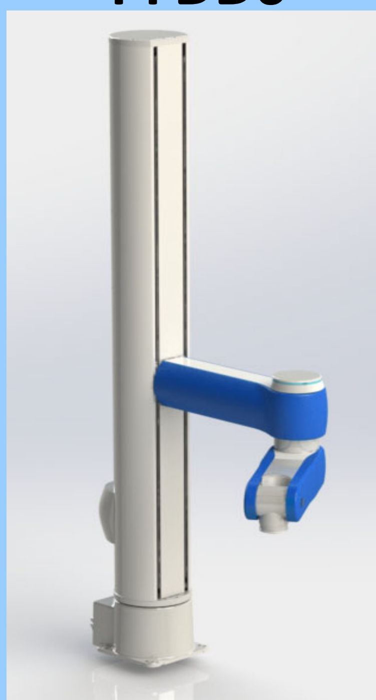
PFDD6



PFDD4

PreciseFlex™ DDR Collaborative Robots

Hardware Introduction and Reference Manual

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Revision History

Revision	ECO Number	Date	Explanation of Changes
Rev 1.1		May 20, 2020	Working draft
Rev 1.2		Sept. 8, 2020	Working draft, gripper detail added
Rev 1.3		Jan. 4, 2021	Working draft 1. CALPP detail updated. 2. PAC file and GPL update changed for Windows 10. 3. Added unpacking instructions.
Rev 1.4		Dec. 28, 2021	Working draft 1. Environmental spec updated. 2. Minor edits
Rev 5.0.0	TBD	April 9, 2022	Working draft. first version as Brooks

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, will 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 PFDD Direct Drive Robots are available in either a four-axis or six-axis configuration. Both robots include embedded motion controllers, a 48VDC motor power supply, and a 24VDC logic power supply located inside the robot. In addition, they may optionally include an electric gripper and electric gripper controller, or solenoid valves to support pneumatic grippers.

The Z axis of these robots is available with a standard travel of 500 mm, and optional travels of 1000mm and 1420mm. The 6-axis robot can carry a payload of up to 5kg and the 4-axis robot can carry a payload up to 7.0kg. These robots are 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, Automotive, and Electronics industries.

In general, assuming a collaborative gripper with no sharp edges or other dangerous features, is attached to the robot, these robots can make horizontal motions at tip speeds up to 1.5 -2.0 m/sec, and bump into a person without causing a severe injury. For vertical motions, the Z speed should be limited to 150mm/sec when the robot comes within 100mm of a rigid surface, as the effective moving mass in Z is much greater than the effective moving mass in the horizontal plane. More detail is provided in the Collaborative Robot section of this manual.

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 four programming modes: a Digital IO (PLC) mode, a Graphical User Programming Mode (Guidance Motion), an Embedded Language mode (GPL), and a PC Control mode (TCS). When programmed in the PLC, Graphical User Mode 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, which is implemented through a command-server interface.

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 PFDD Direct Drive robots are being released in 2020, with Beta and Pilot versions scheduled for release this year.

Beta Units, designated by Serial Numbers FD0-yymm-AA-zzzzz, were released in early 2020, and are for customer feedback and evaluation, while factory testing is completed. Some improvements may be incorporated into Pilot Units, below.

Pilot/Production Units, designated by Serial Numbers FD0-yymm-xB-zzzzz, will be released in the spring of 2021

Yy – year
Mm – month
X – controller rev
Y – robot rev
Zzzzz – unique number

PFDD Robots

The PFDD6 has a rated payload of 6kg, including the gripper. The PFDD4 has a rated payload of 8kg.

Note that for the PFDD robots, 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). ***The payload can also be set using the operator Web Interface (see “Control Panels > Robot Rayload”). This is very important prior to entering “Free Mode” as a drastically incorrect payload can cause the Z axis gravity compensation to be incorrect and thus cause the Z axis to start to move up or sag down, until the velocity restrict safety limit cuts in to stop any excessive speed.***   For the 6-axis robot 100% equals 6kg for the gripper and payload mass. For the 4-axis robot 100% equals 8kg 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 for proper gravity compensation, including “free” mode. For pick and place applications, the property “robot.payload” can be set by the application program to change the payload.

