected to pins 1 and 2 to connect pin 6 to a line that goes back to the controller RS232 RXD input. J7 is connected to pins 2 and 3 to connect Digital Output 3 to pin 3 and is connected to pins 1 and 2 to connect pin 3 to a line that goes back to the controller RS232 TXD input. Note further that on the controller CPU board, two more jumpers must be correctly installed to connect RS232 to the GSB. On the CPU board, shown below, J14 and J15 must be connected to pins 2 and 3 to connect the TXD and RXD inputs from the GSB to the serial inputs in the CPU. The factory configuration for J14 and J15 is connecting pins 1 and 2. This is because prior to Rev 4 of the GSB, the wires connected to these pins in the RS485 cable were grounded, and if you plug in a GSB earlier than Rev 4, you will ground the RS232 signals unless J14 and J15 are in their factory configuration.



J4 and J7 on GSB Board



J14 and J15 on CPU Board

The GSB I/O signals are shown in the table below:

Pin	GPL Signal Number	Description
1	200013	Digital Output 1
2	200014	Digital Output 2
3	200015	Digital Output 3 (LED Output or TXD, select with J7)
4		24 VDC output
5		GND
6	210001	Digital Input 1 (Pushbutton on some Electric Grippers or RXD, select with J4)
7	210002	Digital Input 2 (End of travel sensor option)
8	210003	Digital Input 3

Optional Pneumatic or Vacuum Gripper

It is possible to order an optional pneumatic or vacuum gripper. In these cases there is no servo gripper controller (GSB) board. The J4 motor FFC motor interface board is replaced by a vacuum/pneumatic gripper interface board which includes 2 digital outpus, 2 digital inputs, and 1 or 2 analog inputs for a vacuum sensor. The RS485 cable from the controller to the GSB board is removed. A different IO cable is installed from the FFC interface board on the side of the inner link to the vacuum/pneumatic interface board. This different cable routes the IO signals from the robot controller to the outer link.

While some grippers for OEM customers differ slightly from the following, in general for the pneumatic gripper controller digital output 1 will open the gripper. Controller digital input 1 goes high when the gripper is open and input 2 goes high when the gripper is closed. (See the section on controller digital input and output signals for the software assignments of these signals.)

For vacuum grippers, digital output 1 turns on vacuum and digital output 2 turns on blowoff air. Digital input 4 goes high when vacuum is present.

G1400B Dedicated Digital Outputs

The G1400B adds one dedicated digital output to the standard dedicated signals found in the Guidance Controller, as shown in the table below.

Users normally do not need to modify the setting of the status lamp (IO 20) since the standard robot software typically manages this signal. However, if desired this signal can be manually altered under program control via the GPL SIGNAL.DIO instruction. This is controlled by DOUT signal 20. If direct control of this signal is desired, DataID 235 should be set to 0 and signal number 20 should be controlled by program control.

Signal Number	I/O	Label	Description
20	O		Outer Link status lamp. Set to 1 to turn on the lamp. Normally parameter “Power State DOUT” (DataID 235) is set to this signal number so that the Outer Link lamp displays the robot power state.

Service Procedures

Recommended Tools

The following tools are recommended for these service procedures:

1. Gates Sonic Belt Tension Meter, Model 507C for checking timing belt tension.
2. A set of metric “stubby” hex L-keys, for example McMaster Carr PN 6112A21 with 1.5, 2.0, 2.5, 3.0, 4, 5, and 6mm L Keys.
3. A set of metric hex drivers including 1.27, 1.5, 2.0, 2.5 and 3.0mm driver, for example McMaster Carr PN 52975A21.
4. A pair of tweezers or needle nose pliers.
5. A pair of side angle cutters.
6. Small flat bladed screw driver, with 1.5mm wide blade typical
7. M5 socket driver or M5 open end wrench or pliers

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 both Phoenix plug and 9 pin Dsub for Estop jumpers.
“Encoder Battery Low”	Replace absolute encoder battery 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”	Check that the FPGA code is dated Jan 25, 2012 or later. Upgrade FPGA if necessary. Encoder cable may be damaged and encoder is getting intermittent communication, causing apparent jumps in position. Check encoder connectors on flat ribbon cable. Replace cable. Replace motor.
“Encoder Communication Error”	Check that the FPGA code is dated Jan 25, 2012 or later. Check encoder connectors on flat ribbon cable. Replace encoder cable or motor/encoder.
"Encoder quadrature error"	Replace slip ring. Replace motor/encoder (only Gripper motor).
"Missing zero index"	See "Encoder quadrature error"
“Motor duty cycle exceeded”	Reduce speed or acceleration of robot. Check for instability.
“Amplifier under voltage”	Motor power supply has reached current limit and shutdown. Slow down robot. Check Energy Dump PCA. Replace 48V supply.
“Amplifier Fault”	Check harness and motor for shorts.
“Amplifier Over Voltage”	Replace energy dump board. Check harness for shorts.
“Soft Envelope Error”	Make sure robot not pressing against surface. If this occurs on the gripper repeatedly, replace slip ring.
“Hard Envelope Error”	Typically means robot has crashed into something.
Pneumatic Gripper Sensor not working	Check continuity of cable through wrist. Check green lights on sensor to see if sensor is triggering.
“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. If Gripper, replace slip ring after checking that brake releases.
“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	
Brown streaks on linear bearing	Clean with alcohol and add grease to bearing blocks. This should not be required sooner than 20,000 hours of run time. Grease is Alvania Grease EP2 from Shell.
Mechanical noise from any joint	Check joint bearings for failure. Re-tension belt.
Loud buzzing or vibration from any joint	Re-tension timing belts. If timing belt will not hold tension, replace.
Squeaking from Z belt	Apply thick grease to front and rear edges of belt, (Mobile 222 XP). Belt can get stiff over time and squeak against pulley flanges.

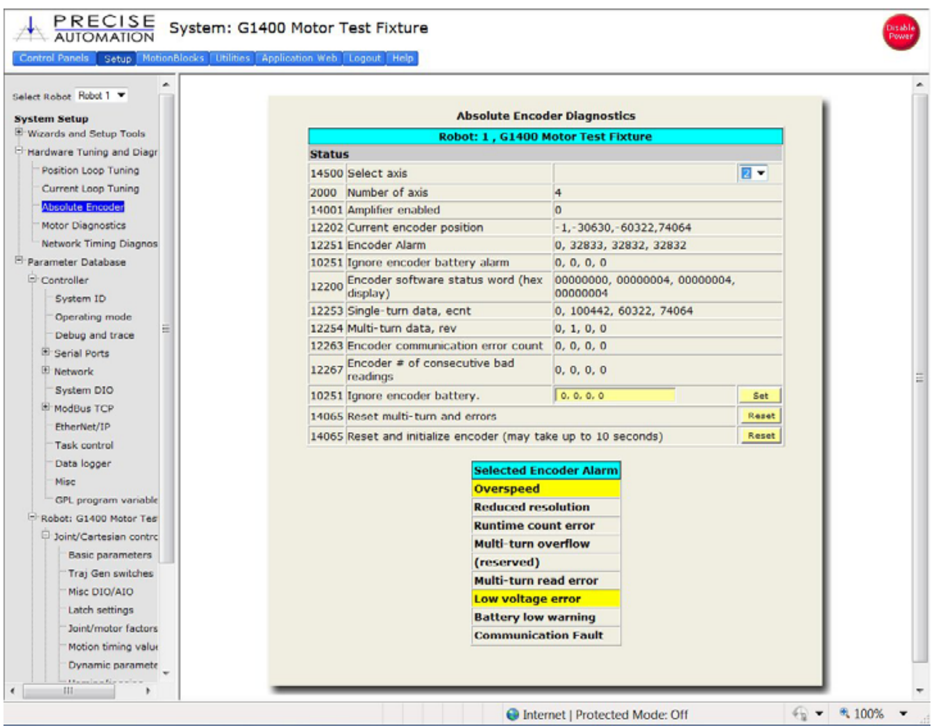
Encoder Operation Error

The PF400 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 (using the calibration pins if desired-see

Calibrating the Robot), or another known position, and check the joint angles in the Virtual Pendant in the Web Operator Interface. The joint angles in the Calibration Position are:

Z Axis: -1mm (-2mm for Beta robots)
J2 or Shoulder: -90
J3 or Elbow: 179.99
J4 or Wrist: -180

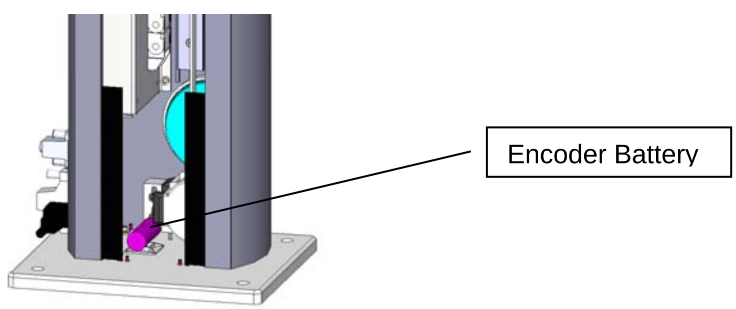
If the robot joints after this procedure followed by homing are different from the above, then the robot needs to be re-calibrated. See procedure below.

Replacing the Encoder Battery

DANGER: Before replacing the encoder battery, the AC power should be disconnected. Removing the front cover allows access to the AC power terminals.

The Encoder Battery 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.



Tools Required:

1. 3.0mm hex driver or hex L wrench

Parts Required:

1. New Encoder Battery PN PF00-EA-00002
2. 6 in long by .125 wide tie wrap

To replace the Encoder Battery the user must:

1. Turn off power to the robot and remove the AC power plug.
2. Remove the Top Plate of the robot by removing the 4 M5 low socket head screws from the top plate of the robot that attach the top plate to the Z column. Lift up the Top Plate.
3. Remove the Front Cover by lifting it out vertically.
4. The Encoder Battery is located in the base of the robot behind the Z Column Front Cover. The Encoder Battery has a connector which plugs into one of two identical connectors on a pigtail. A new Encoder Battery should be plugged into the second connector before the depleted Battery is removed. This allows the procedure to be performed without robot power.
5. Attach the new Encoder Battery to the hold down with a tie wrap.
6. Replace the Front Cover and Top Plate.

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.

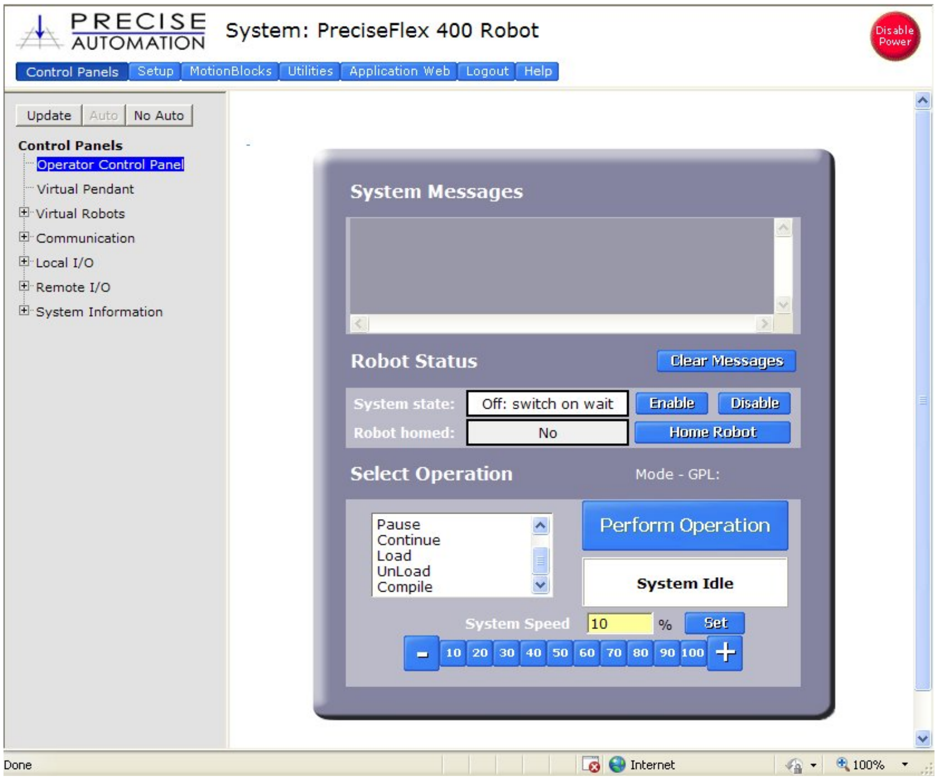
Cal_PP is supplied on the *Guidance Controller System Software CD*. To run Cal_PP, the controller must be configured to run GPL programs and Cal_PP must be loaded into the controller's memory (See Appendix D).

Tools Required:

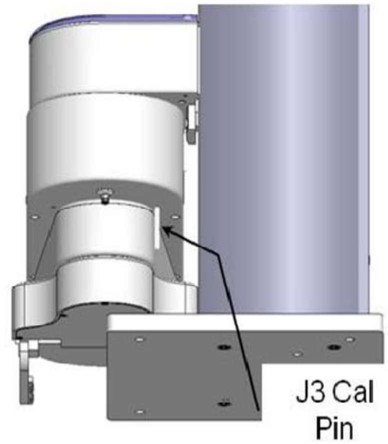
1. 2.5mm and 3.0mm hex drivers or hex L wrenches
2. Set of 3 Calibration Dowel Pins**, located in plastic bag inside the hollow slot in the front cover**.

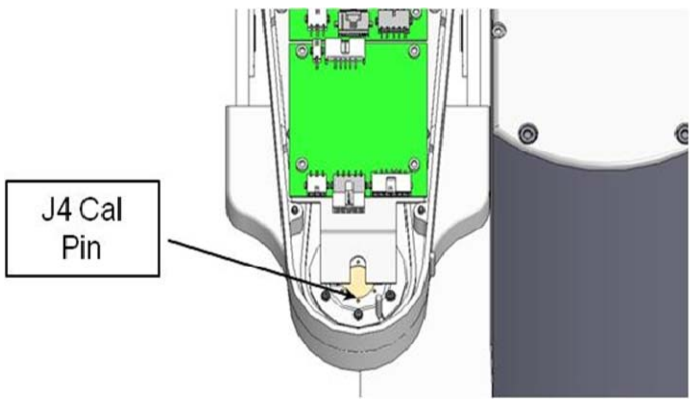
The following describes the procedure for defining the zero positions of the PF400 robot axes using Cal_PP.

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 "***Perform Operation***" 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, select "***Start application***" and press the "***Perform Operation***" 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.

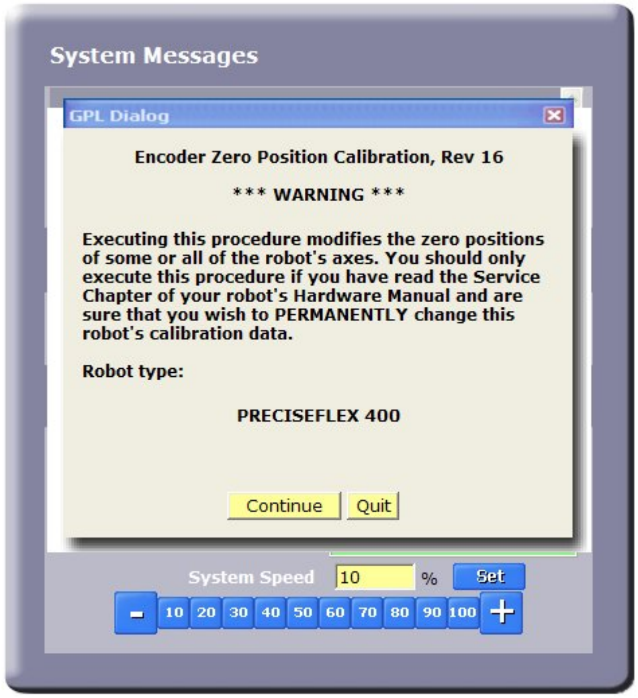


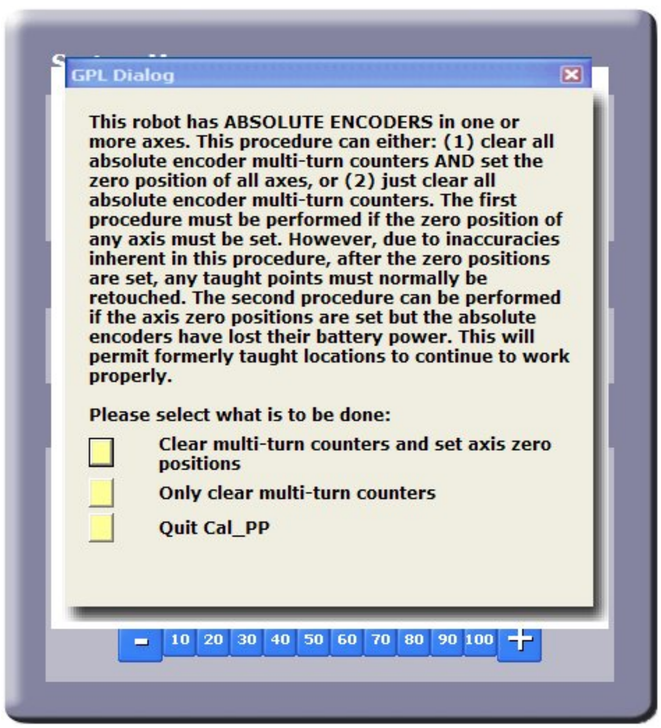
3. Manually move the robot into the configuration shown below.
    a. The top cover of the outer link will need to be removed by removing the 4 M3 X 20 SHCS that are located in counter bores under the outer link.
    b. If the optional Linear Axis is installed, move the Linear Axis carriage to the hard stop near the connector end cap. For the Linear Axis calibration be sure to use CALPP Rev 21 or later.
4. Ensure Z-axis is resting on the lower hard stop by releasing the Z axis brake by pushing on the brake release button under the shoulder while supporting the robot arm with your hand, and lowering the robot arm gently until it rests on the lower hard stop.
5. If the Calibration Pins have not already been removed from the robot, it may be necessary to remove the top cover of the robot by removing 4 M5 Low Head screws with a 3.0mm hex driver and then to remove the front cover to access the bag with the Calibration Pins which is inside the front cover extrusion at the bottom.
6. Insert a M3 X 30mm Calibration Dowel Pin into the J4 (wrist) pulley with the gripper positioned under the outer link and rotate the gripper back and forth until the pin drops into a slot in the outer link, locating the gripper under the center of the outer link.
7. Insert a tapered .5in Calibration Dowel Pin into the hole in the bottom of the shoulder. Rotate the inner link counterclockwise until it rests against this pin as shown below.
8. Insert an tapered .5in Calibration Dowel Pin into the hole on inner link as shown below. Rotate outer link clockwise until it rests against the dowel pin.
9. If the robot is installed on a linear rail, push the rail carriage all the way to the hard stop at the linear rail connector end cap.





10. With the CALPP application loaded, select “Start Application”, then press “Perform Operation”
    a. Application should start and prompt user to confirm correct robot position for calibration





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

11. After calibration is complete, use the brake release button and move the Z-axis up from the hard stop. Failing to do this will produce an error as the robot is outside of the soft stop limits.
12. **Make sure the pins are removed.**
13. **Enable power and home the robot. Calibration does not take effect until the robot is homed.**

Replacing Belts and Motors

The timing belts and motors are designed to last the life of the robot. It is not expected that they will need to be replaced in the field. In most cases, if a belt or a motor needs to be replaced, the robot should be returned to the factory. While there are procedures at the end of this manual for replacing belts and motors, only experienced service technicians should attempt these procedures.

General Belt Tensioning

The PreciseFlex 400 has been designed to make belt tensioning very simple. Prior to 2014 each axis had a spring preload system that sets the correct belt tension when the axis motor mount plate screws are loosened. After 2014 the springs were removed from the inner and outer links and access hatches were added to make belt tensioning more accurate. See Appendix D for belt tension specifications.

Tensioning the J1 (Z Column) Belts

DANGER: Before tensioning the timing belts or replacing any motors, the AC power should be disconnected. Removing the front cover allows access to the AC power terminals.

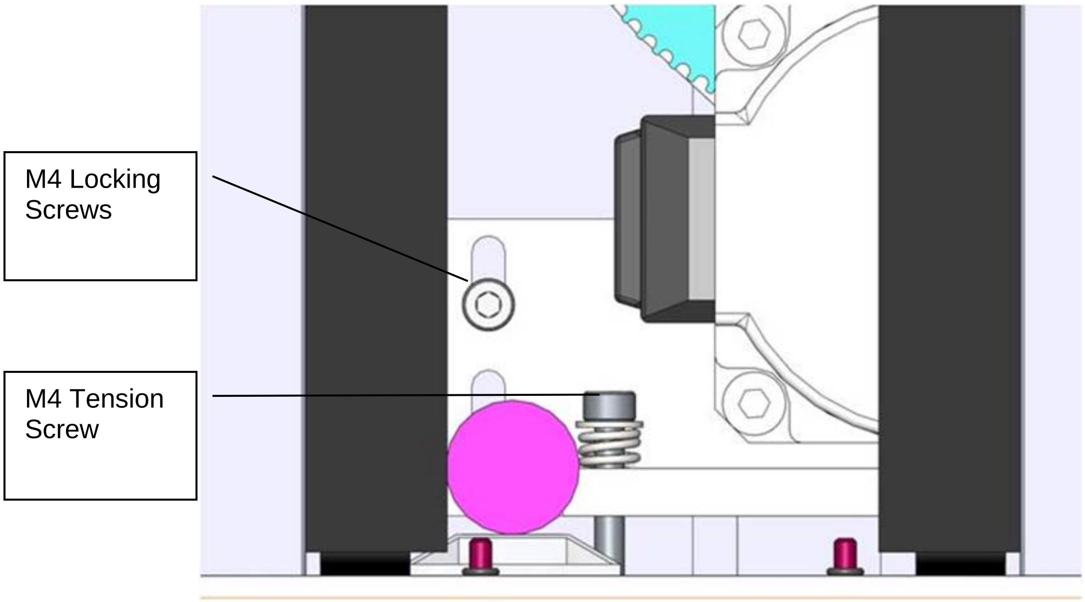
Tensioning the 1st Stage Belt

Tools Required:

1. 3.0mm hex driver or hex L wrench

To adjust tension in the 1st Stage Belt the user must:

1. Turn off robot power and remove the AC power cord.
2. Remove the Top Plate of the robot by removing the 4 M5 socket head screws from the top plate of the robot that attach the top plate to the Z column. Lift up the Top Plate.
3. Remove the Front Cover by lifting it out vertically.
4. Loosen the 2 M4 locking screws on the J1 Motor Mount Bracket to allow the Mount Bracket to slide up and down.
5. Adjust the M4 Tension Screw compressing the spring assembly. The tension spring should be compressed until the spring length is 5.5mm under the washer.
6. After adjusting the Tension Screw, the M4 locking screws should be tightened to lock the assembly in place and the Front Cover and Top Plate should be replaced.



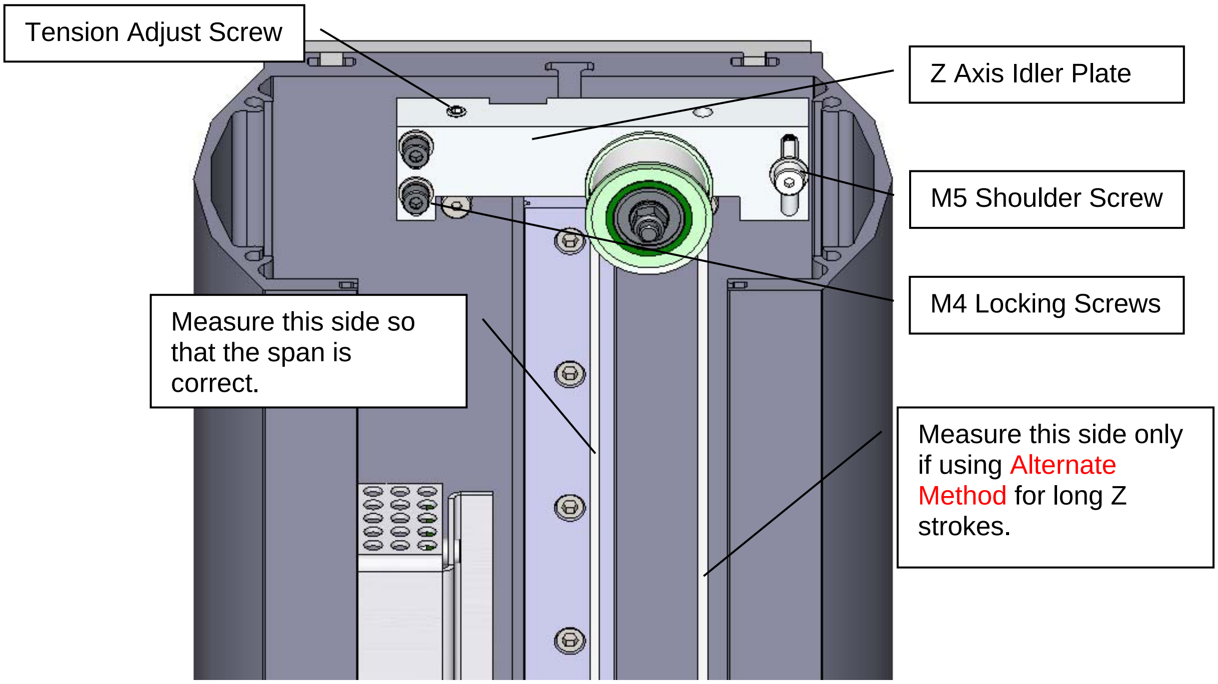
Tensioning the 2nd Stage Belt

Tools Required:

1. Gates Sonic Belt Tension Meter, Model 507C
2. 3.0mm hex driver or hex L wrench
3. 2.5mm hex driver or hex L wrench

To tension the 2nd Stage J1 Belt the user must:

1. Turn off the robot power and remove the AC power cord.
2. Remove the Top Plate of the robot by removing the 4 M5 socket head screws from the top plate of the robot that attach the top plate to the Z column. Lift up the Top Plate.
3. Remove the Front Cover by lifting it out vertically
4. Loosen the two M4 locking screws and the M5 shoulder screw on the Z idler plate.