Also, it is important to set the correct tool X, Y, Z offset distance in mm in the first 3 values of parameter 16051 and tool Yaw, Pitch, and Roll in values 4-6, for the distance of the center of mass of the gripper and payload from the J6 axis of rotation. For example, for a horizontal tool, if the center of a 2kg mass is 150mm from the center of rotation of axis 4 (the wrist), this parameter should be set to 0, 0,150, 0, 90, 0 for the Dynamic Feed Forward calculations to compute the correct feed forward motor torques and achieve optimal performance. For a vertical gripper with the same offset, this parameter should be 0, 0, 150,0, 0, 0. The tool offset length must also be set in the Dynamic Feed Forward parameter 16068 value

8 for the PFDD6 and value 6 for the PFDD4. The tool mass, in kg, must be set in parameter 16067 value 8 for the PFDD6 and value 6 for the PFDD4, in order for the Dynamic Feed Forward to work properly.

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.

See the software documentation about Parameters 16051, 16071, 16067, 16068, and the "*Robot.Tool*" and "*Robot.Payload*" properties for more a more detailed explanation.

These robots have 12 inputs and 8 outputs available at the base connector panel in a 25 pin D-subminiature connector and have 2 digital outputs and up to 3 digital inputs available in the outer link when the pneumatic version is ordered. A belt encoder input is available on the connector panel.

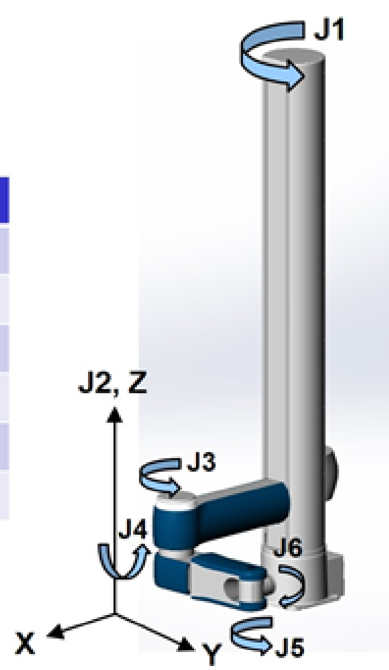
These robots are nominally quoted and shipped with a standard ISO flange, and a single solenoid valve mounted in the outer link for users to add pneumatic or vacuum grippers of their design. Optionally, an additional solenoid can be ordered, or a 23N squeeze, 60mm travel electric gripper can be ordered.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

System Diagram and Coordinate Systems

The major elements of the PFDD Direct Drive robots and the orientation and origin of their World Cartesian coordinate systems are shown in the diagrams below.

PFDD6

Axis	Travel
J1, Theta	+/- 168 degrees
J2, Z	500, 1000, 1420mm
J3, Elbow	+12 to + 348 degrees
J4, Rotate	+100, -220 degrees
J5, Pitch	+/- 110 degrees
J6, Rotate	+/- 295 degrees



The first axis of the robot, J1, rotates the robot column about 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 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. The main PreciseFlex™ controller is located inside the base housing of the robot, and joint controllers are located near the various joint motors, distributed throughout the robot.

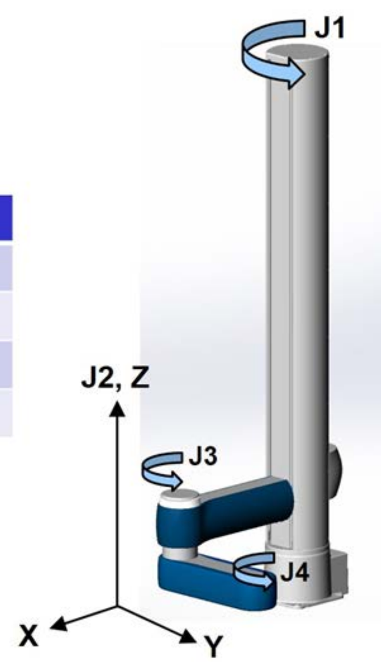
When the Inner Link is centered on its range of motion the J1 axis is at its 0-degree joint angle. A positive change in the axis angle results in a positive rotation about the World Z-axis.

The J3 rotary axis (elbow) rotates the outer link about the J3 axis. A positive change in the axis angle results in a positive rotation about the J3-axis. When the link is centered, it is at its 0-degree 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, and minimizes the radius to the payload, and therefore the kinetic energy of the payload, when moving across a workcell. This helps minimize potential collision forces.

The J4 rotary axis rotates the outer link about its axis. Its travel is asymmetric to allow J5 to be oriented +/- 180 degrees without hitting a J4 hard stop. The J5 pitch axis provides pitch control for the tool. The J6 rotary axis rotates the tool about the tool axis.