5. The tension is set to the value in Appendix E by adjusting the M5 set screw which pushes on a spring in the Z Axis Idler Plate. Re-tighten the 3 screws and replace the Front Cover and Top Plate. (Alternate Method: For the 750mm and 1160mm Z travel robots, it can sometimes be difficult to get a good tension reading for the spans for these long belts, which are 880mm and 1290mm respectively and as a result have low vibration frequencies. In this case it may be easier to position the Z carriage so that the span from the top idler pulley to the Z carriage is 530mm, which is the span for the 400mm Z stroke when measured on the left hand side of the belt as shown above. With the carriage at this location with a span of 530mm, for these longer travel Z strokes, you can then measure the tension on the right hand side of the belt, and use the values for tension and frequency for the 400mm Z stroke.)

Tensioning the J2 Belt

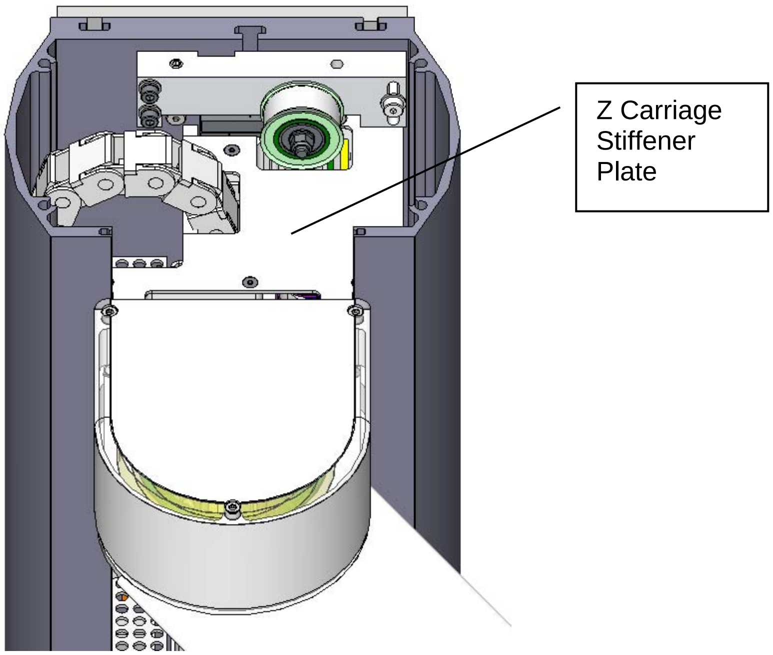
DANGER: Before tensioning the timing belts the AC power should be disconnected. Removing the front cover allows access to the AC power terminals.

Tools Required:

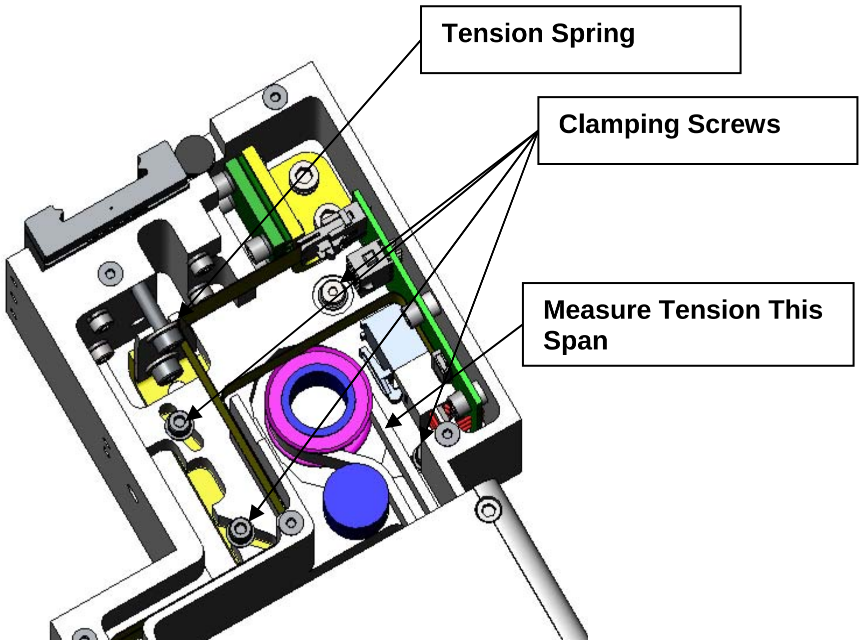
1. Gates Sonic Belt Tension Meter, Model 507C
2. 3.0mm hex driver or hex L wrench
3. 2.5mm hex driver or hex L wrench
4. 2.0mm hex ball driver or hex L wrench

In order to re-tension the J2 (shoulder) Timing Belt, the user must:

1. Move the robot arm to the top of the Z Column travel.
2. Turn off the robot power and remove the AC power cord.
3. Remove the Top Plate of the robot by removing the 4 M5 socket head screws from the top plate of the robot that attach the top plate to the Z column. Lift up the Top Plate.
4. Remove the Front Cover by lifting it out vertically



5. Remove the Z Carriage Stiffener Plate by removing the M3 X 6 FHCS attaching it to the Z Carriage (shoulder).



6. Loosen the 3 M3 SHCS and 1 M4 Shoulder screw clamping the J2 Motor Mount Plate to the Z Carriage. It may be necessary to remove the tie wrap securing the J2 Motor cables to the Z carriage in order to access the clamping screw under these cables. It is best to measure the belt tension with a tension meter as described in Appendix E. If a belt tension meter is not available, the Tension Leaf Spring will automatically reset the belt tension. It is helpful to jiggle the motor a little bit to be sure any friction is overcome. The motor can be easily grasped by reaching under the Z carriage (shoulder). Then re-tighten the clamping screws. Replace the tie wrap if it was removed.
7. Replace the Z Carriage Stiffener Plate.
8. Replace the Front Cover.
9. Replace the Top Plate.

Tensioning the J3 Belt (Before 2014)

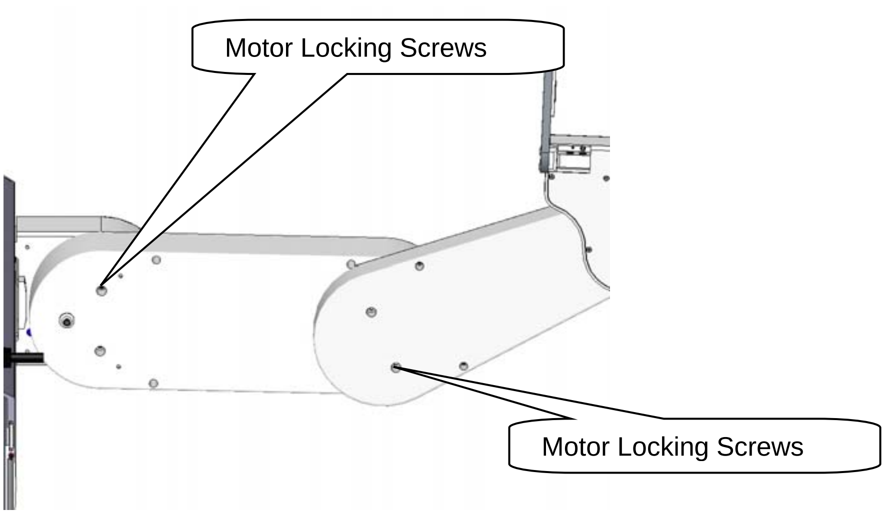
Tools Required:

1. Gates Sonic Belt Tension Meter, Model 507C
2. 3.0mm hex driver or hex L wrench
3. 2.5mm hex driver or hex L wrench

Prior to 2014 the J3 belt had a simple tensioning procedure described below. If this did not work due to high friction in the motor mounting flange, then it became necessary to completely remove the robot controller to accurately tension the J3 belt. Starting with 2014 shipments, an access hatch was added to the bottom of both the inner link and outer link to make J3 and J4 belt access easy and belt tensioning more accurate.

Prior to 2014, to tension the J3 Belt the user must:

1. Loosen the 2 Motor Locking Screws on the bottom of the Inner Link. One screw requires a 2.5mm driver and the second requires a 3.0mm driver.
2. Tighten the 2 screws again. The J3 belt is automatically re-tensioned.
3. The above procedure is an approximate procedure. Its accuracy is limited by the fact that the J3 belt tension will vary according the orientation of the J3 output pulley. The timing belts are very stiff. A .002 in eccentricity (which is the specified tolerance) in the output pulley can cause a 50% variation in the belt tension, depending on the orientation of the output pulley. If performing the quick tensions adjustment outlined in steps 1 and 2 above does not resolve a J3 instability (loud buzzing noise), it may be necessary to remove the controller and J3 belt cover to gain access to the J3 belt, and then set the belt tension by using a belt tension meter as described in Appendix E, while checking for the minimum belt tension every 10 degrees of rotation of the J3 output pulley. This more extensive procedure should be required only rarely.



Tensioning the J4 Belt (Before 2014)

Tools Required:

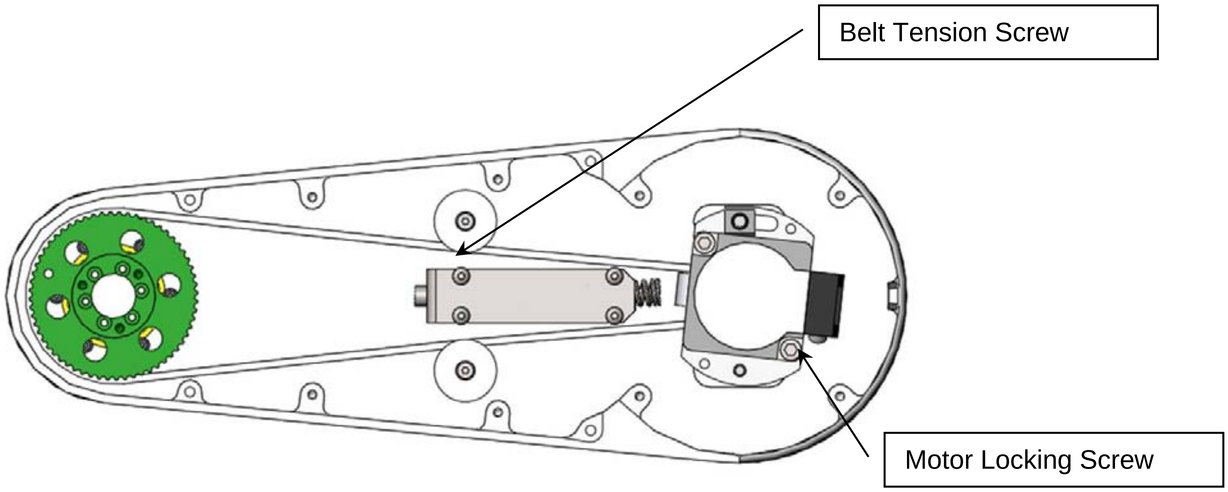
1. Gates Sonic Belt Tension Meter, Model 507C
2. 3.0mm hex driver or hex L wrench
3. 2.5mm hex driver or hex L wrench

Prior to 2014 the J4 belt had the tensioning procedure described below. Starting with 2014 shipments, an access hatch was added to the bottom of both the inner link and outer link to make J3 and J4 belt access easy and belt tensioning more accurate.

To tension the J4 Belt the user must:

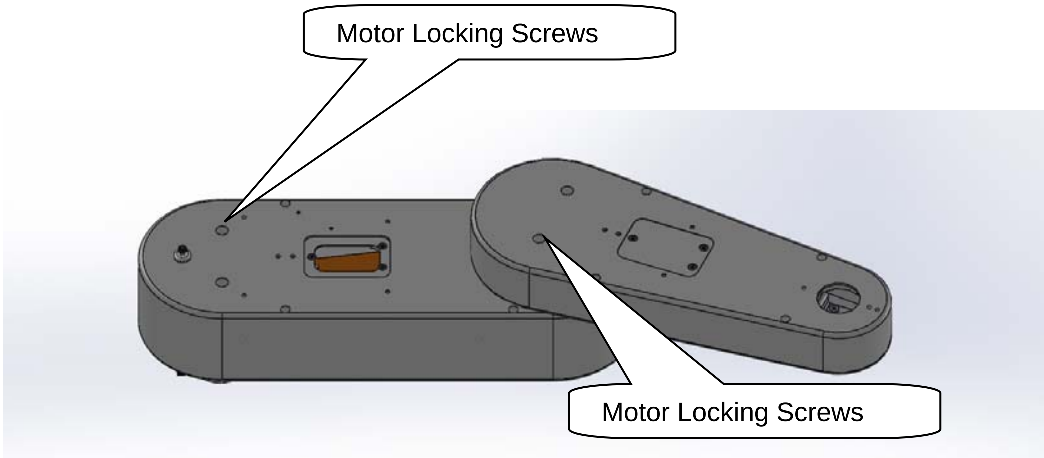
1. Remove the outer link cover.
2. Remove the gripper controller PCA.
3. On robot sold before January 2012, remove the Slip Ring Clamp and remove the 4 M3 X 10 FHCS screws retaining the J4 belt cover. Tip the belt cover upwards to access the timing belt.
4. Loosen the M4 SHCS and M4 Shoulder Motor Locking Screws on the bottom of the Outer Link

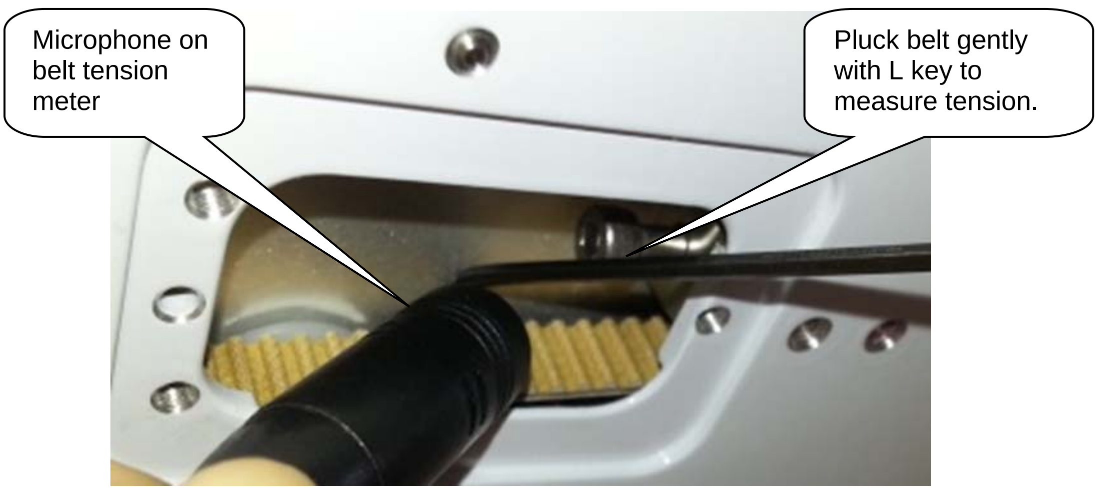
5. Measure the belt tension, every 10 degrees of rotation of the gripper to find the minimum tension.
6. Adjust the minimum belt tension to the value in Appendix E. This may be possible by just releasing and re-tightening the Motor Locking Screws. It may require adjusting the Belt Tension Screw. For some earlier robots, the 18mm M4 belt tension screw may need to be replaced with a longer 20, 22, or 24mm M4 Socket Head Cap Screw in order to get enough tension.
7. Tighten the 2 motor locking screws again.
8. For robots shipped after April 2012, an access hole has been cut in the J4 belt cover so that the tension meter head can reach the timing belt without tipping up the belt cover.



Tensioning the J3 and J4 Belts (2014)

In 2014 the access hatches shown below were added to both the inner and outer links to facilitate belt tensioning. Once the hatch cover is removed, loosen the appropriate motor locking screws one turn to unclamp the motor (do not loosen these screws more than one or two turns or the retaining nuts can fall off inside the link), insert the microphone from the belt tension meter near the belt to measure belt tension and adjust the M4 SHCS to adjust belt tension. Be sure to measure the belt tension 8 times, at 45 increments of the pulley in the axis rotation and set the tension at the position which has the lowest tension. See Appendix E.


Motor Locking Screws
Motor Locking Screws


Microphone on belt tension meter
Pluck belt gently with L key to measure tension.

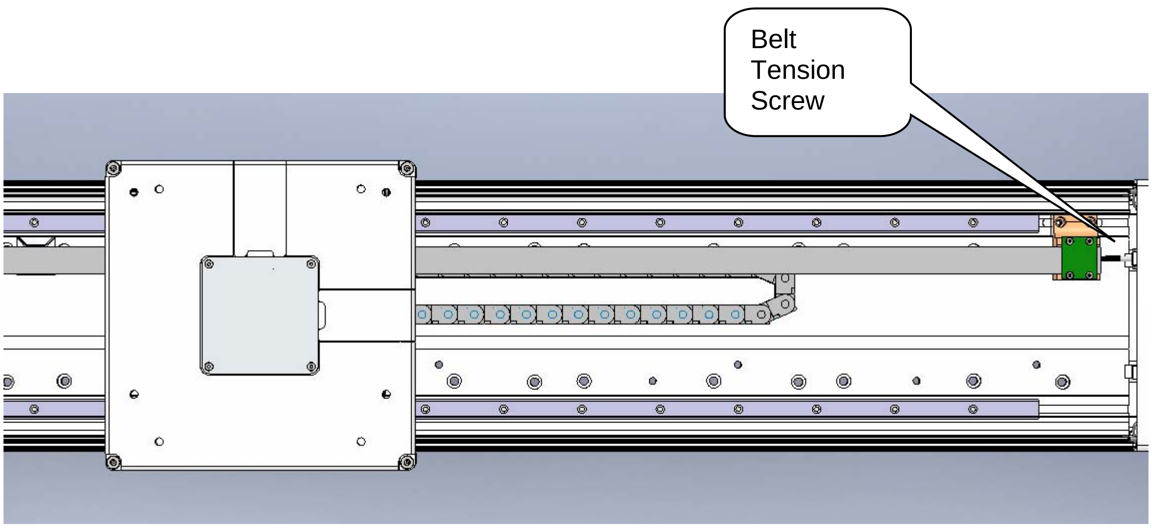
Tensioning the Belt on the Optional Linear Axis

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 E. 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 Supplies, Energy Dump PCA, or J1 Stage Two (Output) Timing Belt

DANGER: Before replacing the power supplies, the AC power should be removed.

Tools Required:

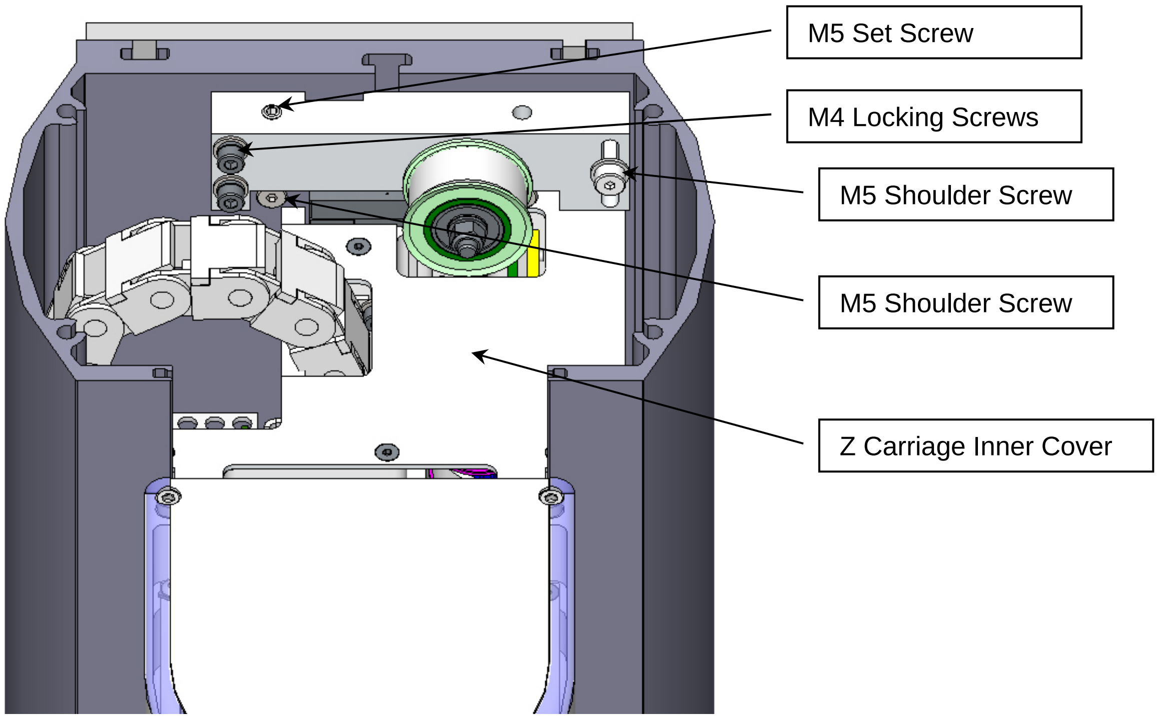
1. 3.0mm hex driver or hex L wrench
2. 2.5mm hex driver or hex L wrench

Spare Parts Required:

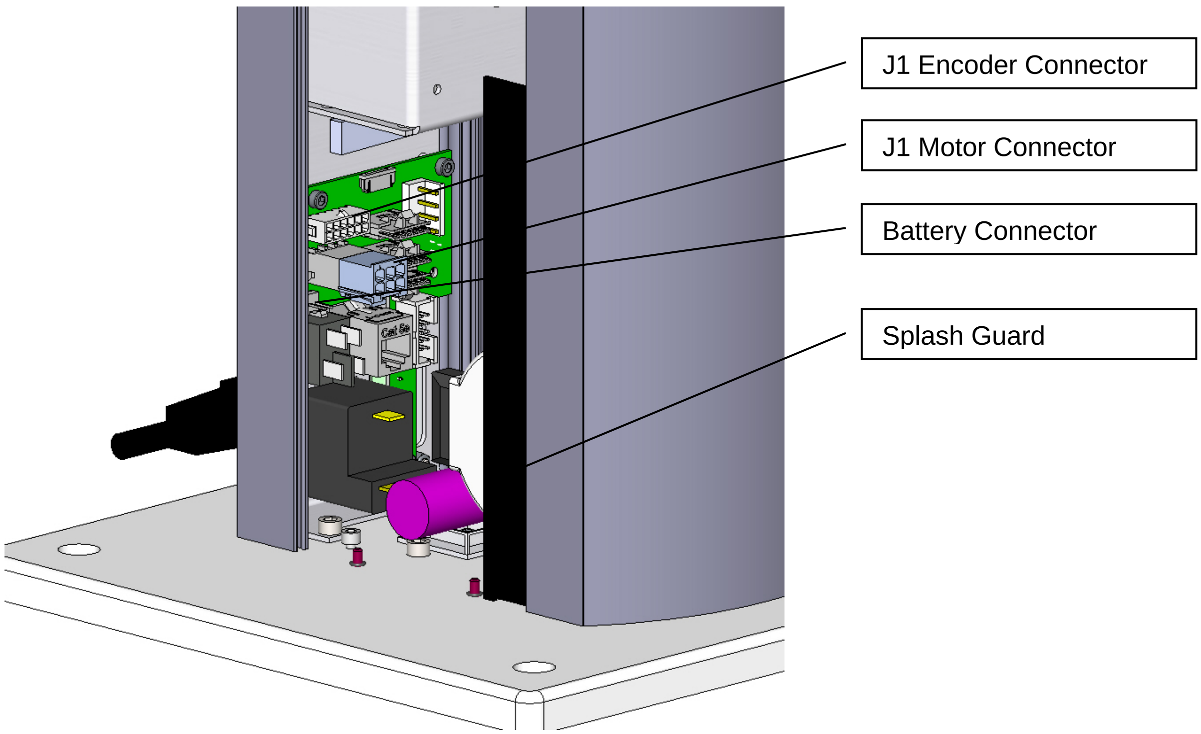
1. 24VDC power supply, PN PS10-EP-00125 or
2. 48VDC power supply, PN PS10-EP-48365 or
3. J1 Stage Two Belt, PN PF00-MC-X0022.

The user must:

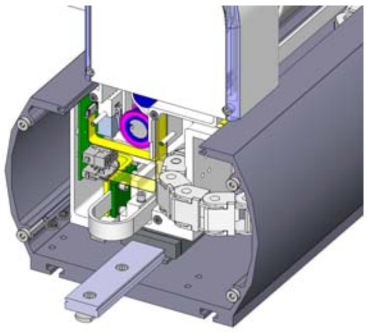
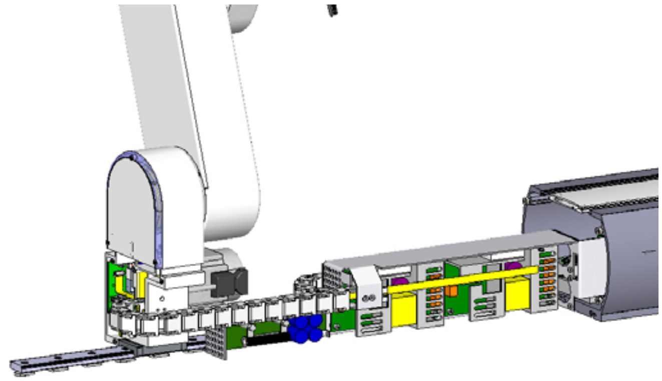
1. Move the robot arm to the top of the Z Column travel.
2. Turn off the robot power and remove the AC power cord.
3. Remove the Top Plate of the robot by removing the 4 M5 socket head screws from the top plate of the robot that attach the top plate to the Z column. Lift up the Top Plate.
4. Remove the Front Cover by lifting it out vertically.



5. Lay the robot down on its back side on a table where there is room to work.
6. Remove the Idler Plate Assembly by removing the M5 set screw that compresses the Idler Plate Spring, the 2 M4 SHCS that clamp the Idler Plate, and the M5 Shoulder Screw that forms the Idler Plate pivot. Be careful not to drop the pressure washer and tension spring that are inside the Idler Plate assembly. The tension spring presses against an M5 shoulder screw to tension the Z axis Stage 2 belt.
7. Remove the remaining M5 shoulder screw.
8. Disengage the Z Carriage Timing Belt from the lower Drive Pulley. If it is necessary to replace the Z Carriage 2nd Stage Timing Belt, remove the the Z Carriage Inner Cover and then the Timing Belt Clamp from the Z carriage by removing 2 M4 X 12 SHCS and lock washers and replace the belt.
9. Remove the left splash guard by removing the M3 X 8 SHCS on the retaining bracket.
10. Remove the 4 screws holding the Electronic Chassis to the Z Extrusion and the 2 screws attaching the Electronic Chassis and ground wire to the Base Plate.



11. Remove the J1 motor and encoder connectors that plug into the J1 Motor Interface Board.
12. Remove the Battery connector that plugs into the J1 Motor Interface Board.
13. Loosen the M4 SHCS screws attaching the Z bearing rail to the Z Extrusion.
14. Slide the Z Rail and Z Carriage with the robot arm still attached partially out the top of the robot, far enough to expose the power supplies. It may be more convenient to slide the carriage and Z rail all the way out of the Z extrusion. Take care the bearing block does not slide off the Z rail. It may be helpful to wrap some tape around the rail to prevent this. If the bearing block slides off the rail, the bearing balls may be lost, damaging the bearing. Simultaneously slide the Electronic Chassis out of the Z Extrusion and lay both assemblies on the table.
15. Unplug the cables from the failed power supply.
16. Remove the 4 M3 X 8 SHCS and lock washers to replace the power supply or energy dump PCA. Be careful not to pull the J1 FFC encoder cable (white 14mm wide flat cable) out of the FFC connector on the J1 Motor Interface PCA. If this cable is pulled out, you must carefully release the clamping lid on the FFC cable connector on the J1 Motor Interface PCA by inserting a small flat bladed screwdriver in the notch in the clamping lid and VERY gently prying the lid out of the connector. This lid is a cam-lock type of lid, which when inserted, clamps the flat white J1 encoder ribbon cable. Re-insert the J1 flat white encoder ribbon cable into this connector and carefully press the clamping lid back into the connector. If the J1 encoder cable is disconnected during this procedure, it will be necessary to re-calibrate the robot as the absolute encoder backup power will be interrupted to the J1 absolute encoder.
17. Re-attach the power supply cables and re-assemble the robot. Be sure the bearing rail reference edge is tightly pressed against the reference boss in the Z extrusion. The top of the bearing rail should be about 35mm below the top of the extrusion and the bottom of the rail should clear the stage one Z timing belt on the large diameter pulley.
18. Recalibrate the robot.

Replacing the Robot Controller

DANGER: Before replacing the Robot Controller, the AC power should be removed.

Tools Required:

1. 2.5mm hex driver or hex L wrench
2. 2.0mm hex driver or hex L wrench
3. Small flat bladed screw driver, with 1.5mm wide blade typ
4. M5 socket driver or M5 open end wrench or pliers

Spare Parts Required:

1. Guidance G1400B Controller PN P/N G1X0-EA-B1400-1

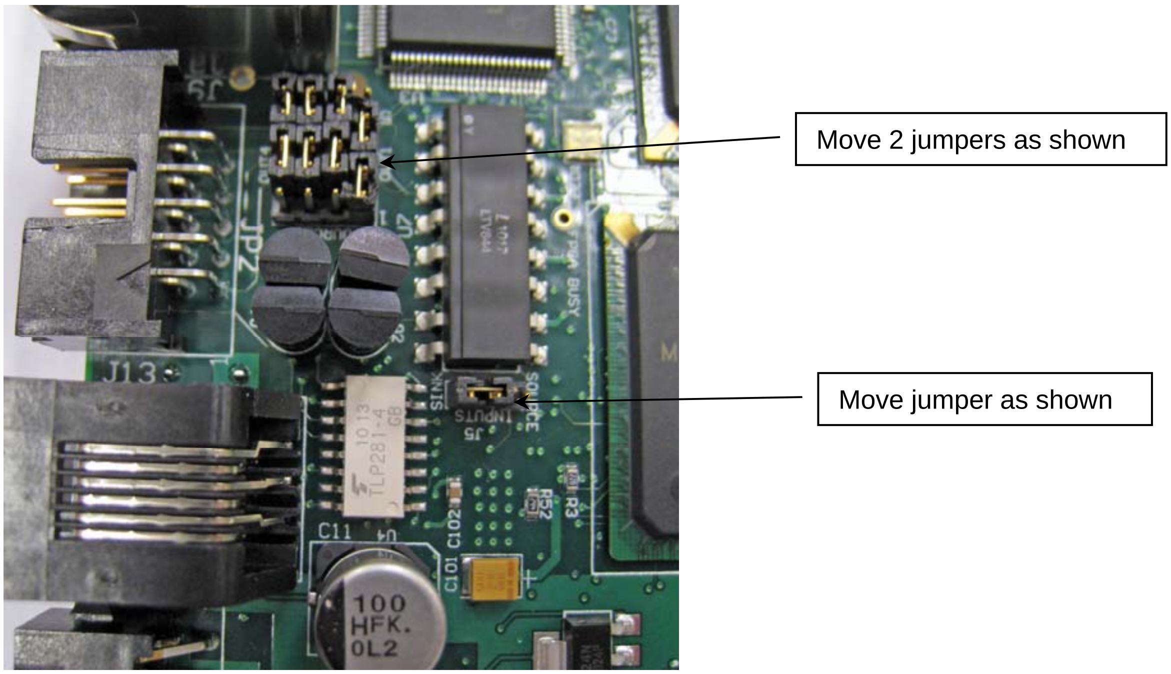
Prior to replacing the controller, the user may wish to make copies of both the robot PAC files, and any project files to a PC, using a procedure similar to that described for loading a project in the Software Reference Section.

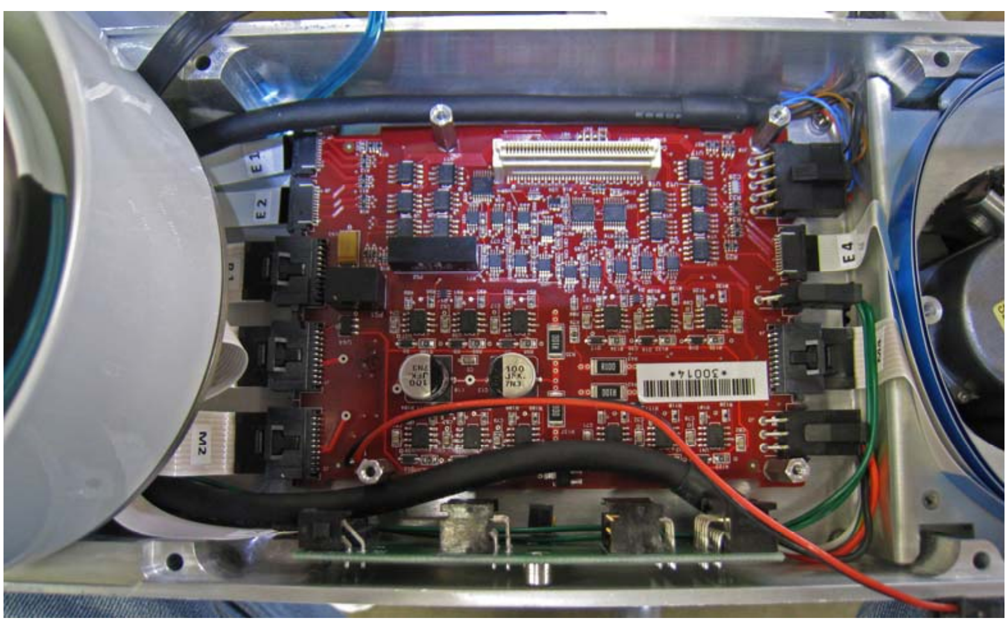
To replace the Robot Controller the user must:

1. Turn off the robot power and remove the AC power cord.
2. Remove the Inner Link Cover by removing the 4 M3 X 20 SHCS that attach the cover.
3. Remove the upper circuit board by removing 4 M2.5 X 6mm screws.
4. Unplug the cables from upper circuit board
5. Remove the lower circuit board by removing 4 M2.5 X 16mm standoffs with an M5 socket driver.
6. Unplug the cables from the lower circuit board. Use a small flat bladed screwdriver to gently release the 3 zero-insertion-force (ZIF) flat flexible cable (FFC) connector compression lids.
7. Check the jumpers on the replacement CPU board (top board) per the photo below.
8. Re-attach the harness and replace the circuit boards. Refer to the schematics section above for connector labeling on the circuit boards. Be careful that the 2 pin plug from the brake release switch plugs into the lower board and the 2 pin plug on the pigtail from the lower board plugs into

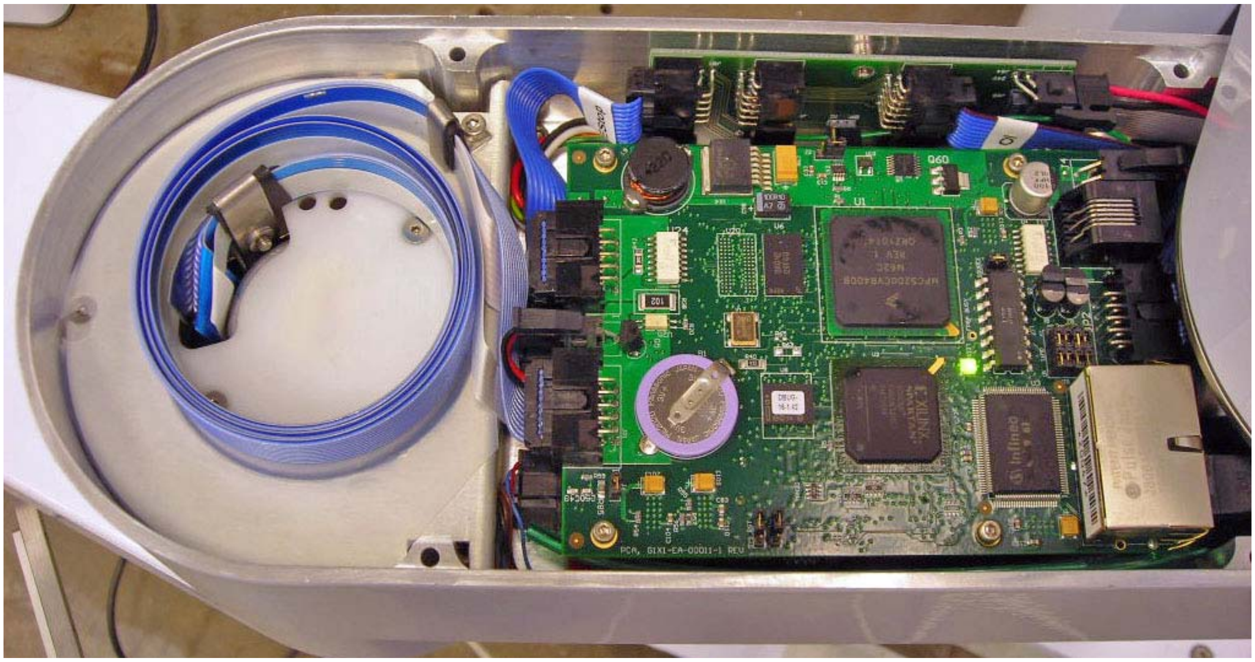
the upper board. Be careful to gently press in the compression latch on the FFC encoder connectors with your finger, not a sharp object.

9. Make sure the EtherNet cable folds back along the under the upper circuit board but does not obstruct the board to board connector.
10. Make sure no cables will be pinched by the Inner Link Cover and replace the Cover.
11. After replacing the Robot Controller the robot must be re-calibrated. See Calibrating the Robot.
12. After replacing the Robot Controller the BenchBot PAC files and BenchBot application program must be installed. (These may be pre-installed by Agilent Field Service)



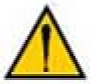


Power Amplifier Installed in Inner Link



Controller Installed in Inner Link

Replacing the Servo Gripper Controller



DANGER: Before replacing the Gripper Controller, the AC power should be removed.

Tools Required:

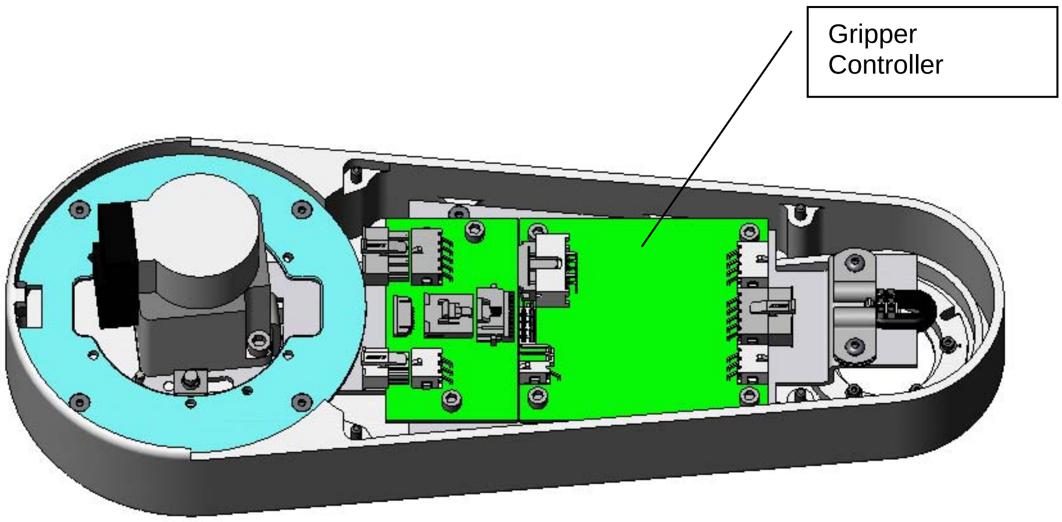
2.5mm hex driver or hex L wrench

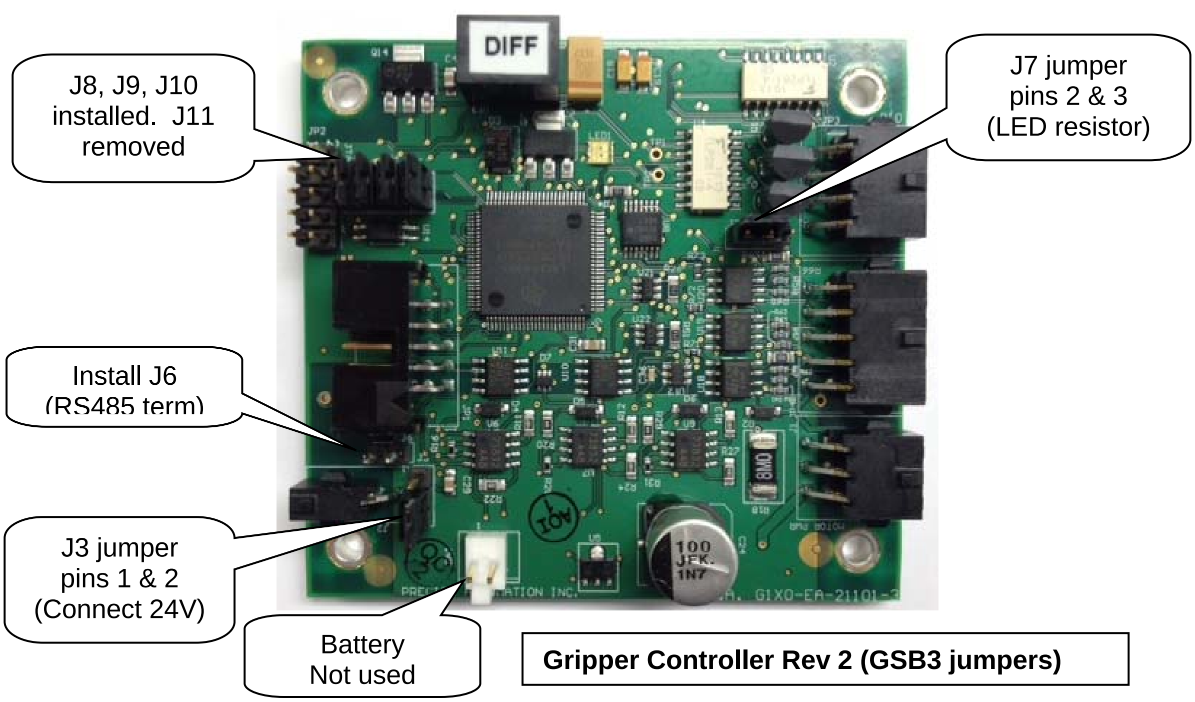
Spare Parts Required:

For the 23N PF400 Servo Gripper: Guidance Gripper Controller P/N G1X0-EA-T1100 or G1X0-EA-T1101
For the 60N PF3400 Servo Gripper: G1100T Slave Controller (“GSB3-DIFF”) G1X0-EA-T1101-4D

To replace the Gripper Controller the user must:

1. Turn off the robot power and remove the AC power cord.
2. Remove the Outer Link Cover.
3. Remove the Gripper Controller by removing 4 M3 X 10mm SHCS and unplugging the cables.
4. Replace the Gripper Controller and re-attach the harness.
5. Replace the Outer Link Cover.
6. It is not necessary to recalibrate the robot after replacing the Gripper Controller.
7. Starting January of 2013 gripper controllers are a new rev (GSB3), which replaces the address DIP switch with jumpers. To make the SW in the GSB3 work in a compatible mode with the standard PAC files, Jumper J11 must be removed.
8. In the case of the controller for the 60N gripper, the battery pigtail must be attached, with the positive red wire soldered to pin 1 and the black wire soldered to pin 2of the white Molex connector on the GSB controller, with shrink tube to insulate the wires, and the leads must be bent over to clear the cover.

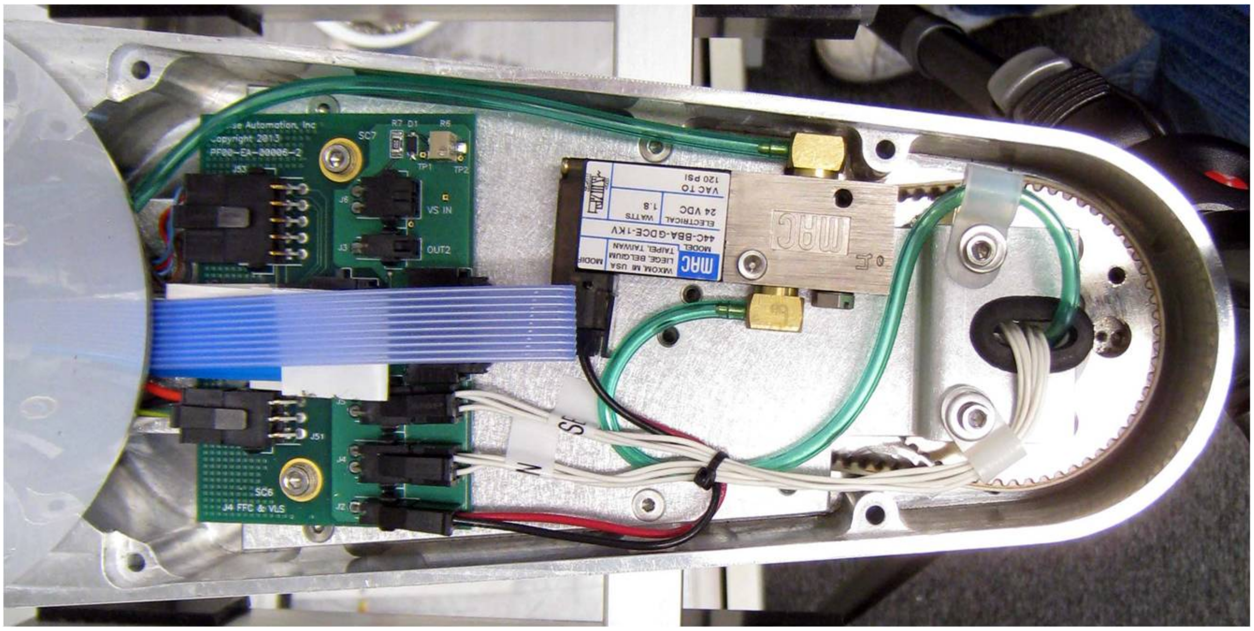




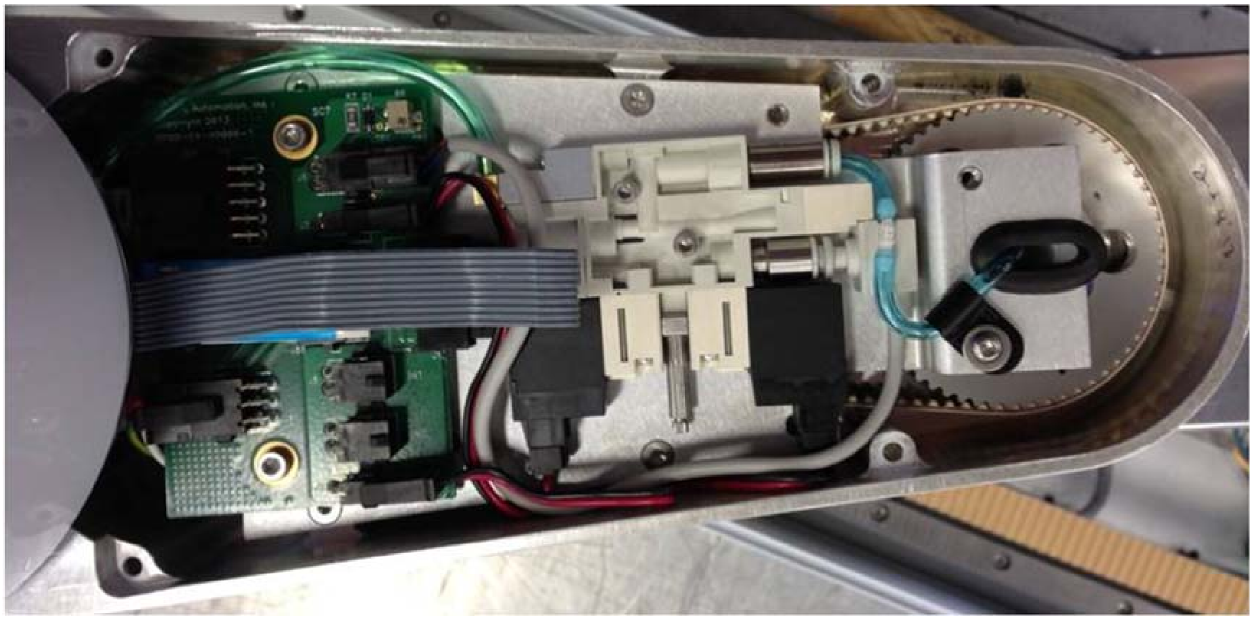
Gripper Controller Rev 2 (GSB3 jumpers)

Wiring for 60N Gripper with Battery Pigtail

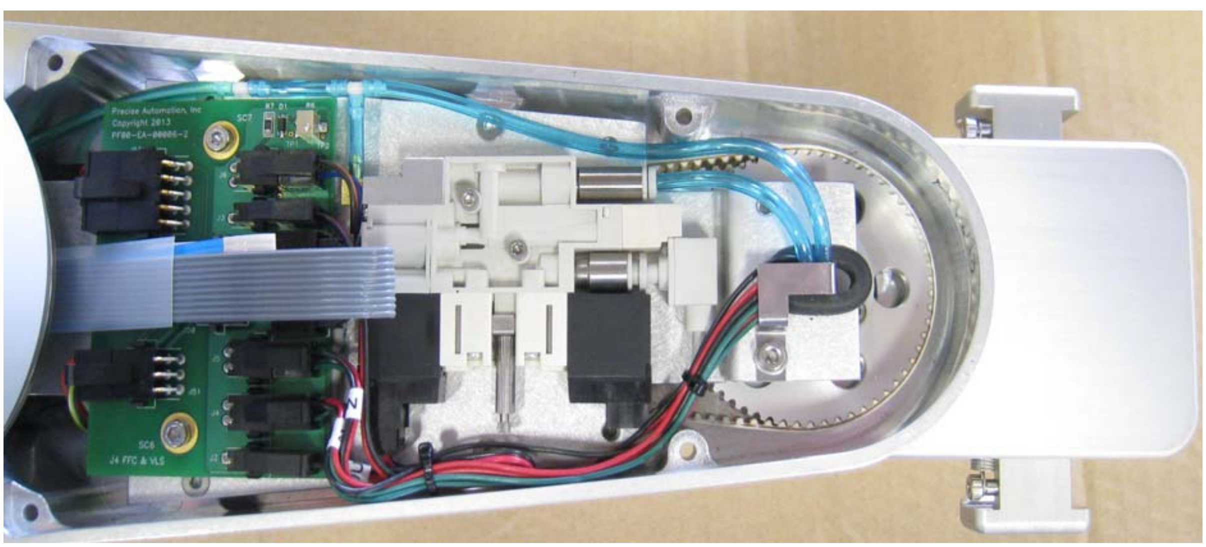
Wiring for Pneumatic Gripper



Wiring for Vacuum Gripper



Wiring for Vacuum-Pallet Gripper



Replacing the Agilent Servo Gripper Finger Pads

Tools Required:

1. 1.3mm hex driver or hex L wrench

Spare Parts Required:

1. Guidance G1400B Controller PN P/N PF0A-MA-00011, set of 4 pads.

To replace the Gripper Finger Pads the user must:

1. Remove 3 M2 X 6mm FHS to remove the Spline Bumper Plates.
2. Replace the Finger Pads by pressing new pads into the Spline Bumper Plates.
3. Re-attach the Spline Bumper Plates. Do not use Loctite.