PFDD4

Axis	Travel
J1, Theta	+/- 168 degrees
J2, Z	500, 1000, 1420mm
J3, Elbow	+12 to + 348 degrees
J4, Rotate	+240, -240 degrees



For the PFDD4, the J4 axis is at the end of the outer link and is parallel to the J1 axis. A positive change in the J4 axis angle results in a positive rotation about the World Z-axis.

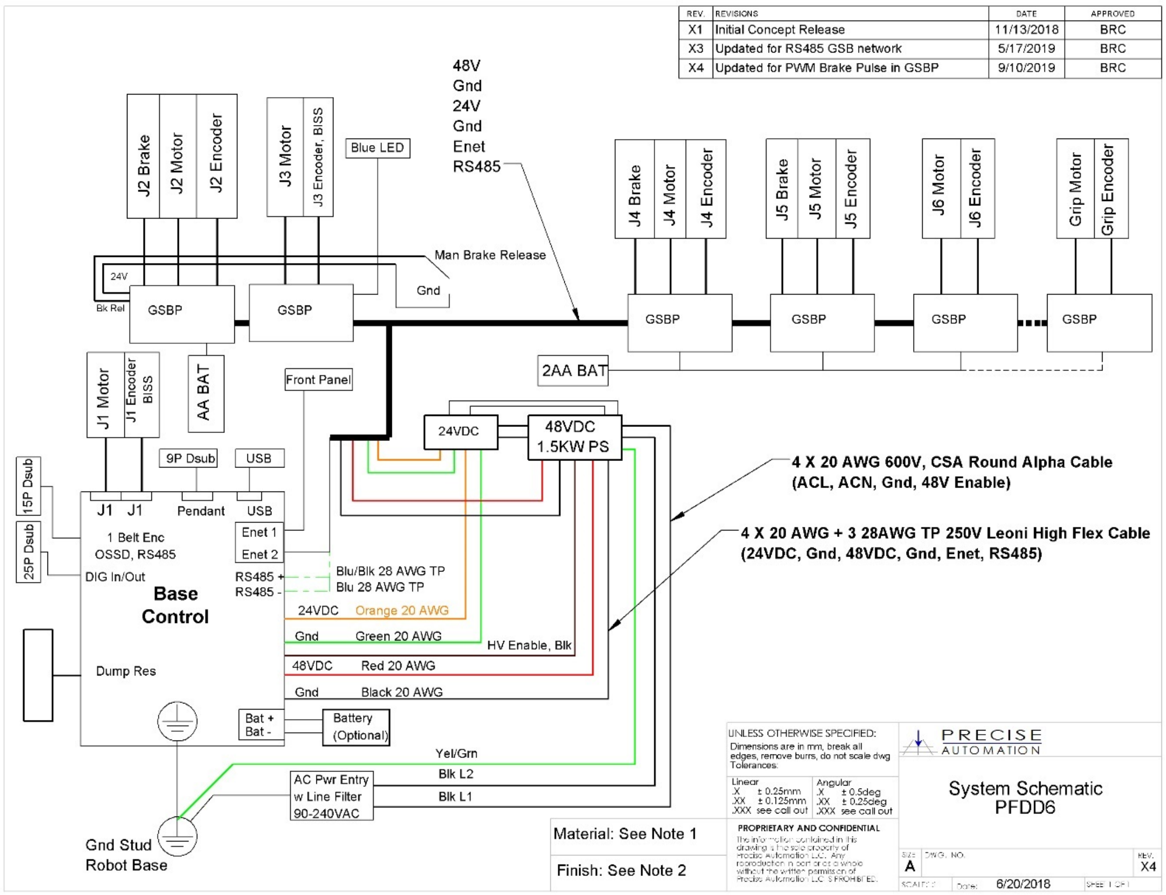
The outer link may include a gripper controller that provides control of the optional electric gripper. It is also possible to order the robot with a pneumatic gripper; in which case the outer link will house a solenoid to control air to the pneumatic gripper. A light bar is mounted at the top of the elbow 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 Diagram

Control System Overview

The PFDD Robots are controlled by a distributed control system (see below). The main control board (PFD0) is located in the base casting behind the connector panel. This board contains various IO functions, the main CPU, RAM and Flash memory, and the motor drive for the J1 motor. The 24VDC and 48VDC power supplies are located on the back of the Z column. A flexible ribbon cable is routed around the robot to provide 24VDC, Gnd, 48VDC, Gnd, Ethernet, and RS485. Ethernet is routed to the outer link and is available for certain gripper applications. A series of smart amplifiers (GSBP) are distributed around the robot and located near each motor to minimize wiring through the robot. These are connected by means of an RS485 network.