Replacing the Gripper Spring or Cable

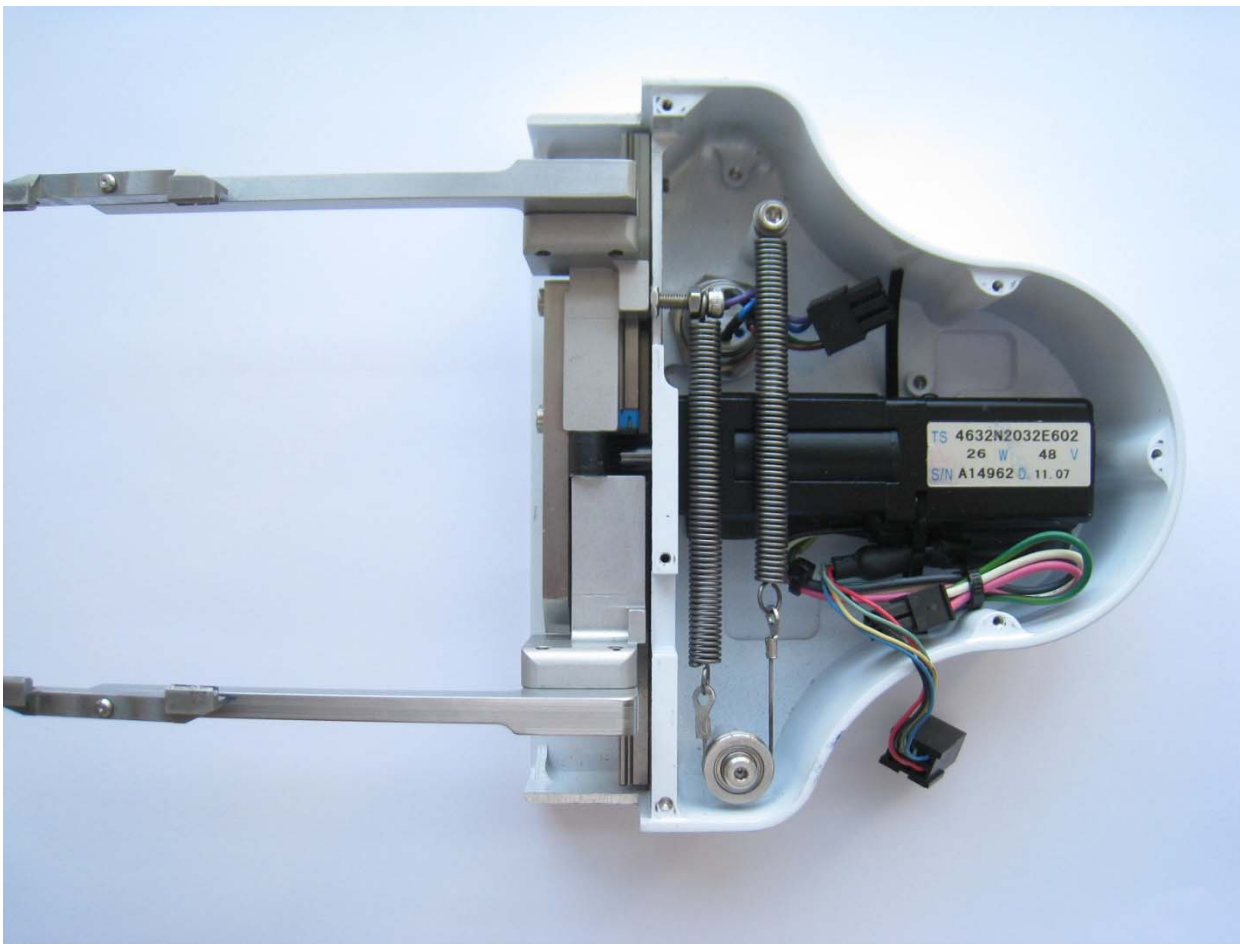
Tools Required:

1. 1.3mm hex driver
2. 2.5mm hex driver
3. 7mm open end wrench
4. Loctite 222

Spare Parts Required: Spring or Cable Assembly

To replace the spring or cable the user must:

1. Remove the Gripper Cover by removing 4 or 6 M2 X 6mm FHCS (depends on model).
2. Remove the spring cab le assembly by removing the M3 screws shown below.
3. Replace the spring cable assembly and replace the cover.



Adjusting the Gripper Backlash or Centering Fingers

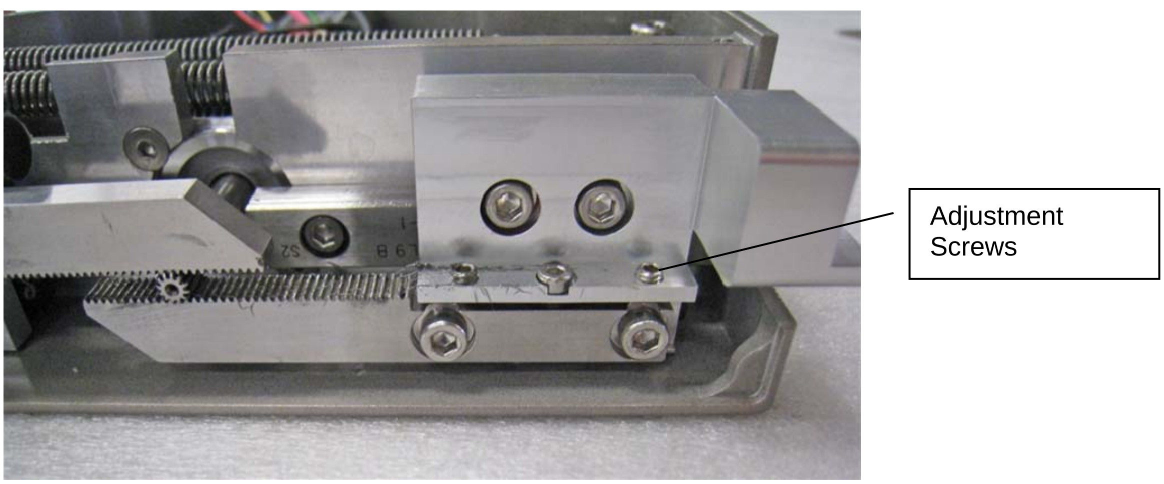
Tools Required:

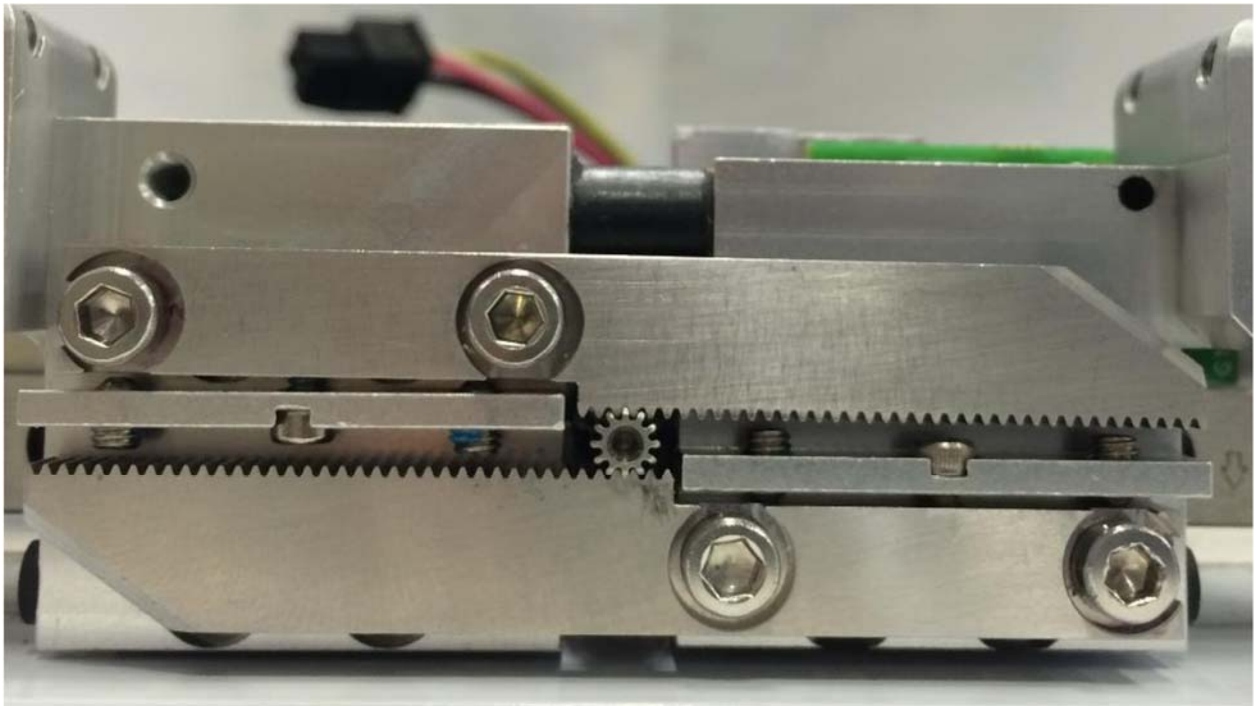
1. 1.3mm “stubby” hex L wrench
2. 1.5mm “stubby” hex L wrench

Spare Parts Required: none

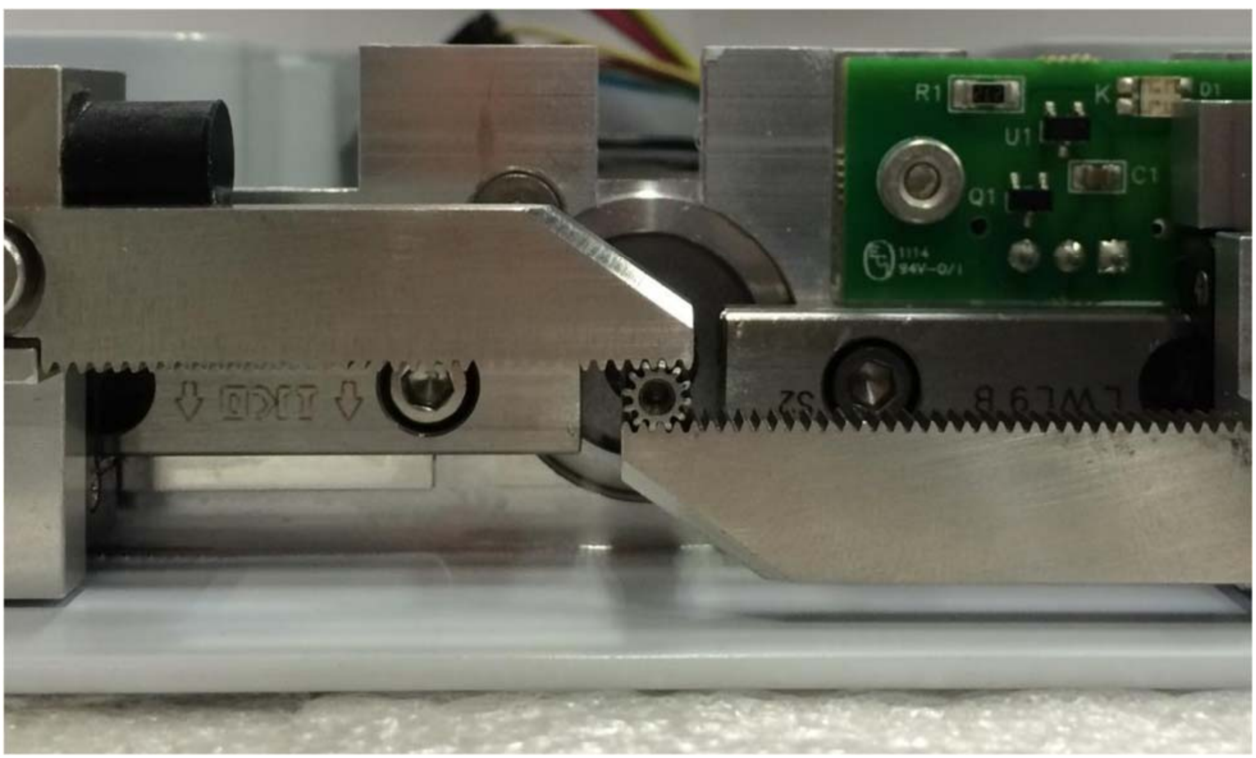
To adjust the gripper backlash the user must:

1. Remove the Gripper Cover by removing 6 M2 X 6mm FHCS.
2. For grippers with spring return, disconnect one end of the spring to remove spring tension.
3. Move the racks back and forth to determine which rack has backlash and where it is located on the rack.
4. Loosen the 2 M3 X 8 SHCS clamping the rack to the finger mount.
5. Adjust the M2 SHCS and M3 set screws to adjust the rack backlash or center the racks as needed if a crash has caused the racks to skip teeth or come loose.
6. Remove the 2 M3 X 8 SHCS one at a time, apply Loctite 243 screwlock, reinstall and tighten.





Gripper racks centered in fully closed position



Gripper racks centered in fully open position

Adjusting the Gripper Brake (for Grippers with Brake)

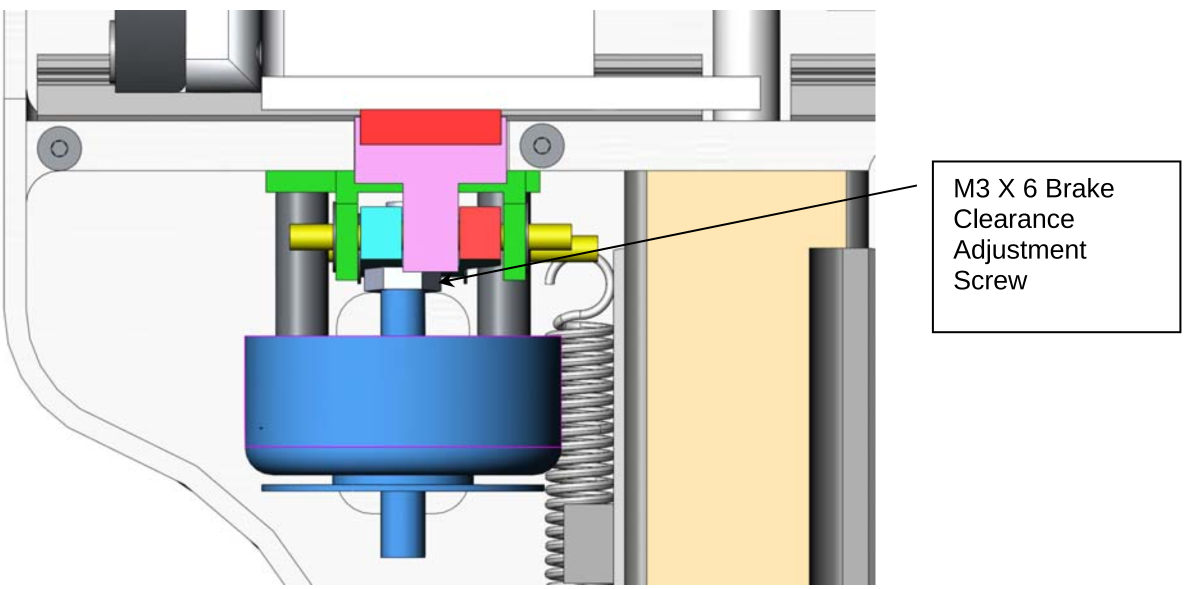
Tools Required:

5. 1.3mm hex driver
6. 5.5mm open end wrench
7. Loctite 222

Spare Parts Required: none

To adjust the gripper brake the user must:

4. Remove the Gripper Cover by removing 6 M2 X 6mm FHCS.
5. Energize the brake to activate the solenoid to release the brake.
6. Check the clearance between the brake shoe and the finger mount brake surface. This clearance should be between .1mm (.004in) and .25mm (.010in), and the gripper fingers should slide freely.
7. If necessary, use a 5.5mm open end wrench to adjust the M3 X 6mm hex head screw that adjusts the brake backlash. This screw should be backed out 2mm, Loctite 222 applied to the screw threads, and then screwed back in to the brake lever to set the brake clearance.
8. Make sure the brake pad is held up in the brake notch in the gripper wall and engage the brake.
9. Replace the cover.



Replacing the Electric Grippers or Slip Ring Harness

DANGER: Before replacing the Gripper Harness, the AC power should be removed.

Tools Required:

1. 2.5 mm hex driver or hex L wrench
2. 2.0 mm hex driver
3. 1.5mm hex driver
4. 1.3mm hex driver

Spare Parts Required for Gripper, one of the following:

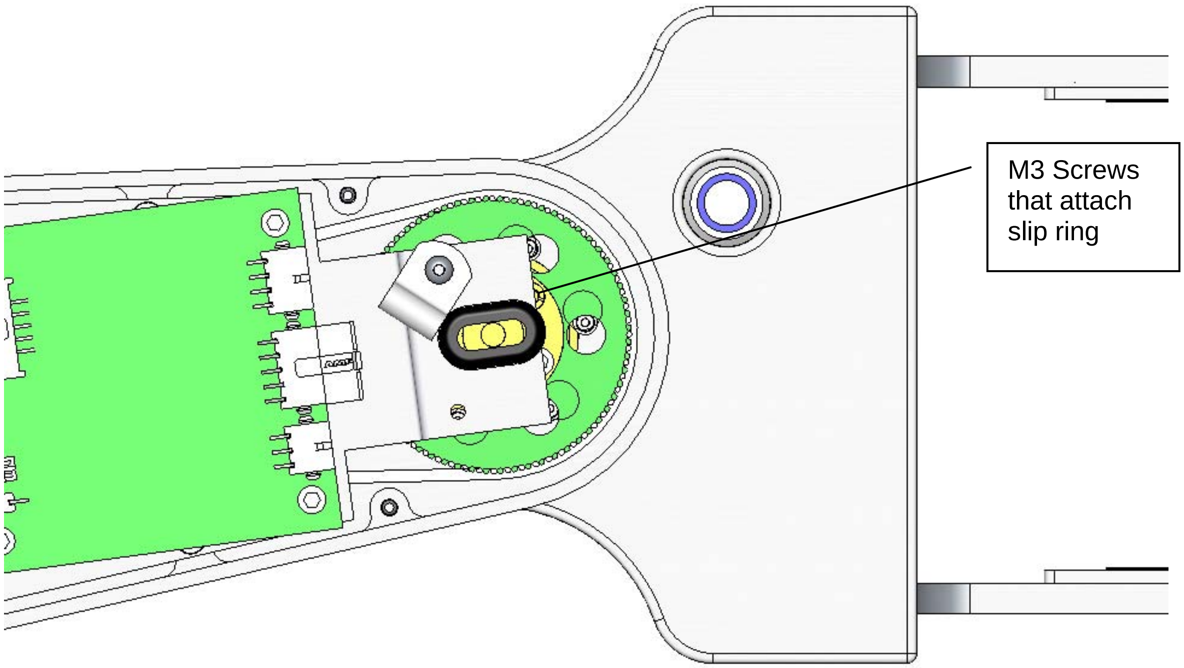
1. Low Profile 23N Electric Gripper” Precise P/N PF0A-MA-00001 (Agilent).
2. PF400 23N Servo Gripper without fingers Precise P/N PF0S-MA-00001 (Standard)
3. PF3400 60N Servo Gripper without fingers PF3S-MA-00001 Rev A1

Spare Parts Required for Slip Ring, one of the following:

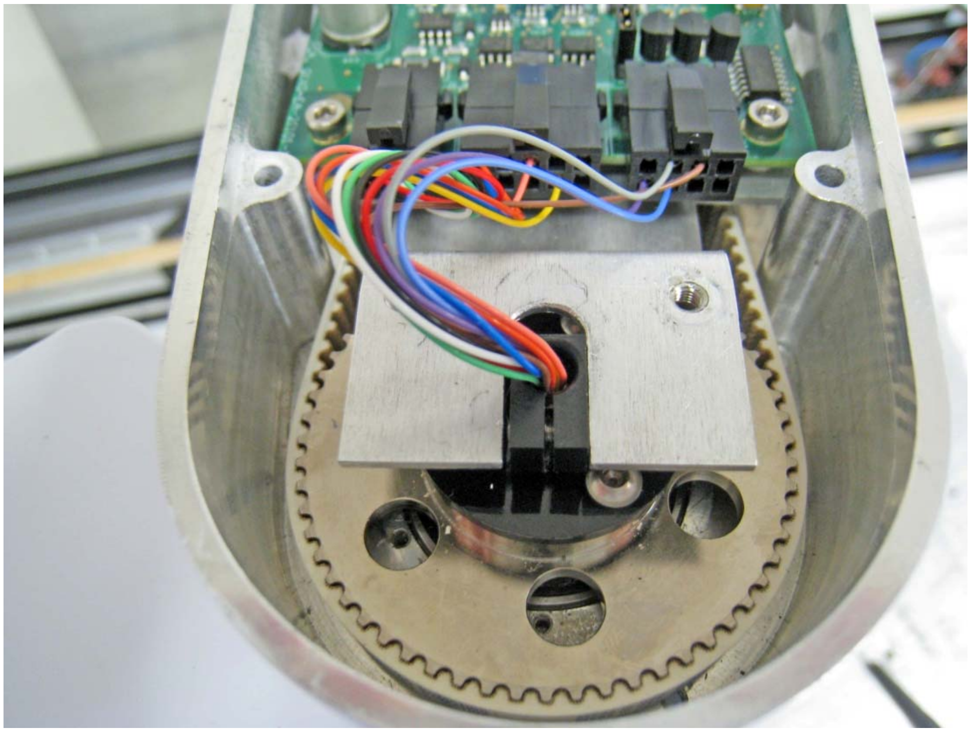
1. PF400 Slip Ring Harness Assembly, 23N Brake Gripper (Agilent) PF04-MA-00002
2. PF400 Slip Ring Harness Assembly, 23N Spring Gripper (Standard) PF04-MA-00010
3. PF3400 Slip Ring Harness Assembly, 60N Spring Gripper PF04-MA-00030

To replace the Gripper the user must:

1. Turn off the robot power and remove the AC power cord.
2. Remove the Outer Link Cover.
3. Remove the Gripper Controller and P Clamp holding the slip ring cable. Slide the grommet out of the notch in the belt cover.
4. Remove the 4 M3 FHCS that attach the belt cover. Tip up the belt cover and slide a pencil under it to hold it up to provide access to the slip ring flange.



5. Rotate the Gripper so that the 3 M3 X 6 BHCS which attach the Slip Ring to the J4 Output Pulley can be removed one by one thru the notch in the Outer Link Belt Cover.
6. Remove the bottom cover from the Gripper by removing 6 M2 X 6mm FHCS.
7. Disconnect the Slip Ring harness (4 plugs) from the Gripper harness.
8. Rotate the Slip Ring housing 30 degrees to allow access to 3 of 6 M2 X 16 SHCS. Loosen these screws. Rotate the Slip Ring housing 30 degrees in the opposite direction to access and loosen the remaining 3 screws.
9. Gently pull the Gripper down a few centimeters and slide the Slip Ring harness and connectors through the access hole in the Gripper housing.
10. At this point the slip ring harness can be replaced if necessary.



11. After the slip ring is installed, rotation of the wire bundle must be prevented by attaching a black Delrin clamp around the slip ring hub. This clamp is slotted so that it can be slipped over the wires and attached to the hub with a M2.5 X 6mm SHCS. Some older slip rings had heat shrink tube over the hub. This should be removed when attaching the Delrin Clamp.
12. Replace the Gripper and re-attach the new Gripper. Be sure the dowel pin in the wrist pulley flange is located in the notch in the top of the gripper housing. Be sure the slip ring wires do not get pinched during re-assembly.
13. It is not necessary to re-calibrate the robot after replacing the 23N Gripper. However, after replacing the 60N Gripper for the PF3400, you must run CALPP Rev 33 or later, with the 60N gripper fingers closed.

Replacing the Linear Axis Controller

Tools Required:

2.5 mm hex driver or hex L wrench

2.0 mm hex driver

Spare Parts Required:

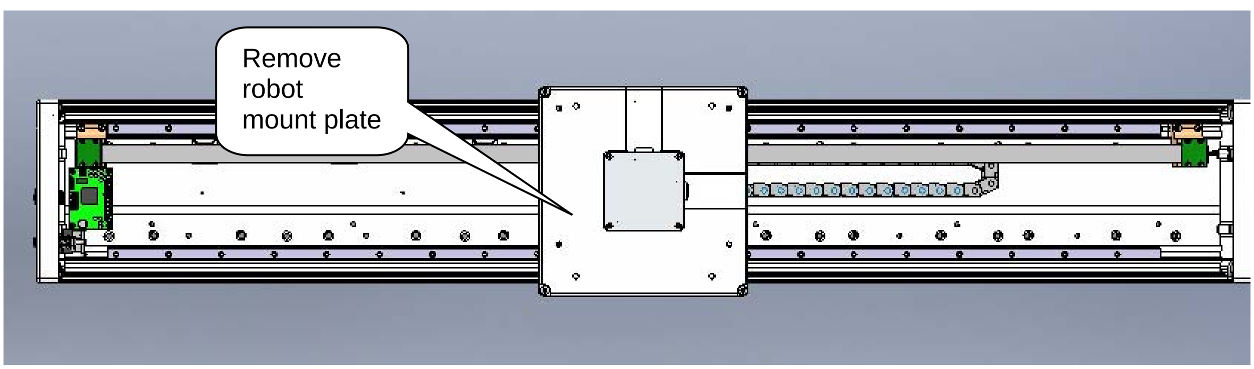
G1100T Slave Controller ("GSB3-DIFF") see "Spare Parts List". Note this part has differential encoder inputs and is NOT the same part as the GSB3-SE for the gripper, which has single ended encoder inputs.

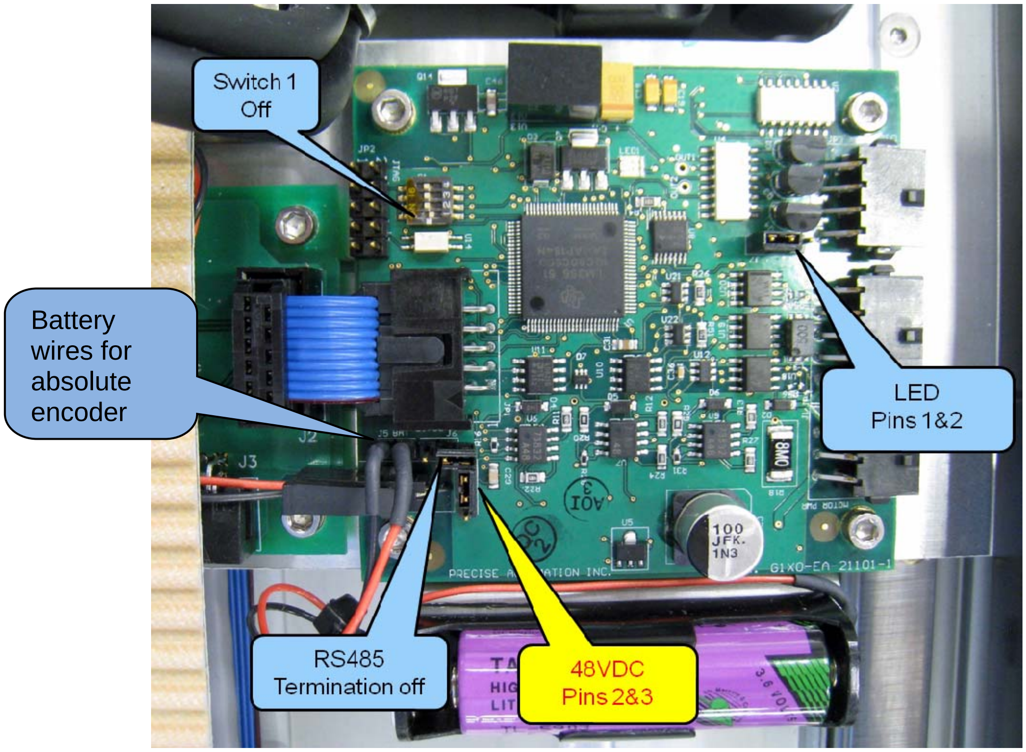
To replace the Linear Axis Controller the user must:

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.

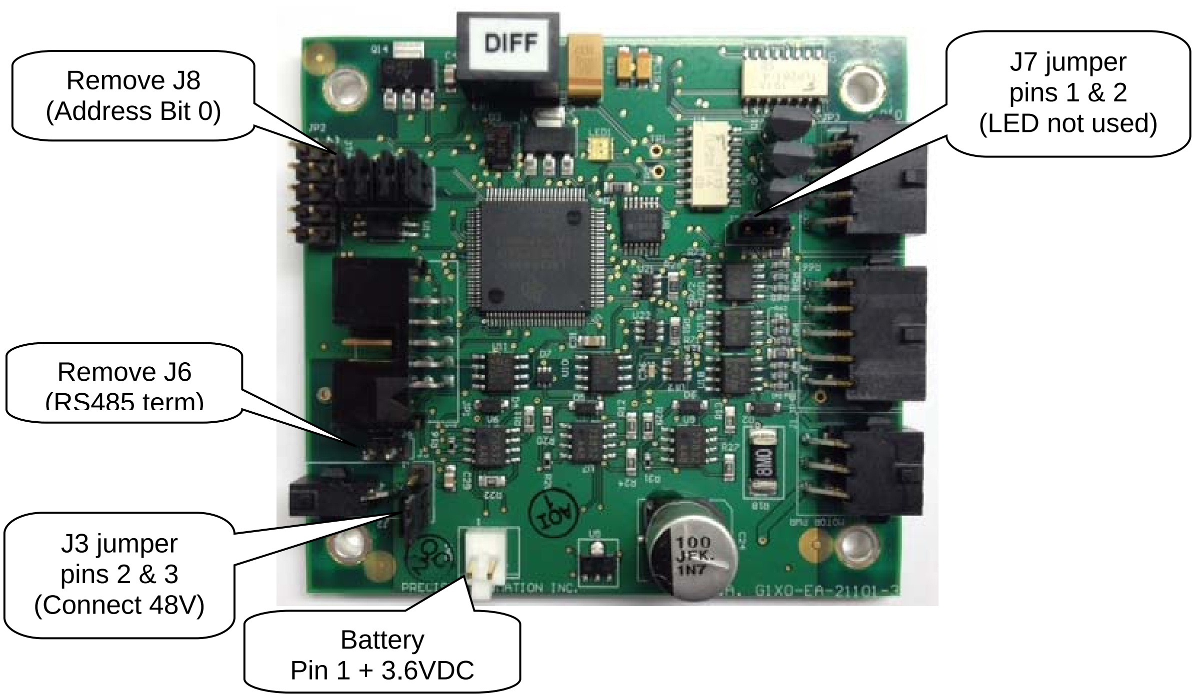
Remove the cable covers on the robot mount plate. Remove the robot mount plate.

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 2)



Linear Axis Controller Rev2 (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 Z column of the robot for standalone PF400 robots, or in the Linear Axis extrusion for robots with the Linear Axis option. The PF3400 robot has an IO board installed in the base with 8 inputs and 8 outputs as a standard feature, so it is not possible to add this optional board.

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 for robots shipped after July 2012 which have the appropriate mounting holes.

To install the GIO in a robot:

Tools Required:

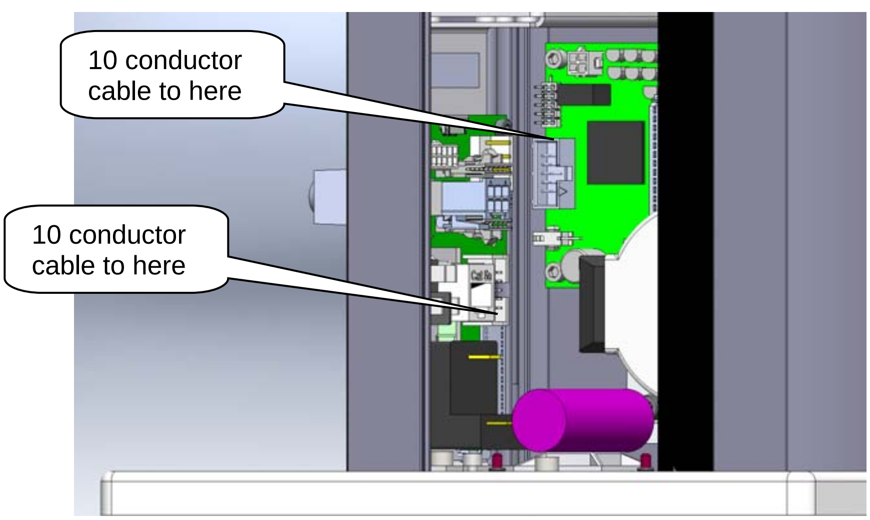
1. 3 mm hex driver or hex L wrench
2. 2.5 mm hex driver
3. M5 socket driver
4. M5 open end wrench

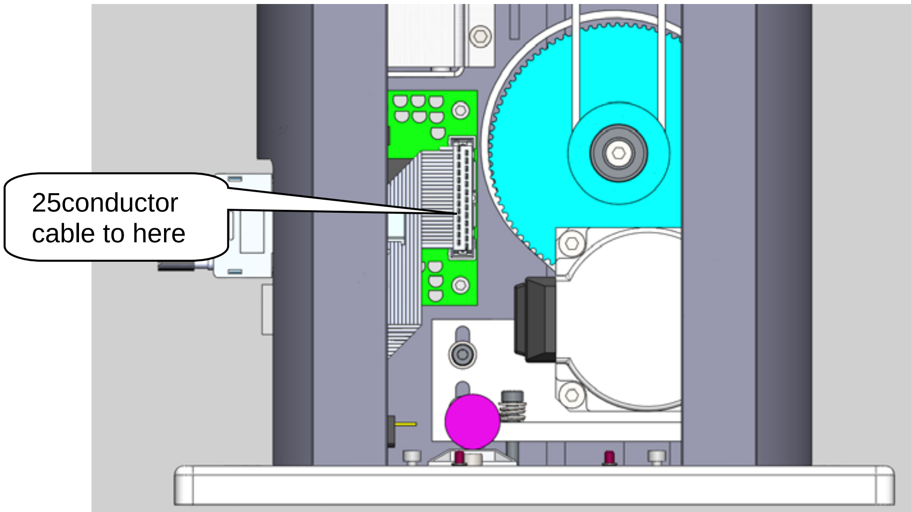
Spare Parts Required:

1. GIO Digital IO Board see “Spare Parts List”

To install the GIO Board in a robot without a linear axis the user must:

1. Remove the top cover plate from the top of the robot Z column by removing 4 M5 X 10 LHCS.
2. Remove the front Z column cover by sliding it upwards through the Z carriage.
3. Remove the left splash guard by removing the M3 X 8 SHCS and star washer holding the splash guard to the robot base plate.

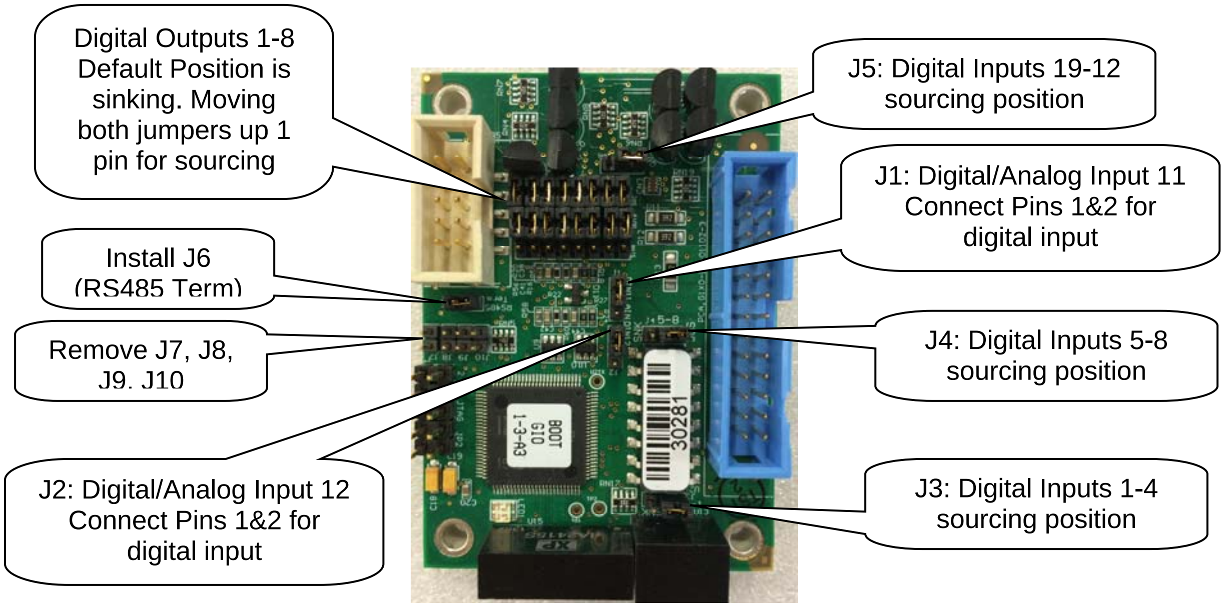




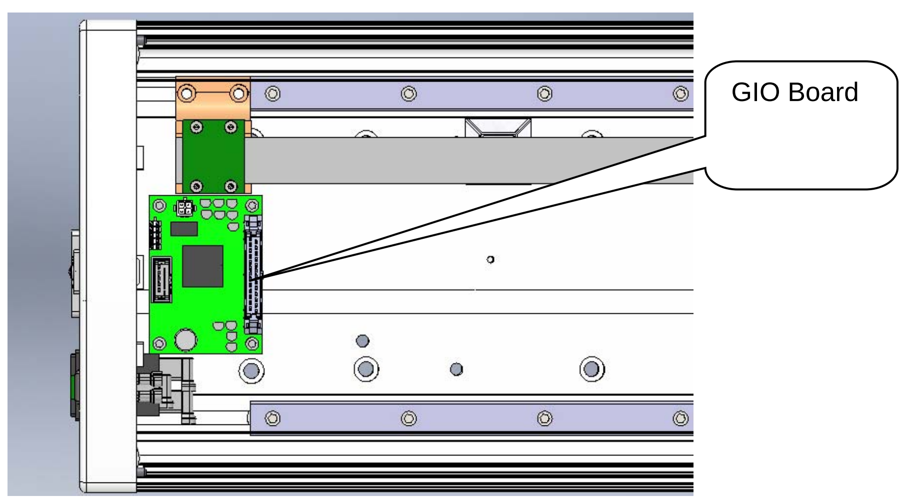
4. Disconnect the Ethernet cable and move it out of the way if necessary.
5. Remove the 25 pin Dsub blank cover plate from the connector panel by removing the M3 BHCS. These screws are retained by M3 nylon insert hex nuts on the back of the front connector panel.
6. **Remove all 4 address jumpers on the GIO board J8-J11, see picture below.**
7. Install the GIO board with 4 M3 X 10 SHCS on the rear surface of the Z column as shown below.
8. Install the 10 conductor RS485 jumper cable from the GIO board to the connector panel board.
9. Attach the 25 pin Dsub connector pigtail to the connector panel with the 4-40 standoff kit and plug the 26pin connector into the GIO board.   Be careful to fold the harness to the D sub as shown.
10. Reconnect the Ethernet Cable.
11. Replace the covers.
12. **Set value 8 in Data ID 151 to “GIO_8”, so that this ID reads “<Controller Serial No>”, “GSB_1”, “”,“”,“”,”“”,“”,GIO_8”** This parameter may be found in Setup/Parameter Database/Controller/System ID.
13. GIO signals may then be checked under Control Panels/Remote IO/Network Node 8.

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

1. Slide the carriage of the Linear Axis to one end of travel.
2. 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.
3. **Remove all 4 address jumpers on the GIO board J7-J10, see picture below.**



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



5. 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.
6. 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.
7. Replace the covers.
8. **Set value 8 in Data ID 151 to “GIO_8”, so that this ID reads “<Controller Serial No>”, “GSB_1”, “”,“”,“”,”“”,“”,GIO_8”** This parameter may be found in Setup/Parameter Database/Controller/System ID.
9. GIO signals may then be checked under Control Panels/Remote IO/Servo Node 8.

Replacing the Main Harness

Replacement of the Main Robot Harness is typically only performed at the factory. The Main Robot Harness is intended to last for the life of the robot.

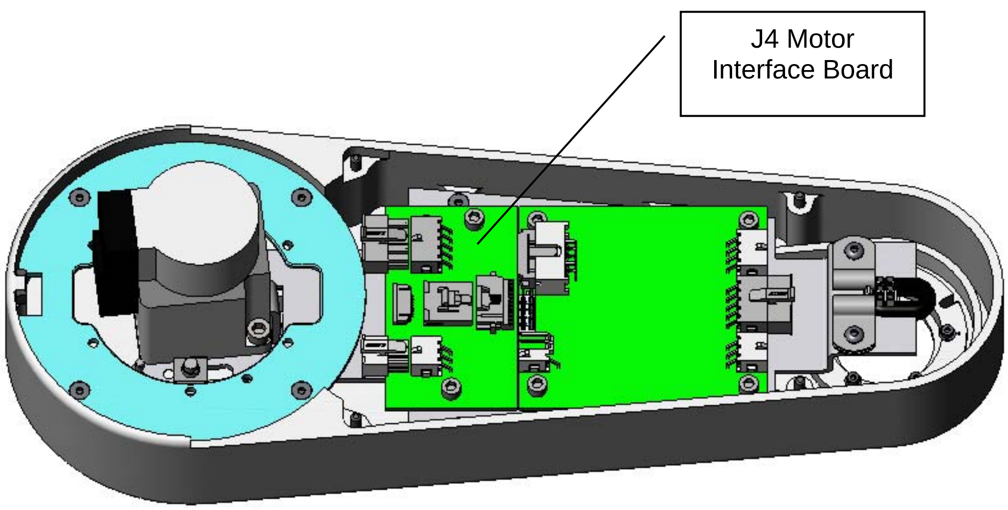
Replacing the Outer Link Harness

The Outer Link Harness is comprised of 3 cables: Harness, FFC, J4 Motor, (Precise P/N PF0H-MA-00002-02-E3), Harness, FFC, J4 Encoder (Precise P/N PF0H-MA-00005-02-E3), and Harness, Gripper Controller (Precise P/N PF0H-MA-00014).

Replacing the Outer Link Harness does not require un-mounting the robot from its surface.

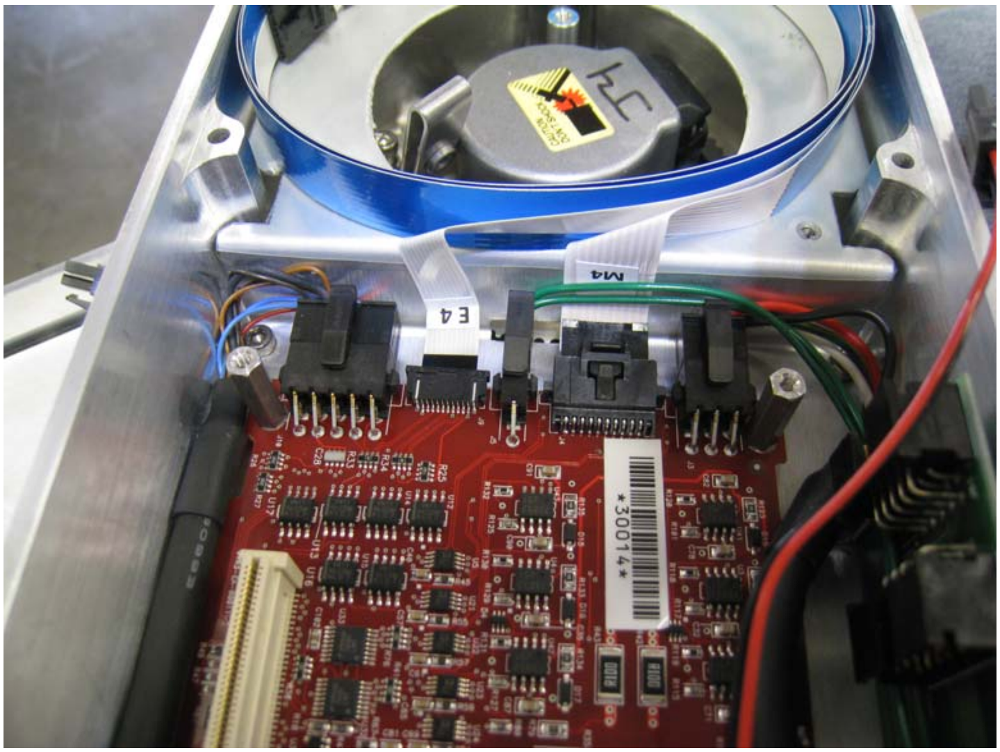
The user must:

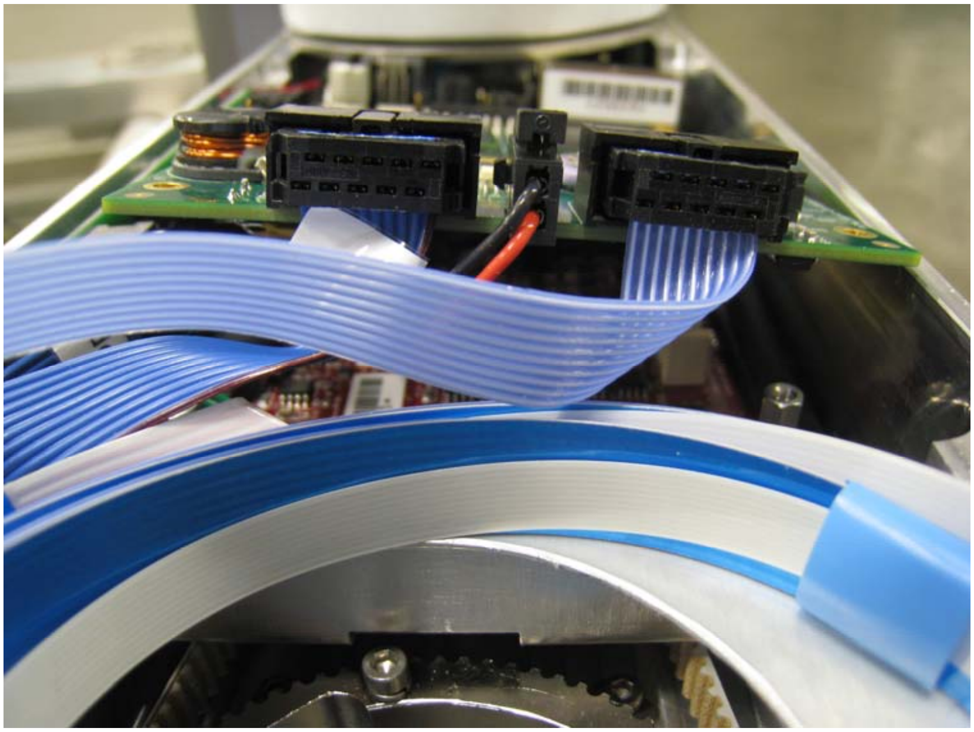
1. Remove the Inner Link Cover.
2. Remove the Outer Link Cover.
3. Unwind the Outer Link in counterclockwise direction, looking down from above the J3 axis until it reaches the hard stop.
4. Release the J4 Motor Interface circuit board by removing 2 M3 X 10mm SHCS.



5. Disconnect the Outer Link Harness from the J4 Motor Interface PCA and the Guidance 1100C Slave Controller in the Outer Link.
6. Remove the upper circuit board in the Robot Controller by removing 4 M2.5 X 6mm screws and disconnect the harness.

7. Remove the Harness Retaining Clip from the Robot Controller Mount Plate to release the controller end of the harness.
8. Remove the 4 M2.5 X 16mm standoffs attaching the lower circuit board in the Robot Controller. Gently tip the lower circuit board upwards and disconnect the motor and encoder cables from the lower circuit board.
9. Release the Harness Retaining Clip from the J3 Output Pulley by loosening the M3 by 25 SHCS attaching the clip to the pulley. Pull the clip upwards and remove the M3 X 4 BHCS that clamps the harness to release the harness from the clip.
10. Replicate the folds on the controller end of the replacement harness.
11. Insert the replacement harness into the Robot Controller circuit boards and reattach the Robot Controller circuit boards.





12. Attach the Harness Retaining Clip near the Robot Controller to retain the Robot Controller end of the Harness.
13. Coil the replacement harness into 3 loops.
14. Fold the ends of the harness down at a right angle to replicate the replaced harness.
15. Insert the connectors down thru the Elbow into the Outer Link.
16. Attach the J3 Harness Retaining Clip with the M3 X 4 BHCS and the 1/32 in thick Neoprene rubber strain relief pad around the harness to protect it along with the bent stainless steel retaining clip that protects the harness fold.

17. Attach the J3 Harness Retaining Clip to the J3 Output Pulley.
18. Attach the connectors to the circuit boards in the Outer Link.
19. Attach the J4 Motor Interface circuit board.
20. Replace the covers.
21. After replacing the harness the robot must be re-calibrated. See Calibrating the Robot.

Replacing the Z Axis Motor Assembly

DANGER: Before replacing the Z Axis Motor, the AC power should be removed.

Tools Required:

1. 5.0mm hex driver or hex L wrench
2. 4.0mm hex driver or hex L wrench
3. 3.0mm hex driver or hex L wrench
4. 2.5 mm hex driver or hex L wrench
5. Loctite 243

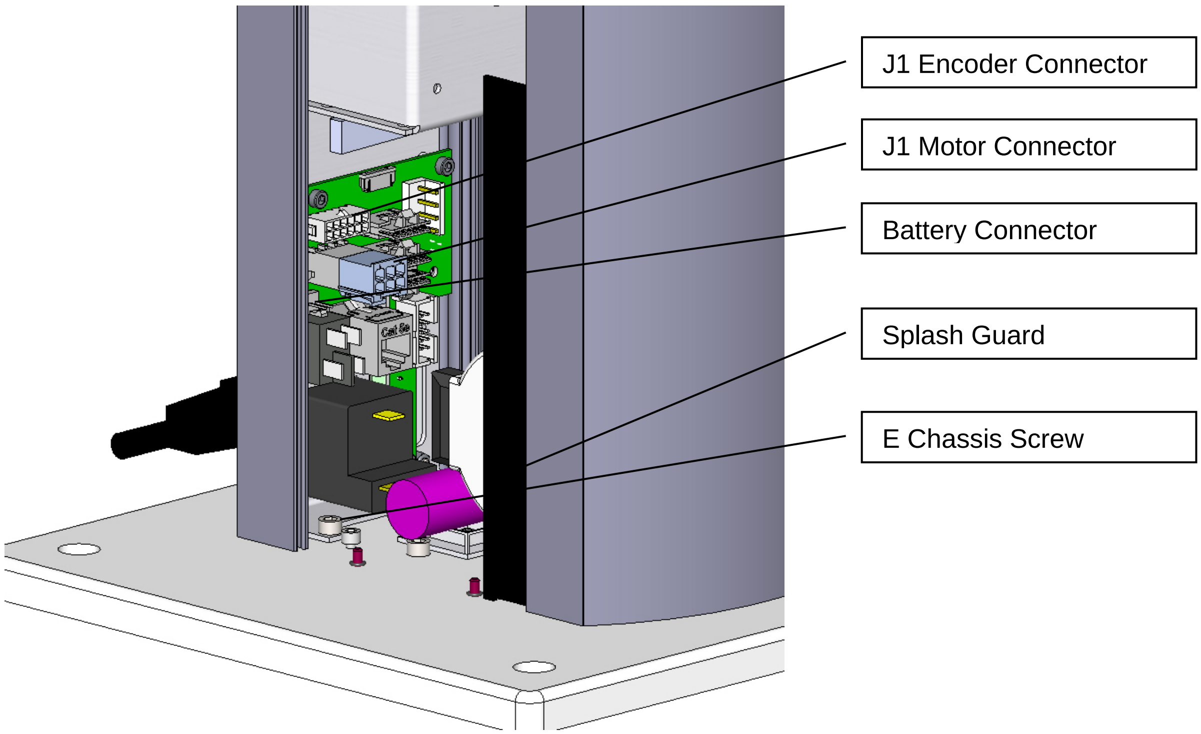
Spare Parts Required:

1. J1 Motor Assembly PN PF01-MA-00011.

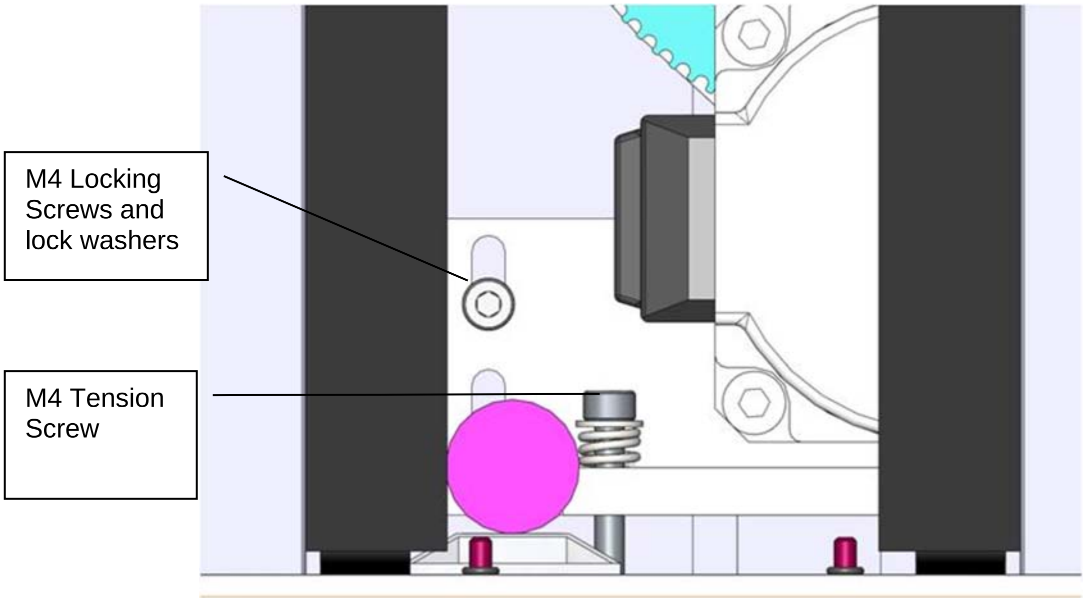
The J1 Motor Assembly is comprised of the J1 motor, connectors, and a timing belt pulley.