Power Supplies and Power Considerations

The PFDD controllers require two DC power supplies, a 24 VDC power supply for the processor and user IO, and a separate 48VDC motor power supply.

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

The PFDD robots power supplies have an input range of 100 to 240 VAC, +/- 10%, 50/60 Hz. Inrush current can be as high as 40 Amps at 240 VAC for short periods of time. The power supplies are protected against voltage surge to 2000 volts. Transient over voltage (< 50 µs) may not exceed 2000 V phase to ground, as per EN61800-31996. The power supplies have over-current protection, and over-voltage protection.

The robot consumes less than 500 Watts during normal operation. With the motor power turned off the controller consumes about 20 Watts. With the motor power on and the Z brake released, the robot consumes about 80 Watts. The PFDD6 running at 60% speed consumes about 150 Watts. These numbers may be useful when mounting this robot on mobile platforms.

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.

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 included in the base controller board and connected to the 48 VDC bus.

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

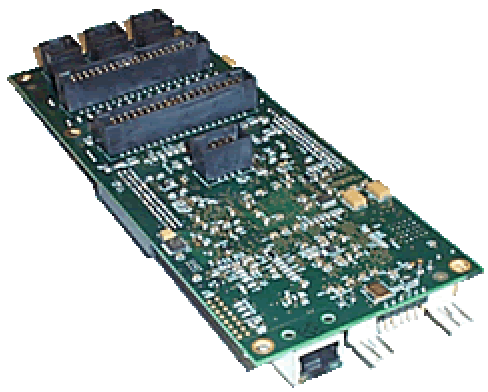
For users that wish to have a hardware E-Stop button, Precise offers an E-Stop Box or a portable Hardware Manual Control Pendant that includes an E-Stop button. The E-Stop box can be plugged into the 9 pin D-Sub connector in the connector panel in the base casting. The E-Stop box completes a circuit from Pin 1 (Estop 1) to Pin 6 (FE Out 1) and from Pin 2 (Estop 2) to Pin 7 (FE Out2) in this connector. If this circuit is not completed it is not possible to enable motor power to the robot. The FE Out signals allow each Estop circuit to be toggled during the CAT3 startup sequence to make sure both circuits are working. If no E-Stop box or Manual Control Pendant is connected, jumpers must be connected between these four 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.

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 PFDD robot and its embedded PreciseFlex™ 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.



Machine Vision Software and Cameras

The PreciseFlex™ 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 PFDD 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 robot 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 (will) carry the CE and CSA marks.

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

Moving Machine Safety

The PFDD 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. It is important that operators wear safety glasses when inside the robot’s operating volume.

In Computer Mode, the robot can move quickly. The PFDD 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.

Mechanical and Software Limit Stops

All joints 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 in the PFDD4 has a slip ring when the electric gripper is installed, allowing +/- 240 degrees rotation. Since the robot has absolute encoders with battery backup, even if the robot is turned off, the encoders keep track of joint position. The joint position can be viewed either on the optional Manual Control Pendant, or in the Virtual Manual Control Pendant in the Web Based Operator Interface. (See Guidance Controller Setup and Operation Quick Start Guide).

Stopping Time and Distance

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

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

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

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

A Hard E-Stop is generated by one of several hardware E-Stop inputs and causes motor power to be disabled. However, there is a parameter that determines a delay between the time the Hard E-Stop signal is asserted and the time the motor power supply relay is opened. This delay is nominally set at 1.0 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 motor power will be disabled within 1ms.

For the PFDD6 robot, the base rotation, elbow, and J6 axes do not have mechanical brakes. For the PFDD4 robot, the base rotation, elbow, and J4 axes do not have mechanical brakes. Therefore, leaving the motor power enabled for 1.0 sec allows the servos to decelerate the robot. The servos are set to decelerate the robot at 0.015G, or 150mm/sec^2. If the robot is moving at a joint speed of 100 degrees/sec, the distance traveled will be about 30 degrees to reach a full stop, and the time will be 0.66sec. These settings provide a smooth deceleration and stop with full payload. If a faster deceleration is desired, contact Precise application engineering to increase the deceleration setting for Estop.

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 J1, J3, and J6 axes on the PFDD6, and the J1, J3, and J4 axes on the PFDD4 do not have 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. Note the J4 and J5 brakes on the PFDD6 are not released by the brake release switch to prevent unexpected sagging of the payload.

Collaborative Robot Safety

General Information

Summary

The PFDD 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 PFDD robots do not exceed the forces (quasi-static) in the standard. For horizontal collisions where the foam covers of the robot strike a rigid surface, the 15066 impulse limits of 280N are not exceeded. For horizontal motions where a rigid gripper can trap an operator against a rigid surface, the maximum horizontal speed should not exceed 600mm/sec when the rigid part of the robot or gripper comes within 100mm of a rigid surface. Vertical motions have a larger effective mass (15-22kg) at the gripper than horizontal motions (3-10kg). *For vertical downward motions where a rigid gripper can trap an operator against a rigid surface, the maximum vertical downward speed should not exceed 150mm/sec when the rigid part of the robot or gripper comes within 100mm of a rigid surface. Horizontal and vertical motions at 100% speed may be programmed as long as an approach point is specified at least 100mm from any rigid surfaces with a final motion at a speed as specified above*. Collision testing has been performed and ~~certified by TUV (pending)~~ and a table of collision speeds and forces is provided at the end of this section.

These robots have extensive safety features as listed in Appendix C of this section, including full dual Estop circuitry and a circuit to turn off the 48V motor power supply in addition to the standard amplifier disable circuitry and meets Performance Level d, CAT3*. (* There is one exception to the CAT3 specification: in the PFDD robots 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 enable this capability.)

All controller failures which might result in an uncontrolled motion have been listed and tested under supervision by TUV(pending). None of these failures can result in an uncontrolled motion.

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 PFDDR workcell is given in Appendix A of this section, where it is shown that a PL of "b" is sufficient for the workcell. UPPDATE with DDR example.

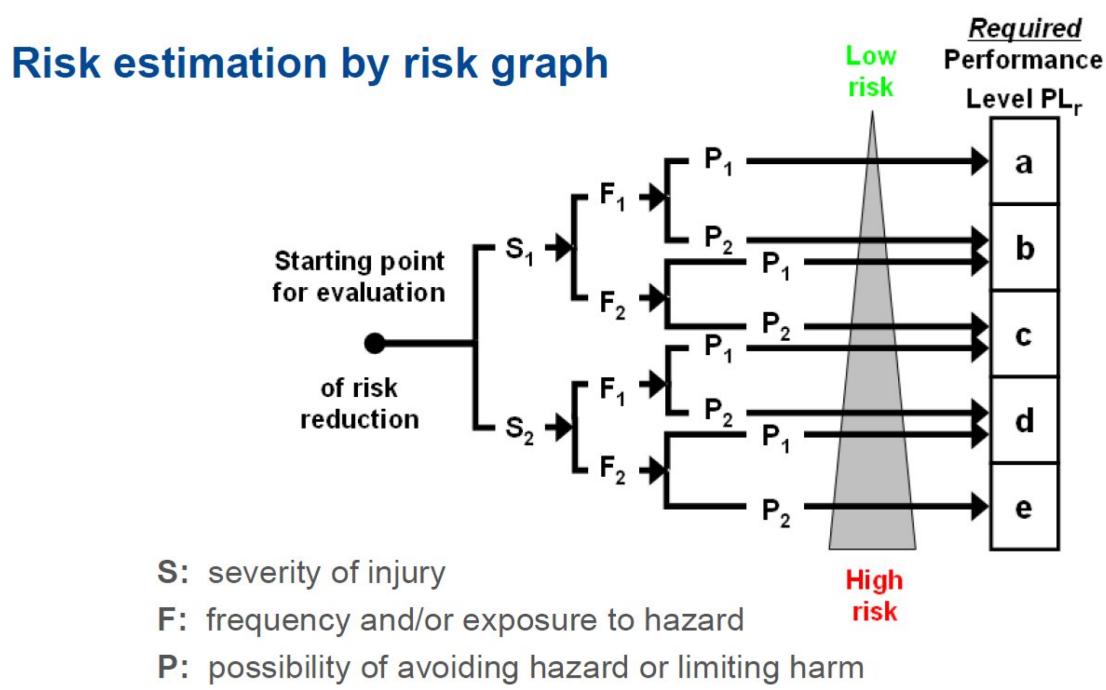


Figure 1

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 B) 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 short term forces (transient forces less than 0.5 seconds) 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 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 workcell 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

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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. **Based on the ISO/TS 15066 standard, Precise has selected 280N for short term (less than 500ms) impact forces against 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 (pending) the forces for the PFDD robots (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. The PFDD robots have Cat 3 safety circuits.