The user must:

1. Remove AC power and connectors from the base of the robot.
2. Unfasten the robot from its mounting surface by removing 4 M6 SHCS.
3. Lay the robot on its back, being careful the robot links do not fall over and damage the paint. It is a good idea to wrap the links with a protective cover first, such as a sheet of foam.
4. Remove the top cover by removing 4 M5 Low Head Cap Screws.
5. Remove the Front Cover by sliding it out.
6. Remove the left splash guard by removing the M3X8 SHCS and M3 star washer.
7. Remove the screws attaching the Electronics Chassis and ground lug to the Bottom Mounting Plate.
8. Unplug the Battery from the J1 Motor Interface Board.



9. Remove the screw compressing the J1 Motor Tension Spring and spring.



10. Remove the Base Mounting Plate by removing 4 M5 SHCS. The right splash guard is attached to the base mounting plate.
11. Remove the M4 Locking Screws that attach the J1 Motor Mount Bracket to the Z Column.
12. Slide the J1 Stage 1 timing belt off the large idler pulley.
13. Slide the J1 Motor and Motor Mount Bracket assembly out the bottom of the Z Column.
14. Remove the J1 Motor Assembly from the J1 Motor Mount Bracket and replace with the new motor, using Loctite 243.
15. Replace the components in reverse order. Compress the tension spring to 5.5mm under the washer with the M4 Motor Bracket Locking screws slightly loose, then tighten the screws. Use Loctite 222 or 243 on the Base Plate and Top Plate screws.
16. Before replacing the Front Cover and Top Plate, the Cal Pins should be removed from inside the Front Cover and the robot should be re-calibrated following the Calibration Procedure.

Replacing the J2 (Shoulder) Axis Motor or Timing Belt

DANGER: Before replacing the J2 Motor, the AC power should be removed.

Tools Required:

1. 5.0mm hex driver or hex L wrench
2. 4.0mm hex driver or hex L wrench

3. 3.0mm hex driver or hex L wrench
4. 2.5 mm hex driver or hex L wrench
5. 2.0mm hex driver or hex L wrench
6. Fine point tweezers
7. .06 in flat blade screwdriver

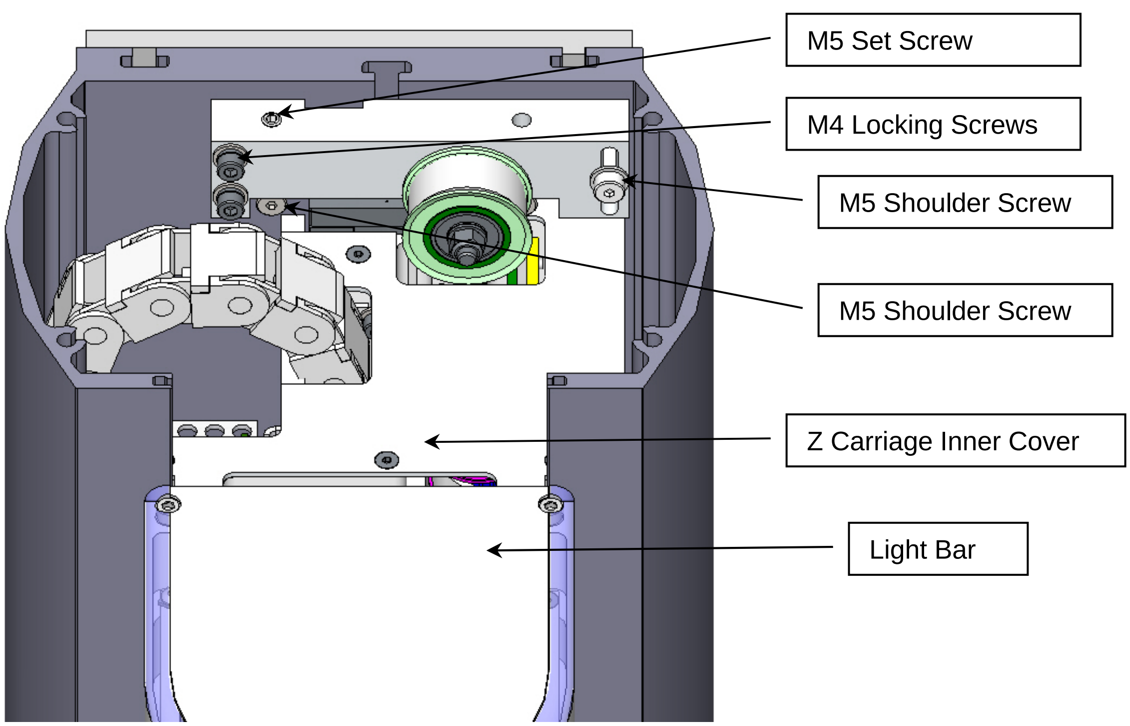
Spare Parts Required:

1. J2 Motor Assembly PN PF02-MA-00011 or J2 Timing Belt PN PF00-MC-X0005.
2. 2 1/8th by 8 in tie wraps
3. Loctite 243

The J2 Motor Assembly is comprised of the J2 motor, connectors, and a timing belt pulley.

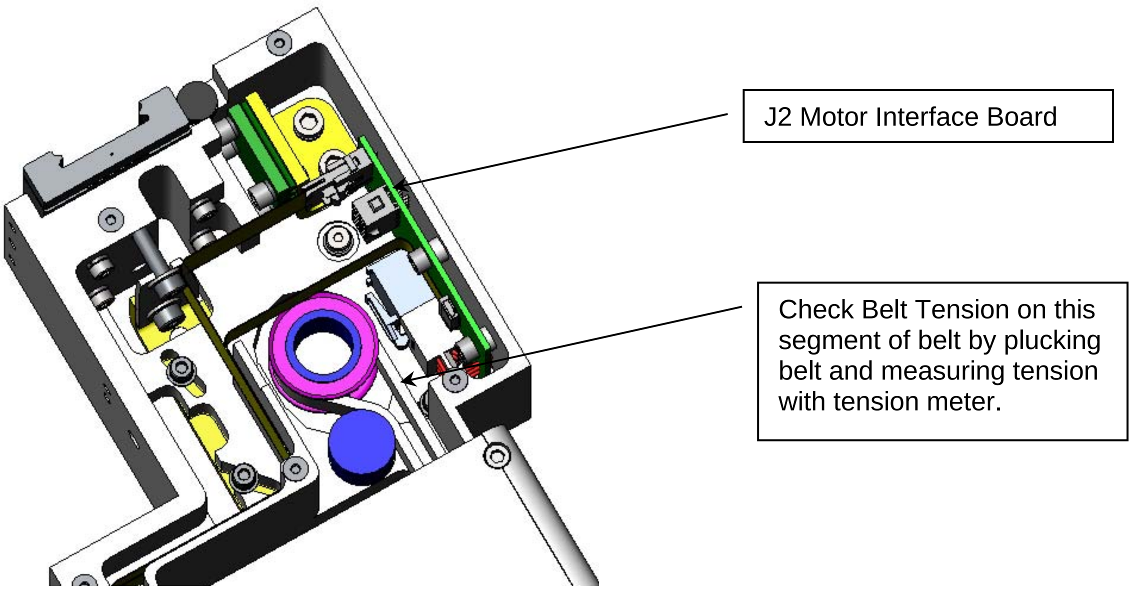
The user must:

1. Unbolt the robot from its mounting surface and set it vertically on the floor or a low surface.
2. Move the robot arm to about 2 inches below the top of the Z Column travel.
3. Turn off the robot power and remove the AC power cord.
4. Remove the Top Plate of the robot by removing the 4 M5 socket head screws from the top plate of the robot that attach the top plate to the Z column.
5. Remove the Front Cover by lifting it out horizontally.
6. Remove the Z carriage inner cover by removing 5 M3 X 10 FHCS.

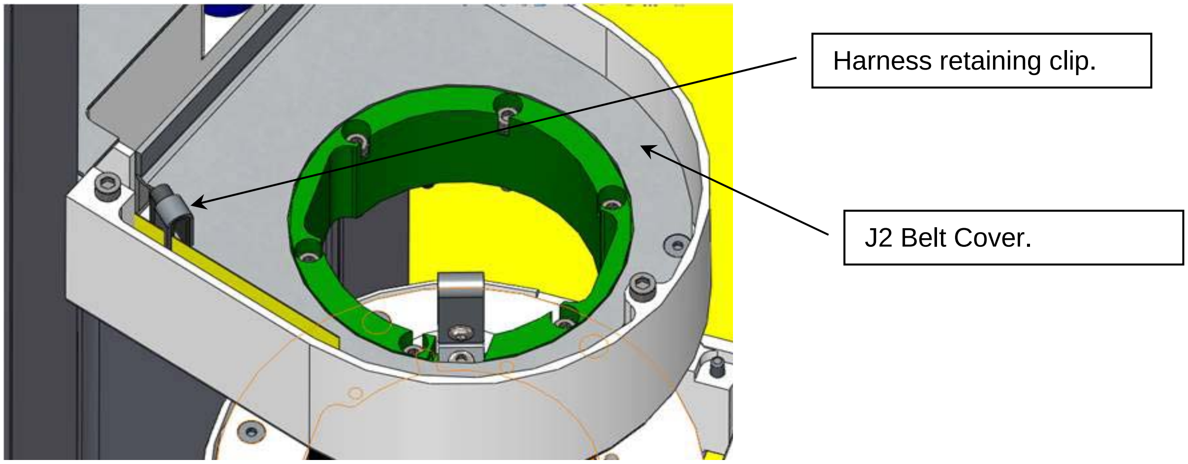


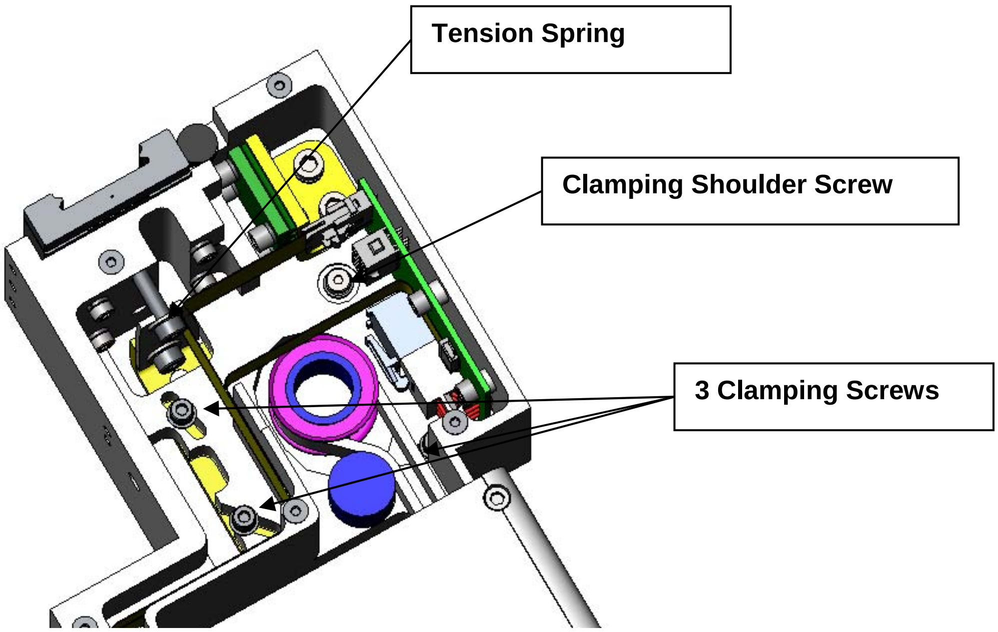
7. Remove the Light Bar by removing 3 M3 X 8 SHCS and unplugging the connector from the J2 Motor Interface PCA.
8. Remove the tie wrap securing the harness loop to the Z carriage.
9. Remove the M2 and E2 Flat Ribbon Cables from the J2 motor interface board. The E2 connector Cam lid must be VERY gently pried open with a .06 in flat bladed screwdriver.

10. Remove the J2 Motor Interface PCA by removing 2 M3 X 8 SHCS. Cut the tie wrap securing the J2 motor cables to the Z Carriage. Unplug the J2 motor and encoder cable from the J2 Motor Interface PCA.



11. Disconnect the harness retaining clip from the Z carriage, but do not remove the clips that attach the harness to the J2 pulley.
12. Uncoil the harness. One end will remain connected to the EChain and the other end connected to the J2 Pulley.
13. Remove the J2 Belt Cover by removing 3 M3 X 10 FHCS, and pull it partially up the uncoiled harness to expose the J2 timing belt.
14. Unsnap 3 or 4 of the EChain harness retaining segments, working up from the carriage, and fold the Echain and harness back over the power supply side of the robot to get it out of the way.





15. Loosen the 3 M3 SHCS and 1 M4 shoulder screw that attach the J2 motor bracket.
16. Measure and record the distance from the back of the Tension Spring to the carriage, then remove the M4 X 20 SHCD and washer that compress the Tension Spring.
17. Pull the timing belt up over the idler cam follower closest to the large J2 pulley to release belt tension and provide enough slack to remove the motor
18. If it is necessary to replace the J2 timing belt, replace the belt and reassemble the robot. Otherwise, skip this step and continue.
19. Now unscrew the 4 Screws and washers that attach the motor mount plate to the Z carriage while supporting the motor. It may be easiest to leave these screws in the carriage during this process..
20. Drop the motor assembly downwards while threading the motor cables thru the access hole in the bottom of the Z carriage, and pulling the timing belt up over the pulley flange.
21. Remove the motor from the Motor Mount Bracket by removing 4 M5 X 12 SHCS. Attach new motor to Motor Mount Bracket using Loctite 243.
22. Re-install motor, threading cables through the Z carriage first, and pulling timing belt over pulley flange. Attach motor, with 4 clamping screws. Do not tighten clamping screws all the way.
23. Re-install M4 X 20 Tension Bolt and compress Tension Spring to previous value. Tighten M4 Jam nut to lock bolt and Tension Spring. This will cause motor assembly to pivot on the shoulder screw and will apply tension to the timing belt. Before tightening the clamping screws, rotate the J2 output pulley back and forth to be sure the timing belt is running true on the output pulley.
24. Tighten the clamping screws. If a Tension Meter is available check the belt tension for a minimum tension of 150N. (See Appendix D)
25. Re-assemble the robot except for the front cover and top cover.
26. Remove the Calibration Pins from the inside of the front cover extrusion and re-calibrate the robot following the Calibration Procedure.

Replacing the J3 (Elbow) Axis Motor or Timing Belt

DANGER: Before replacing this motor, the AC power should be removed.

Tools Required:

1. 3.0mm hex driver or hex L wrench
2. 2.5 mm hex driver or hex L wrench
3. 2.0mm hex driver or hex L wrench
4. Fine point tweezers
5. .06 in flat blade screwdriver

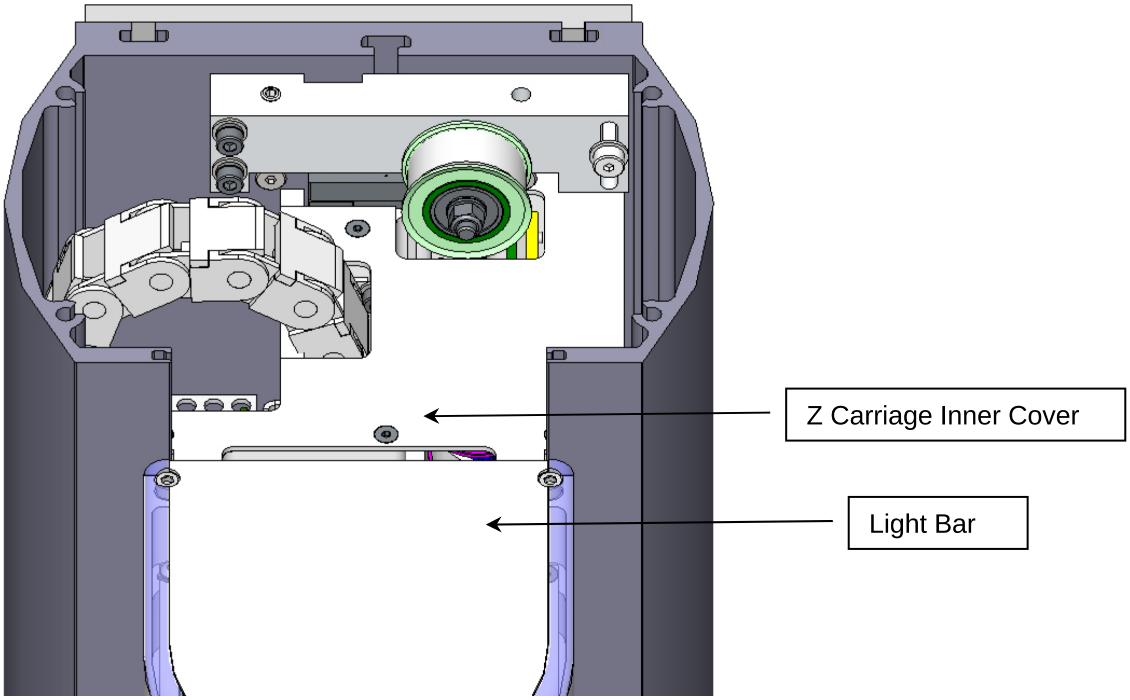
Spare Parts Required:

1. J3 Motor Assembly PN PF03-MA-00011or J3 Timing Belt PN PF00-MC-X0003.
2. 2 1/8th by 8 in tie wraps
3. Loctite 222 and 243

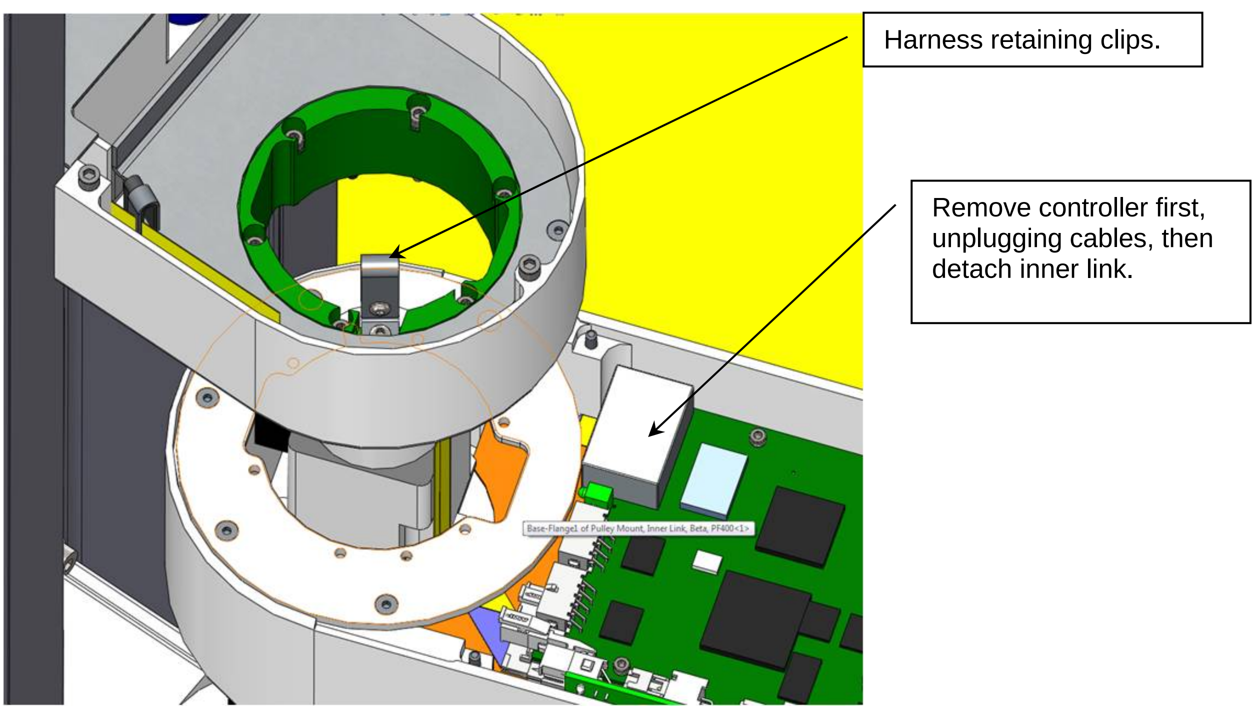
The J3 Motor Assembly is comprised of the J3 motor, connectors, and a timing belt pulley.

The user must:

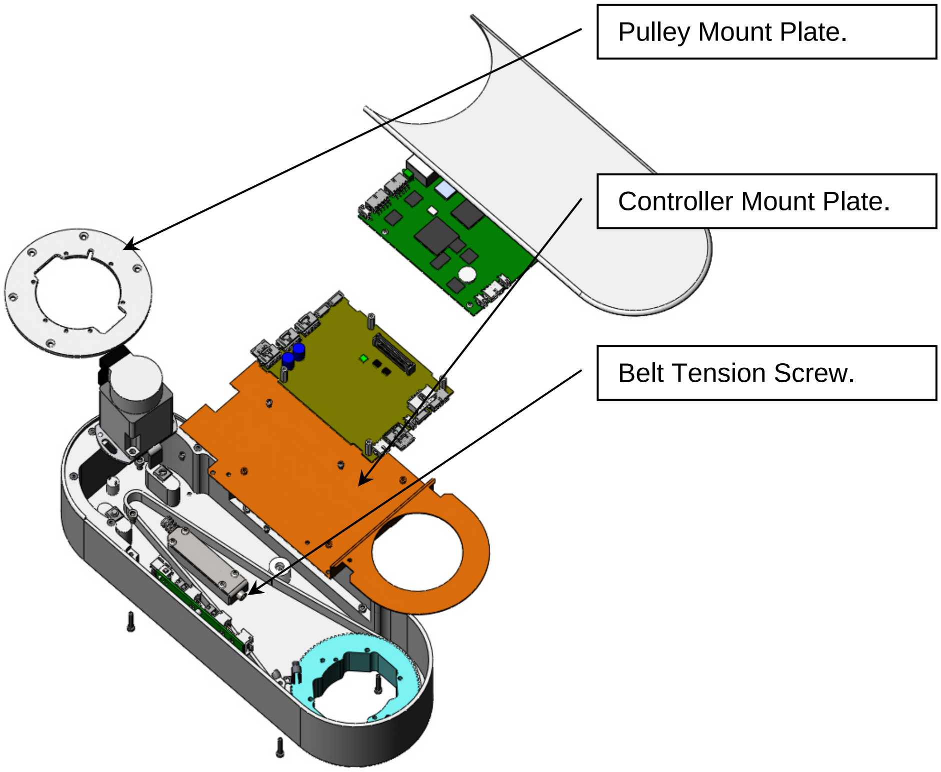
1. Unbolt the robot from its mounting surface and set it vertically on the floor or a low surface.
2. Move the robot arm to about 2 inches below the top of the Z Column travel.
3. Turn off the robot power and remove the AC power cord.
4. Remove the Top Plate of the robot by removing the 4 M5 socket head screws from the top plate of the robot that attach the top plate to the Z column.
5. Remove the Front Cover by lifting it out horizontally.
6. Remove the Z carriage inner cover by removing 5 M3 X 10 FHCS.



7. Remove the Light Bar by removing 3 M3 X 8 SHCS and unplugging the connector from the J2 Motor Interface PCA.
8. Remove controller from inner link.
9. Detach the inner link from the Z carriage by removing 6 M3 X 35 SHCS and lock washers.



10. Remove round Pulley Mount Plate from the Inner Link by removing 5 M3 X FHCS.
11. Remove the J3 Controller Mount Plate from the Inner link by removing 4 M3 X 5 SHCS.



12. Remove the J3 motor by removing the 2 M4 Screws attaching the motor to the motor mount plate, and rotate the motor up and out of the motor mount plate. This procedure will preserve the belt tension and avoid having to use a tension meter to reset the belt tension, as it preserves the position of the motor mount plate.
13. Replace the J3 motor, using Loctite 243, or optionally, replace the J3 timing belt if necessary. Since the motor mount plate has not been removed, the belt tension should not need to be adjusted.
14. If a Belt Tension Meter is available, check the belt tension per Appendix D. Check the belt tension every 10 degrees of rotation of the J3 output pulley and set the belt tension at its lowest point to the minimum value in Appendix D.
15. Replace the pulley mount plate using Loctite 222 and re-assemble the robot.
16. Re-calibrate the robot.

Replacing the J4 (Wrist) Axis Motor or Timing Belt

DANGER: Before replacing this motor, the AC power should be removed.

Tools Required:

1. 3.0mm hex driver or hex L wrench
2. 2.5 mm hex driver or hex L wrench
3. 2.0mm hex driver or hex L wrench
4. Fine point tweezers
5. .06 in flat blade screwdriver

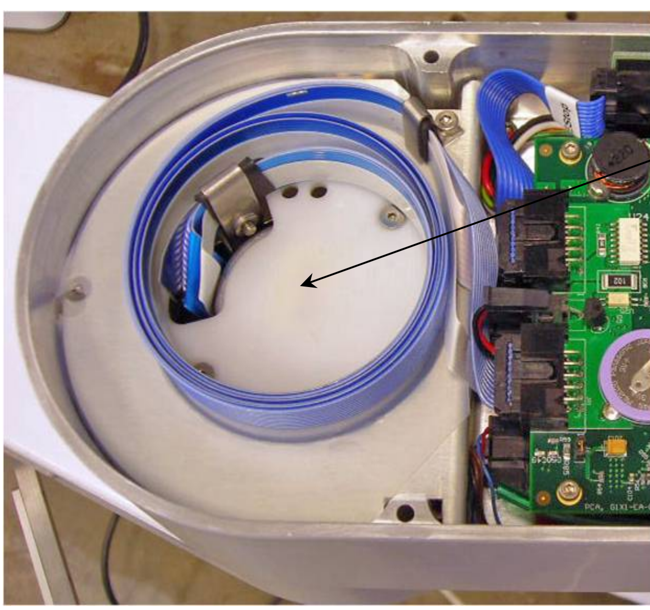
Spare Parts Required:

1. J4 Motor Assembly PN PF04-MA-00011 or J4 Timing Belt PN PF00-MC-X0004.
2. Loctite 222 and 243

The J4 Motor Assembly is comprised of the J4 motor, connectors, and a timing belt pulley.

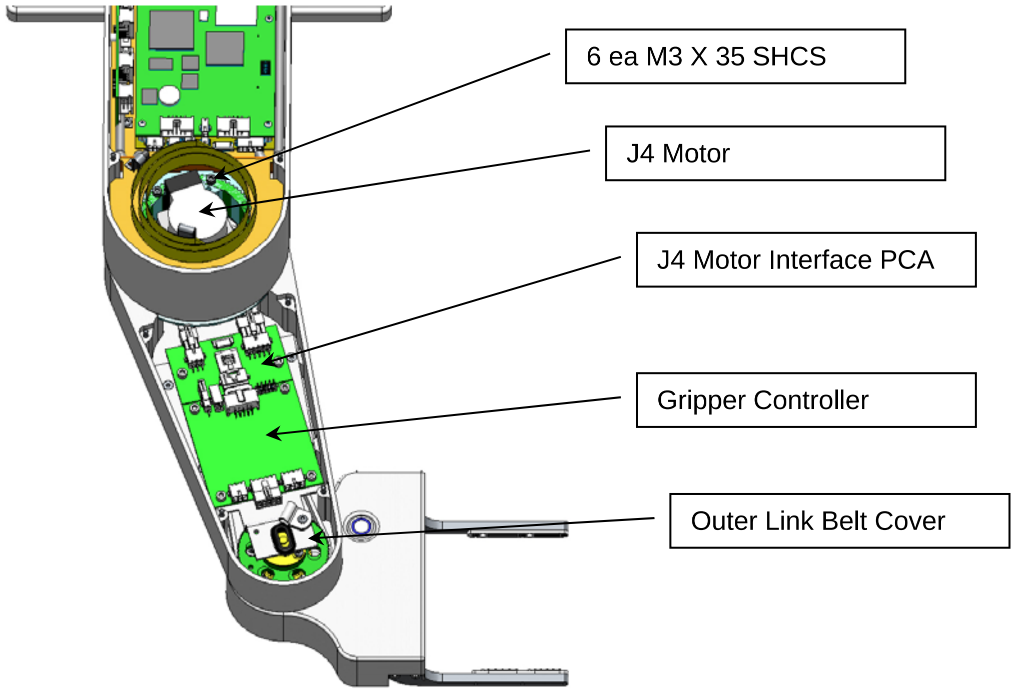
The user must:

1. Move the robot arm to a convenient height on the Z column for removing the outer link.
2. Turn off the robot power and remove the AC power cord.
3. Remove the inner link cover by removing 4 M3 X 20 SHCS and lock washers.
4. Remove the outer link cover by removing 4 M3 X 20 SHCS and lock washers.
5. Remove the J4 Motor Cover in the Elbow by removing 2 M3 X 10 FHCS.

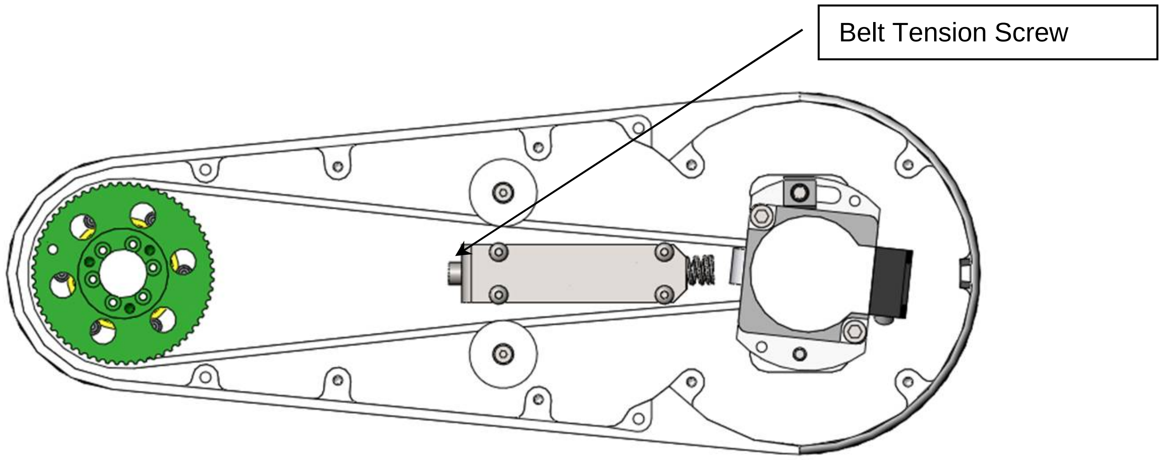


J4 Motor Cover

6. Rotate the Outer Link clockwise (viewing from above) until it hits the hard stop. This will expand the harness coil and the link will be position as shown below, about 10 degrees from straight out.
7. Remove the J4 Motor Interface Board in the Outer Link and unplug the cables.
8. Remove the Outer Link by removing 6 M3 X 35 SHCS in the J3 Output Pulley that attach the Outer Link.
9. Remove the Gripper Controller by unplugging the Gripper harness and removing 4 M3 X 8 SHCS.
10. Remove the Outer Link Belt Cover by removing 4 M3 X 10 SHCS.



11. Remove the J4 motor by removing the 2 M4 Screws attaching the motor to the motor mount plate, and rotate the motor up and out of the motor mount plate. This procedure will preserve the belt tension and avoid having to use a tension meter to reset the belt tension, as it preserves the position of the motor mount plate.
12. Replace the J4 motor, using Loctite 243, or optionally, replace the J4 timing belt if necessary. Since the motor mount plate has not been removed, the belt tension should not need to be adjusted.
13. If a Belt Tension Meter is available, check the belt tension per Appendix D. Check the belt tension every 10 degrees of rotation of the J4 output pulley and set the belt tension at its lowest point to the minimum value in Appendix D.
14. Replace the pulley mount plate using Loctite 222 and re-assemble the robot, with the outer link positioned as shown above so that the link is correctly oriented with respect to the hard stop.
15. Re-calibrate the robot.



Replacing Servo Gripper with Pneumatic or Vacuum Gripper

> **DANGER:** Before replacing this motor, the AC power should be removed.

Tools Required:

1. 3.0mm hex driver or hex L wrench
2. 2.5 mm hex driver or hex L wrench
3. 2.0mm hex driver or hex L wrench
4. 1.3mm hex driver of hex L wrench
5. Fine point tweezers
6. .06 in flat blade screwdriver

Spare Parts Required:

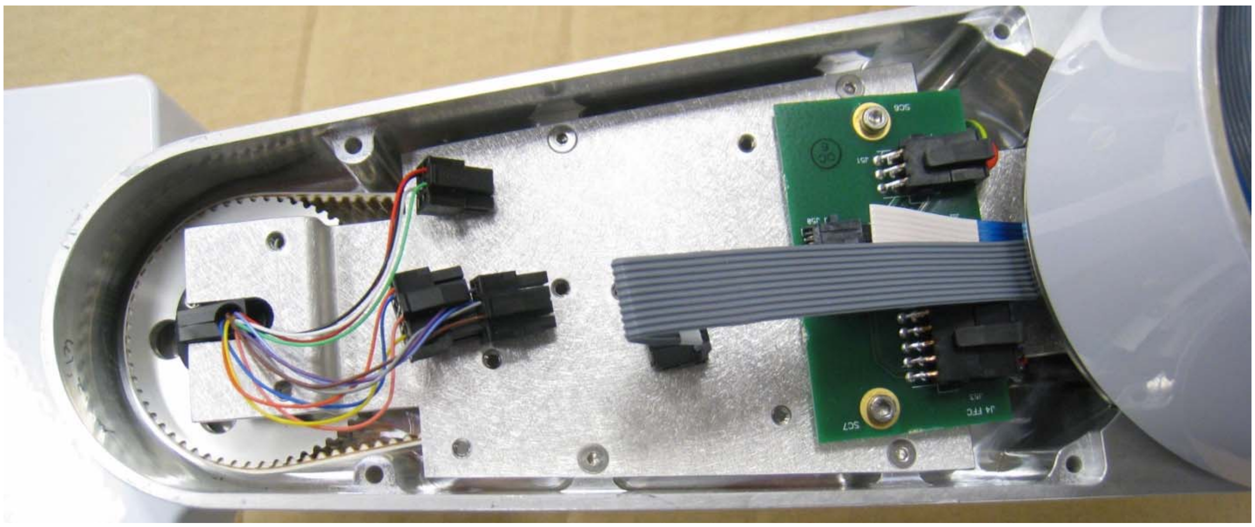
1. Pneumatic or Vacuum Gripper and installation kit, including air harness for elbow, 10 conductor ribbon cable for IO harness, barbed plastic air fittings, and metal retaining clip for air hose in J4 pulley, and vacuum/j4 motor interface board to replace standard J4 motor interface board for

robots older than Revision C (2016) . **You will need to obtain different PAC files from Precise as one servo axis is deleted.**

This modification should only be performed by a trained service technician. It requires a robot that has an air line pre-installed at the factory. Some robots with servo grippers built after April 2014 have this feature. If the air line is installed, a pneumatic fitting will be installed on the robot connector panel.

The user must:

1. Move the robot arm to a convenient height on the Z column for removing the servo gripper.
2. Turn off the robot power and remove the AC power cord.
3. Remove the inner link cover by removing 4 M3 X 20 SHCS and lock washers.
4. Remove the outer link cover by removing 4 M3 X 20 SHCS and lock washers.
5. Remove the gripper controller (GSB) by removing 4 M3 X 8 SHCS.

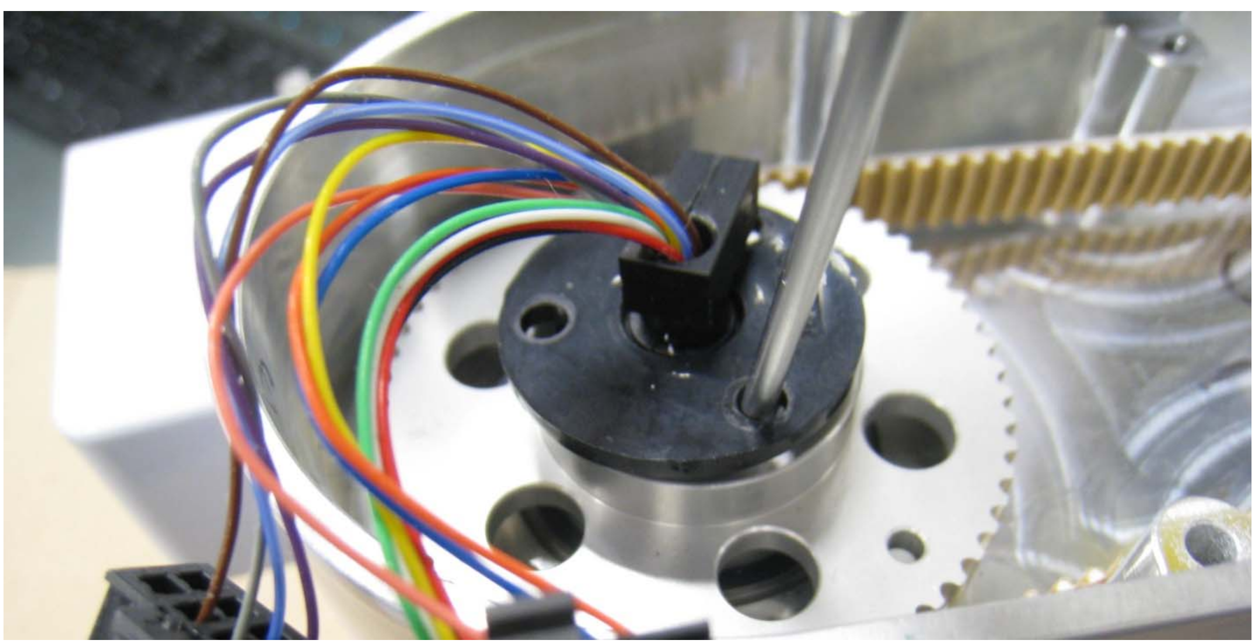


6. Remove the FFC to motor cable interface board and sheet metal belt cover in the outer link.

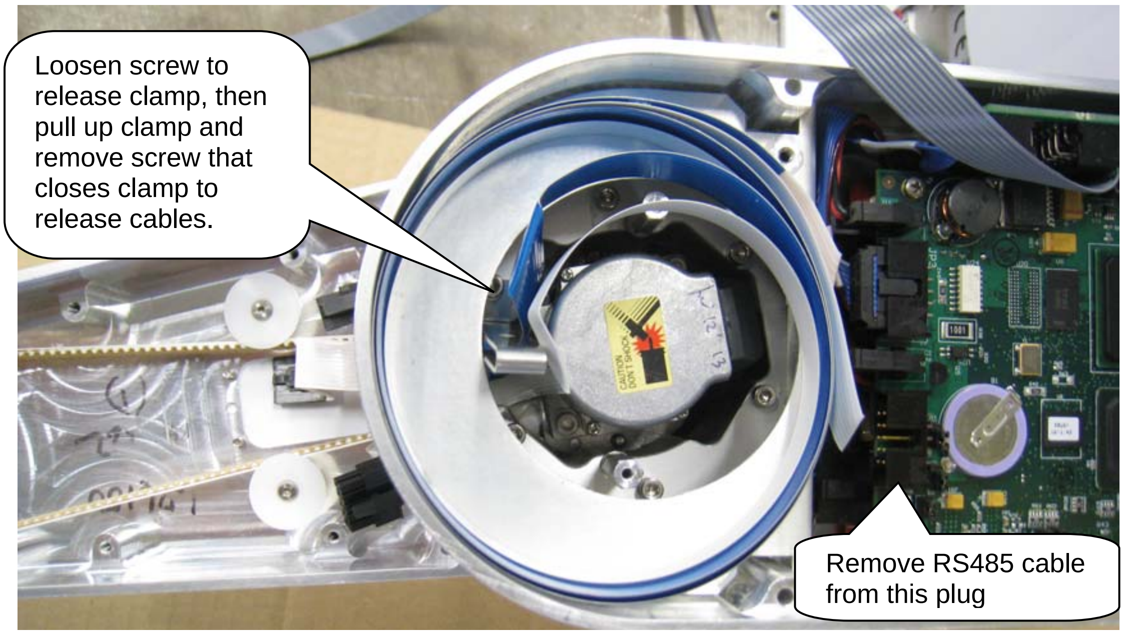
7. Remove the bottom cover from the gripper.

8. Remove the 3 M3 X BHCS that retain the slip ring. (Do not try to remove slip ring yet!)
9. Unplug the slip ring connectors inside the servo gripper.

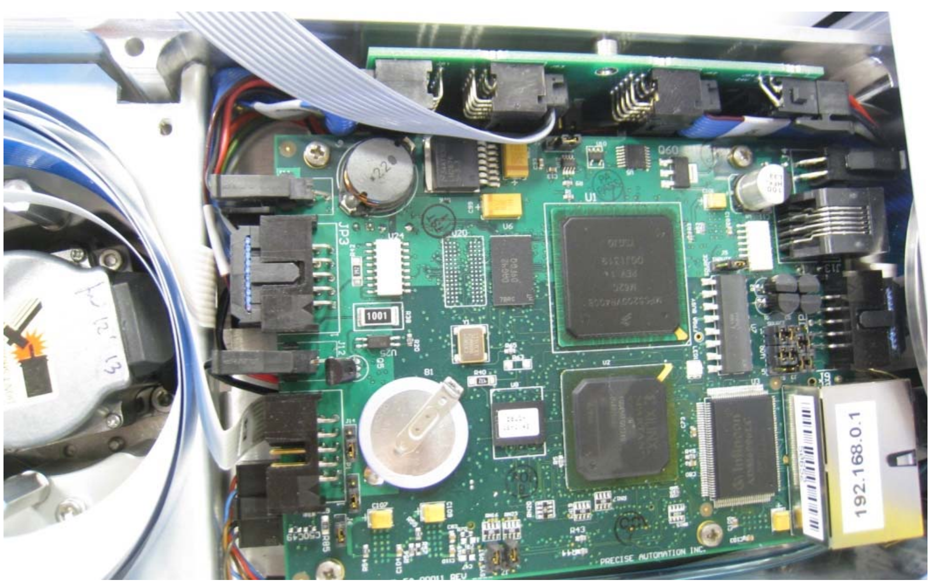
10. Rotate the slip ring slightly to expose the M2 counter bores in the J4 output pulley. Using a M1.5 hex driver, remove 6 M2 X 16 SHCS that attach the gripper. Lower the gripper gently while feeding the slip ring connectors through the hole in the gripper housing.



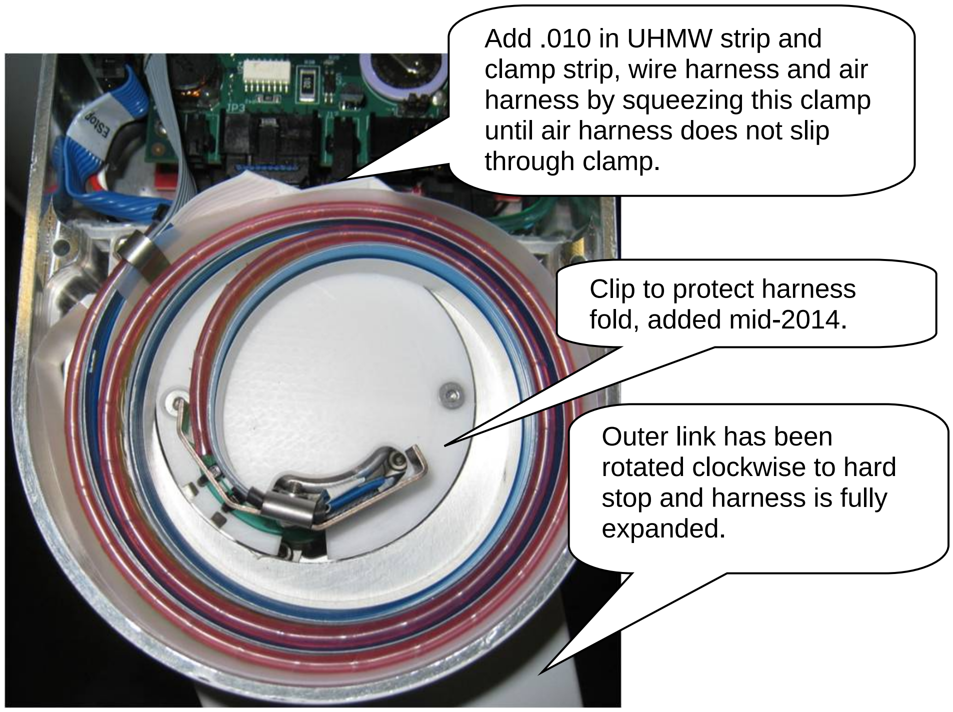
11. Remove the slip ring.
12. Loosen the M3 screw that attaches the harness cable clamp to the J3 output pulley until the clamp can be pulled all the way up to provide access to the M3 X 8 BHCS that closes the clamp. Remove this screw and the rubber pad on the harness.
13. Remove the RS485 10 conductor ribbon cable from the robot by feeding the connector up past the J4 motor in the outer link, removing this cable from the retaining clamps, and unplugging it from the RS485 connector in the controller.



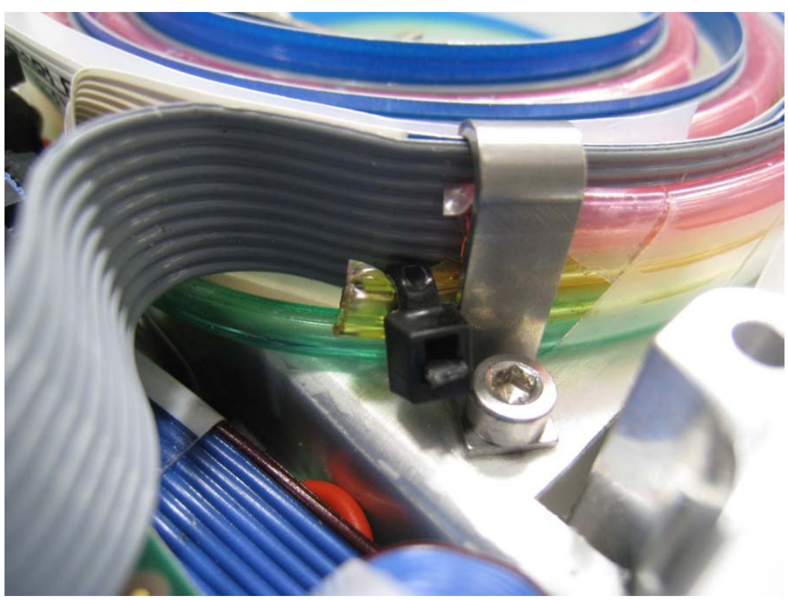
14. Plug IO cable for pneumatic gripper option into IO connector on side of inner link.



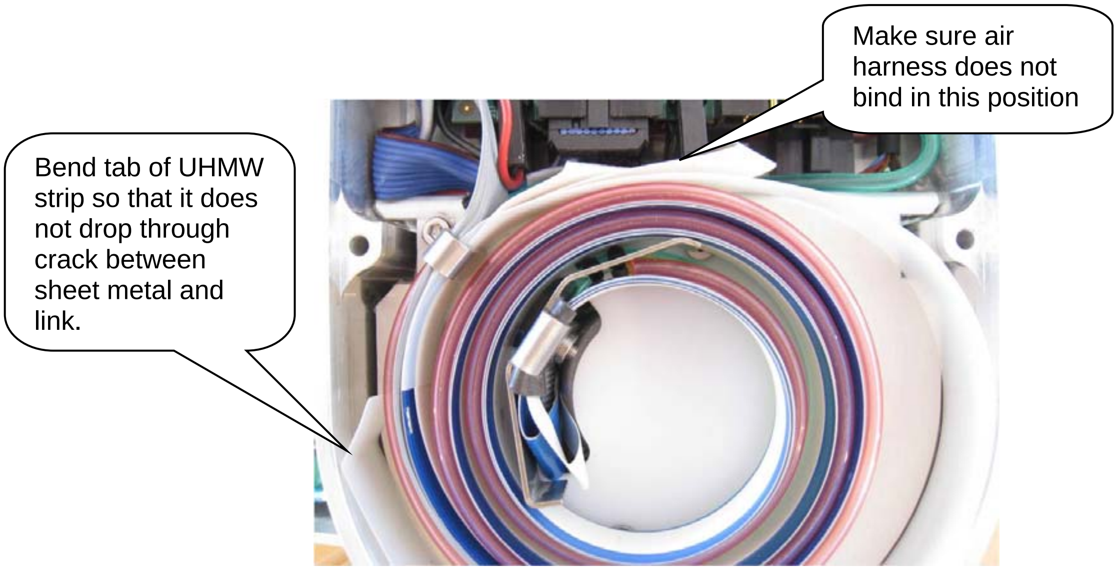
15. Add air harness along with IO harness and clamp as shown, after routing cables back down to outer link. Note order of folds in cable. White encoder cable is on inside, then blue shielded motor cable, then IO 10 conductor ribbon cable.



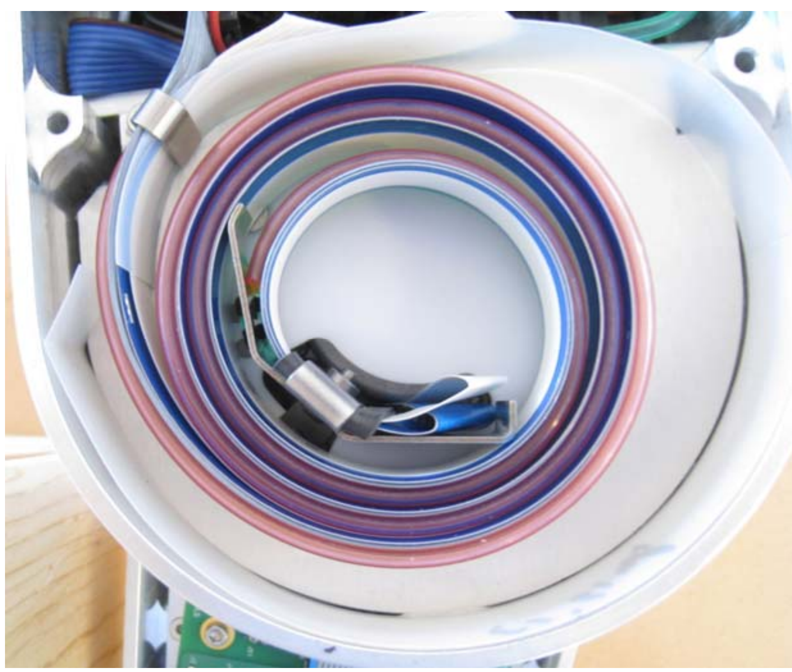
16. Add tie wrap to harness tube to prevent harness from slipping through clamp.



17. Route air tube under IO cable and connect to air tube in inner link with plastic barbed connector.
18. Bend rotating metal clip inwards towards motor as far as possible. Rotate outer link and check that air harness does not bind on controller connectors as rotating clip passes controller.

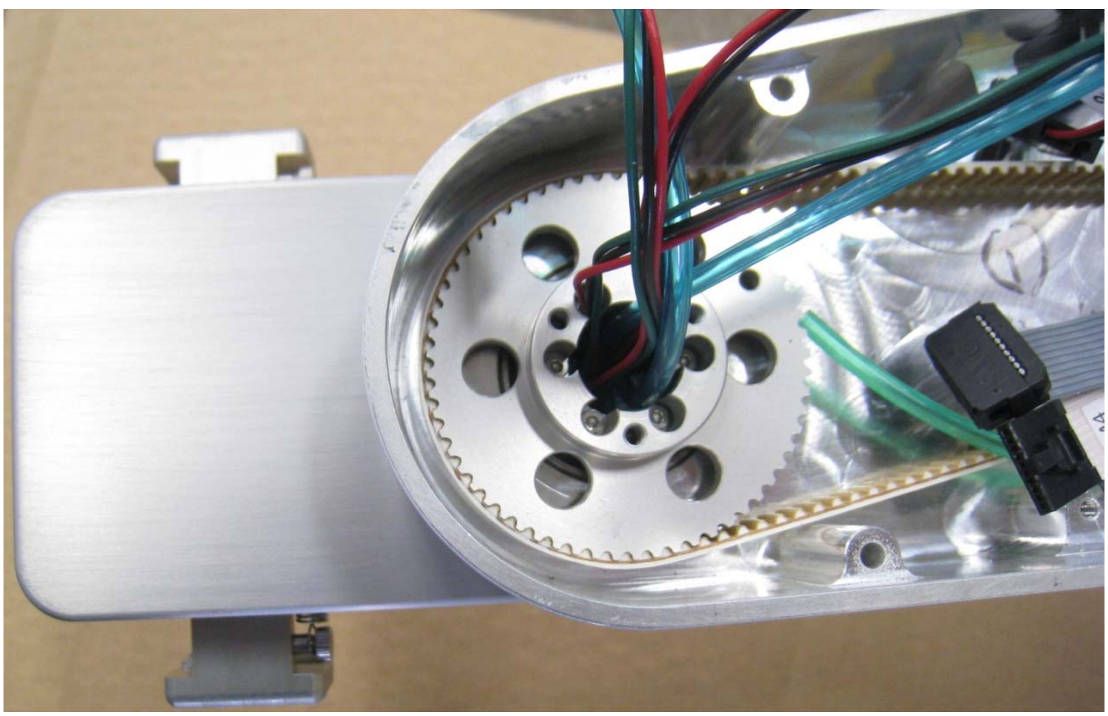


19. Check harness when outer link is fully rotated counter-clockwise to be sure there is no binding.

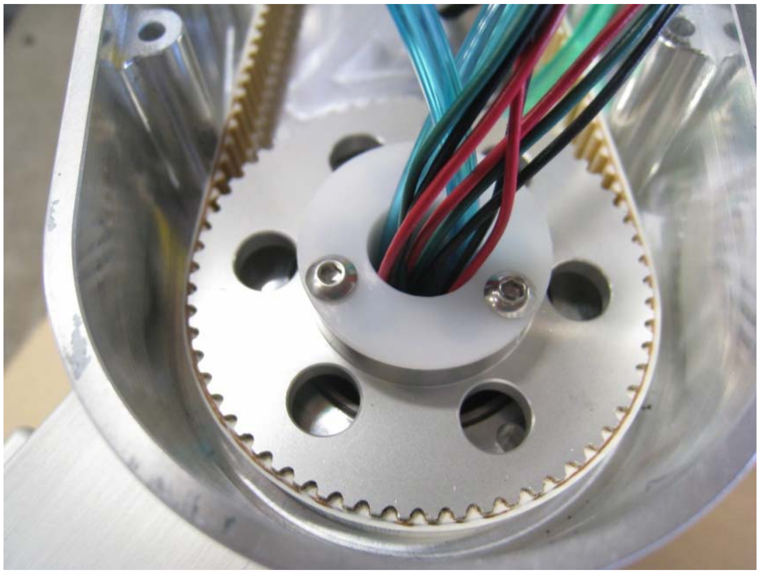


20. Install Delrin bumper for sliding stop in threaded hole under end of outer link with 4-40 X 3/8 Steel Socket Head Cap Screw and Loctite 222.

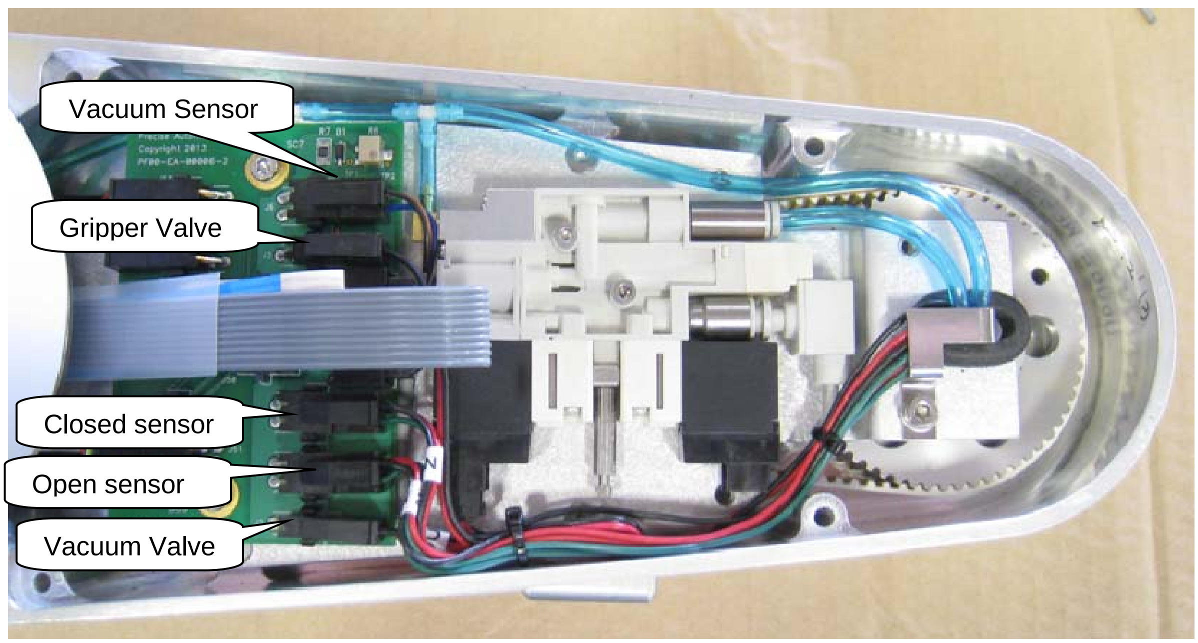
21. Add slider for pneumatic or vacuum gripper to top of gripper and attach gripper to J4 output pulley by tightening 6 M2 SHCS after threading wires and hoses from gripper thru pulley. Make sure dowel pin in J4 pulley fits into notch in gripper to orient gripper. Be very careful not to pinch any wire between gripper and pulley.



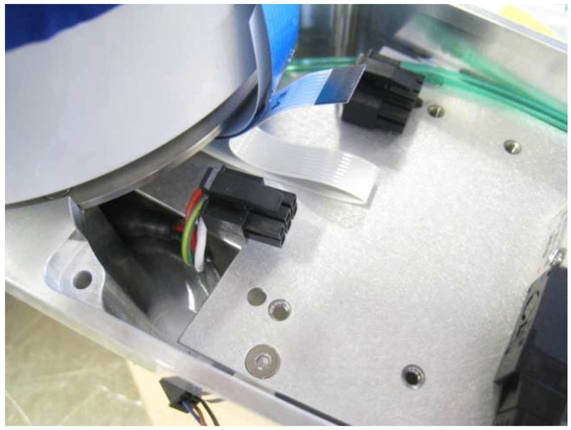
22. Thread wires and hoses through white plastic bushing and install bushing into pulley with 3 M3 BHCS.



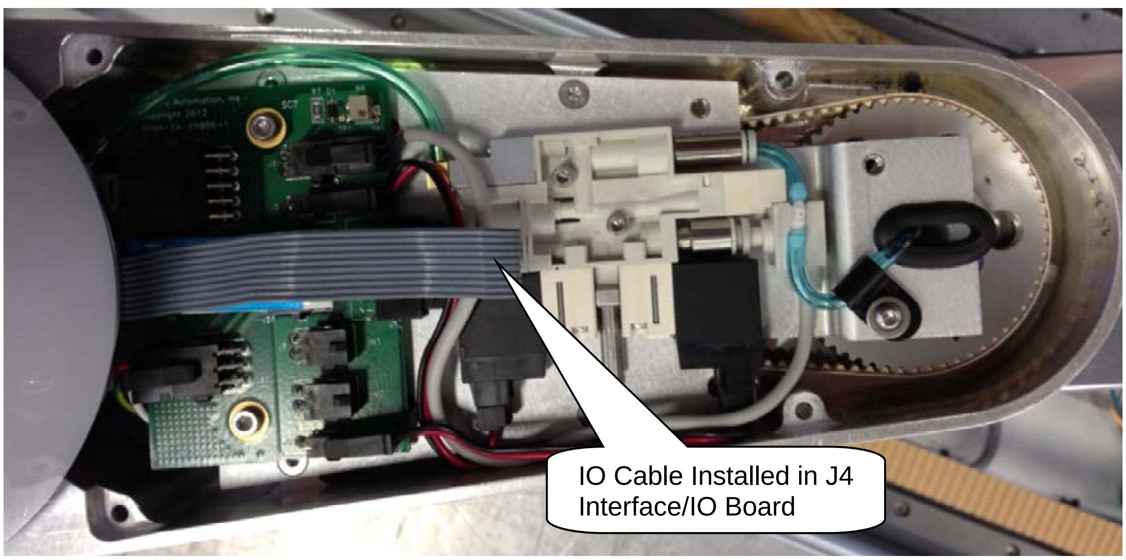
23. Replace outer link sheet metal belt cover, by sliding under cables from motor and inner link, but do not install screws yet.
24. Install vacuum generator as shown for vacuum-pallet gripper and for vacuum gripper. For vacuum-pallet gripper, vacuum gripper and pneumatic gripper rotate gripper until it is centered under outer link. Then stretch rubber grommet over wires and hoses and slide grommet into sheet metal belt cover so that wires are on the inside of any hoses. Be sure the wires are not twisted around the hoses. Check to be sure that the gripper can rotate 270 degrees in both directions without putting any strain on the wires. If the wires are pulled by the rotation of the gripper they will eventually fail.



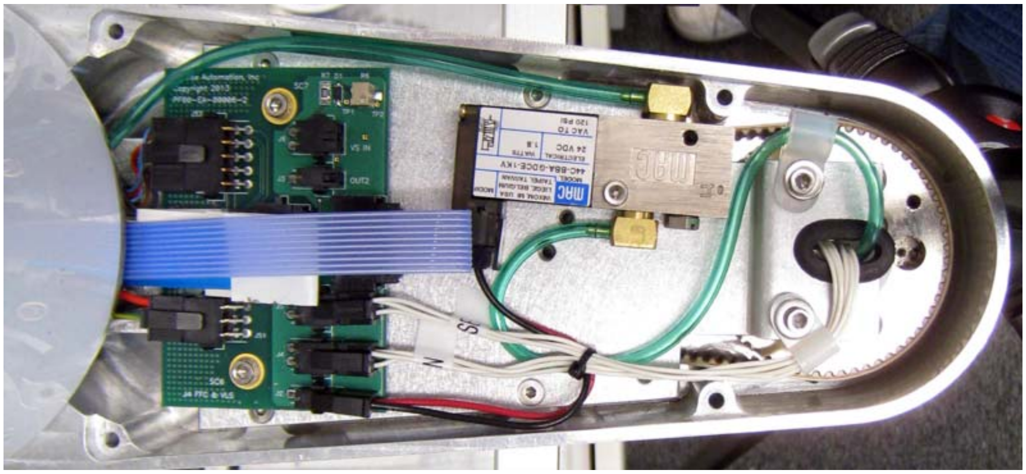
25. Wiring and fold detail for interface board.



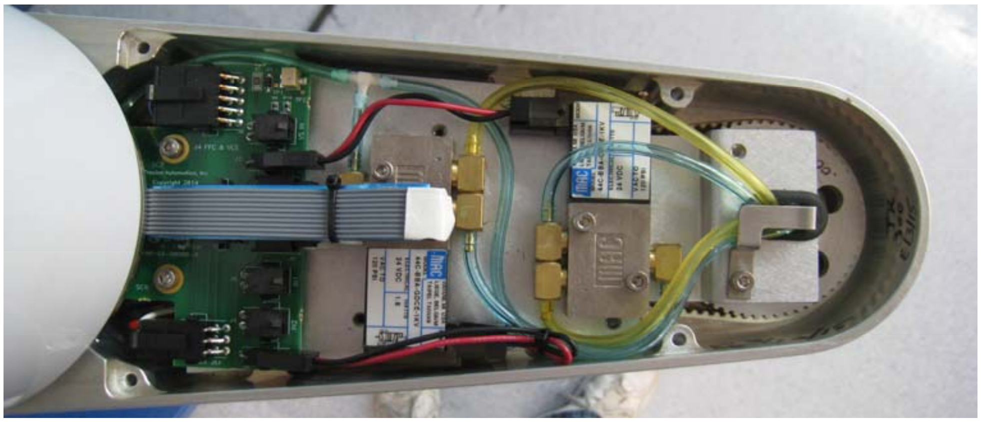
26. Vacuum gripper configuration with vacuum interface board.



27. Pneumatic gripper configuration



28. Dual pneumatic gripper configuration (with Rev C sheet metal, 2016)



29. After installing the appropriate gripper, check Digital Input 1 for Pneumatic Gripper open sensor, Digital Input 2 for Pneumatic Gripper close sensor, and Digital Input 4 for vacuum present sense, if these sensors are installed. For vacuum grippers Digital Output 1 will turn on vacuum valve and Digital Output 2 will turn on vacuum blow-off function in vacuum generator, if installed. For Pneumatic grippers Digital Output 1 turns on the pneumatic valve 1 and Digital Output 2 turns on the pneumatic valve 2.

30. After removing the servo gripper, new PAC files must be installed in the robot to correctly configure it as a 4 axis robot, or 4 axis robot on a linear rail. Unless the correct PAC files are installed, the software will be looking for the missing gripper controller (GSB) and will generate an error. See Updating PAC files in the Software Reference section.

31. After new PAC files are installed, or after unplugging the J4 motor/encoder interface board, the robot must be re-calibrated. See Calibrating the robot under Service Procedures.

Appendix A: Product Specifications

PreciseFlex 400 Specifications

General Specification	Range
Range of Motion & Resolution	
J1 (Z) Axis	400mm or 750mm
J2 Axis	± 90 degrees
J3 Axis	± 167 degrees
J4 Axis	+/- 970 degrees
Linear Axis	1000mm, 1500mm, 2000mm
Gripper Travel	74 to 133mm
Spring Gripper Force	2-23 Newtons closing, 2-10 Newtons opening, 7 Newtons power off
Resolution	10 microns typical
Repeatability	+/- 0.090 mm overall in x,y & z directions at 18-22C, +/- 0.120mm for XR, +/- .050mm for Linear Axis
Performance and Payload	
Maximum acceleration	2500mm/sec^2 with 500gm payload
Maximum speed	500 mm/sec Cartesian, 360 degrees/sec J2, 720 degrees/sec J3, J4
Controller	*AVAILABLE GUIDANCE CONTROLLERS*: Guidance 1400B, Guidance 1100T Slave Amp, GIO optional IO Board
Interfaces	
General Communications	RS-232 channel, 100Mb Ethernet
Digital I/O Channels	1 optically isolated input, 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	One air line, 75 PSI maximum, provided at outer link and routed internally to fittings on the Facilities Panel if Pneumatic Option selected.
Operator Interface	Web based operator interface supports local or remote control via browser connected to embedded web server.
Programming Interface	Three methods available: DIO MotionBlocks (PLC), 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, 365 watts maximum
Weight	20 kg for 400mm travel version, 25 kg for 750mm version, 30 kg for 1000mm Linear Axis option, 60kg for 2000mm Linear Axis Option

PreciseFlex 3400 Specifications

General Specification	Range
Range of Motion & Resolution	
J1 (Z) Axis	400mm, 750mm, 1160mm
J2 Axis	± 90 degrees
J3 Axis	± 167 degrees
J4 Axis	+/- 970 degrees with 60N servo gripper, +110/-470 with ISO mounting flange
Linear Axis	1000mm, 1500mm, 2000mm
Gripper Travel	102 to 142mm
Spring Gripper Force	2-60 Newtons closing, 10-20 Newtons opening, 7 Newtons power off
Resolution	10 microns typical
Repeatability	+/- 0.100 mm overall in x,y & z directions at 18-22C, .050mm for Linear Axis
Performance and Payload	
Maximum acceleration	2000mm/sec^2 with 3000gm payload
Maximum speed	500 mm/sec Cartesian, 90 degrees/sec J2, 720 degrees/sec J3, J4
Controller	*AVAILABLE GUIDANCE CONTROLLERS*: Guidance 1400C, Guidance 1100T Slave Amp
Interfaces	
General Communications	RS-232 channel, 100Mb Ethernet
Digital I/O Channels	8 optically isolated inputs and 8 isolated outputs, available on facilities panel at base. Remote I/O also available.
Pneumatic Lines	Two air lines, 75 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 programming, 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, 700 watts maximum
Weight	25 kg for 400mm travel version, 30 kg for 750mm version, 40kg for 1160mm option, 30 kg for 1000mm Linear Axis option, 60kg for 2000mm Linear Axis Option

Appendix B: Environmental Specifications

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

General Specification	Range & Features
Ambient temperature	4ºC to 40ºC
Storage and shipment temperature	-25ºC to +55ºC
Humidity range	10 to 90%, non-condensing
Altitude	Up to 5000m

Appendix C: Spare Parts List

Reference: the part number format is:

F0v-wwww-xy-zzzzz
v - Major version - "X" for rev A; "B" for rev B; “C” for rev C, 2 for 3kg payload
wwww - Ship date,yymm, so 1207 means July 2012
x is the controller rev
y is the robot rev
zzzzz - is a unique robot number

Description	Part Number	Rev C PN
Absolute Encoder Battery Assembly	PF10-EA-00002	
J1 Motor Assembly	PF01-MA-00011	
J1 Stage 1 Belt	PF00-MC-X0021	
J1 Stage 2 Belt 400mm	PF00-MC-X0022	
J1 Stage 2 Belt 750mm	PF00-MC-X0023	
J2 200W Motor Assembly 9mm Pulley (Rev A)	PF02-MA-00009	
J2 200W Motor Assembly 12mm Pulley (Rev B, C)	PF02-MA-00012	
J2 400W Motor Assembly 20mm Pulley (PF3400)	PF02-MA-00020	
J2 Belt 9mm wide	PF00-MC-X0005	
J2 Belt 12mm wide (Rev B, C)	PF00-MC-X0081	
J2 Belt 20mm wide (PF3400)	PF00-MC-X0099	
J2 Cam Followers for 9mm belt (set of 2)	PF00-MA-00023	
J2 Cam Follower for 12mm belt (set of 2) (Rev B)	PF00-MA-00024	
J2 Cam Follower for 12mm belt (set of 2) (Rev C)	PF00-MA-00062	Thrust Washers
J3 Motor Assembly	PF03-MA-00011	
J3 Belt	PF00-MC-X0035	
J4 30W Motor Assembly	PF04-MA-00011	
J4 50W Motor Assembly (PF3400)	PF04-MA-00023	
J4 Belt	PF00-MC-X0004	
PF400 23N Servo Gripper with Spring, without fingers	PF0S-MA-00001	
PF400 23N Servo Gripper with Brake, without fingers	PF0A-MA-00001	
Fingers for PF400 Servo Gripper	PF0S-MA-00010	
Finger Pads for PF400 Servo Gripper	PF0S-MA-00011	
PF3400 60N Servo Gripper	PF3S-MA-00001 Rev A1	
G1400B Controller with advanced kinematics license	G1XF-EA-B1400	
G1400C Controller with AKL (PF3400)	G1XF-EA-C1400	
G1100T Slave Controller (“GSB3-SE”) for Gripper	G1X0-EA-T1101-4	
G1100T Slave Controller (“GSB3-DIFF”) for Rail or 60N Gripper	G1X0-EA-T1101-4D	
GIO Digital IO Board with pigtails	GIO1-EA-01104	
24 VDC Supply	PS10-EP-00125	
48 VDC Motor Supply	PS10-EP-48365	
Slip Ring Harness Assembly, 23N Brake Gripper	PF04-MA-00002	18Wire
Slip Ring Harness Assembly, 23N Spring Gripper	PF04-MA-00010	18Wire
Slip Ring Harness Assembly, 60N Spring Gripper	PF04-MA-00030	
Harness, FFC, J4 Motor	PF0H-MA-00002-02	
Harness, FFC, J4 Encoder	PF0H-MA-00005-02	
Harness, Gripper Controller	PF0H-MA-00014	
Fuse 6.3A 250V TIME LAG	PS12-EC-F0001	Deleted

Fuse 4.0A	PF00-EC-F0002	
J1 Motor Interface PCA	PF00-EA-00001-J1	New
J1 Motor Interface PCA (PF3400)	PF00-EA-00001-J1IO	With IO integrated
J2 Motor Interface PCA	PF00-EA-00001-J2	
MIDS Interface PCA	PF00-EA-00001-MI	
MIDS Interface PCA (PF3400)		Connector changed
J4 Motor Interface PCA	PF00-EA-00001-J4	New
J4 Motor Interface PCA (PF3400)		Connector Added
Energy Dump PCA	PF00-EA-00001-ED	Deleted
Pneumatic Outer Link Harness Assembly	PF04-MA-00006	
O-Rings for Front Cover dowel pins (2)	0000-HC-X0051	

Appendix D: Preventative Maintenance

Every 1 to 2 years, the following preventative Maintenance procedures should be performed. For robots that are continuously moving 24 hours per day, 7 days a week at moderate to high speeds, a one-year schedule is recommended. For robots with low duty cycles and low to moderate speeds, these procedures should be performed at least once every two years.

Check List	Procedure If Problem Detected
Check all belt tensions	Re-tension if necessary
Check air harness tubing in elbow if present, and theta axis for any wear	Replace if necessary
Replace timing belt in optional linear axis	Typically every 6,000 hours of continuous operation
Check all joints in “free mode” for low bearing friction and any sticking.	If a bearing is getting stiff, return to factory for bearing replacement.
Check second stage (long) Z belt for any squeaking	If noisy, add thick grease to front and rear edge of belt if necessary. (Shell 222 XP or similar). Z timing belt can get stiffer over time (2-3 years) and occasionally start squeaking against pulley flanges.
Check if front cover is rattling	If so, check .125in ID by .062in thick O rings on dowel pins in base plate under front cover for any deterioration and replace if necessary.
Check Cam Followers on J2 timing belt for grease leaking or discoloration.	Replace if necessary. Note earlier units had a 9mm wide timing belt and later units (2014, 2015) have a 12mm wide timing and the Cam Followers are different. See spare parts list.
Replace slip ring	For units with electric gripper shipped before April 2015, replace the slip ring. For units shipped after April 2015, replace the slip ring every third inspection test.

Appendix E: Belt Tensions, 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 or 508C.

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)	Min Tension (N)	Max Tension (N)	Frequency Min Hz	Frequency Max Hz
Z S1	2.8	9	58	50	70	384	454
Z S2	4.1	12	530	100	120	43	47
Z S2	4.1	12	880	100	120	26	28
Z S2	4.1	12	1290	100	120	17	19
J2	2.8	9	108	160	180	369	391
J2 CE*	2.8	12	108	160	180	319	339
J2 PF3400	2.8	20	108	200	250	277	309
J3 S	2.8	12	104	70	110	219	275
J3 S Hatch	2.8	12	**113**	70	110	202	253
J4 S	2.8	9	113	35	60	165	216
J4 S Hatch	2.8	9	95	35	60	196	257
J3 X	2.8	12	183	70	110	125	156
J3 X Hatch	2.8	12	118	70	110	193	242
J4 X	2.8	9	143	35	60	130	171
J4 X Hatch	2.8	9	150	35	60	124	163
Linear Axis	4.1	20	500	140	170	41	46

Note: * denotes 12mm wide J2 timing belt, introduced mid year 2014

Note: S denotes standard reach and X denotes extended reach robots.

Revisions

Rev 4.10, 140922: Updated base plate installation drawing with metric hole pattern

Rev 4.11, 141012: Updated belt re-tension sections

Rev 4.12, 141020: Added detail on jumpers to connect serial lines from gripper to CPU in GSB section. Updated slip ring drawing, sensor, to show TXD and RXD wires in gripper connector. Updated GIO board picture in section on adding GIO to linear axis.

Rev 4.13, 141028: Added note on removing J6 RS485 termination jumper in controller when adding linear axis.

Rev 4.14 141215: Changed instruction p61 on calibrating linear axis to position carriage near connector end cap for CALPP.

Rev 4.15 150121: Changed fuse rating from 6.3A to 4.0A for CSA approval for linear rail.

Rev 4.16 150331: Added Preventive Maintenance Appendix and updated Spare Parts List

Rev 4.17 150911: Updated environmental specification

Rev 4.18 151102: Updated FFC schematic and Gates Tension Meter model number

Rev 4.19 151104: Added finger mount height dimension to installation section

Rev 4.20 151110: Updated Servo Gripper Drawing

Rev 4.21 151124: Updated Changing Servo Gripper to Pneumatic Gripper, Rail Calibration

Rev 4.22 160119: Update gripper rack adjustment for centering fingers

Rev 4.23 160229: Updated spares list for Rev C

Rev 4.24 160323: Added GSB PN for linear rail version with differential encoder input in spares

Rev 4.25 160506: Updated repeatability spec in specification section

Rev 4.26 160907: Added “Danger” warning label definition page iii

Rev 4.27 16908: Updated Slip Ring with Sensor Drawing, changed serial labels to TXD and RXD

Rev 5.01 170114: Updated for Rev C and 3kg robot release

Rev 5.02 170608: Updated for “PF3400” product name for 3kg version of PF400

Rev 5.03 170714: Added PF3400 collision table, some more spare parts

Rev 5.04 170809: Added 60N gripper service details and spare PNs for gripper and slip ring