Possible Precise Controller Faults and Controller Testing

Precise controllers are designed so that no single failure can disable the safety features in the controller and cause an uncontrolled motion.

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

1. **Force Limits by Design or Control.** The PFDD robots are medium power robots and have force limits set by inherent design and control. For all axes *except the Z axis*, the maximum forces that can be applied by the motors, multiplied by the transmission are well under 140N as can be seen in the manual control and low speed collision table entries.

2. **Estop circuit for the PFDD Robots.** The PFDD robots have 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. *This Estop circuit is PLd and CAT 3 if a dual circuit Estop button is attached.*

3. **Power failure while the robot is moving.** If AC Power is turned off while the robot is moving, a fail-safe brake on the Z motor and on axes 4 and 5 of the PFDD6 robot are immediately applied to ensure that the robot does not collapse under gravity. Note that for robot axes without brakes, this will result in a controlled deceleration during a one second delay before motor power is disabled in order to achieve a controlled stop.

4. **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. *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*. *TUV has verified this fail-safe operation.*

5. **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.*

6. **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 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. *Because a shorted transistor in the power amp cannot cause uncontrolled motion, this is a fail-safe situation and therefore CAT 3 compliant.* 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.*

7. **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. *This circuit is both PLd and CAT 3 compliant.* 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.*

8. **Position error, force limits and collision detection**. The PFDD robots have a control function that limits the maximum force of any axis. This function is used to limit the crushing force of various axes. 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. In addition to the position error monitor, there is a PID command limit error. If the PID command is saturated at its limit for 200ms, the motor power will be turned off. *This is a CAT 3 compliant function.* *TUV has verified this fail-safe operation.*

9. **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 PFDD Robots

The worst-case crash condition for the PFDD robots is when the Z axis is moving downwards at the 100% speed of 600mm/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.

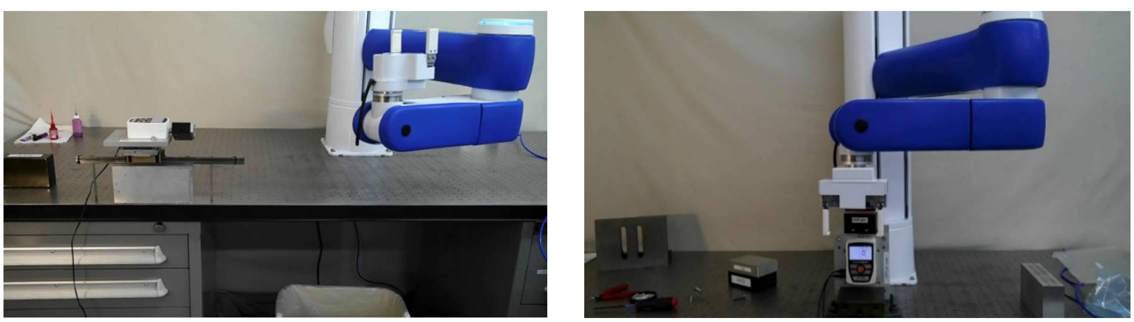


Figure 4: Vertical Rigid Surface and Horizontal Free Space Test Setup

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. For both vertical and horizontal tests, the force gage is fixed for rigid surface testing, and floating on a linear bearing rail for free space collision testing.

Verification of PFDD Collision Force

PFDD6 Test Data
PFdd6 500mm Z
PAC Files PFDD6
190528

Configuration	J1	J2	J3	J4	J5	J6	XYZ
10351	6000	10000	4000	0	0	0	
10352	-6000	-4000	-4000	0	0	0	
Peak current, tcnts	26219	32722	23836	18115	32767	28498	
PID Error (10352) % of peak	23%	12%	17%	100%	100%	100%	
Config Y Straight Line Collision	-31	2	260	3	-90	-8	
100% Joint Speed	120deg/s	600mm/s	360deg/s	360deg/s	200deg/s	360deg/s	
100% Joint Accel	1500	5000	1500	2300	1500	1500	
100% XYZ Speed							600
100% XYZ Accel							5000

Quasi-static Contact Force Limit for Hand > 0.5 sec, N	140
Transient Contact Force for Hand, < 0.5 Sec	280

PFDD6 Collisions at Wrist Foam

Speed	Manual Control Rigid			Free Space Straight Line, 5.4kg				Free Space Joint Mode, 5.4kg, J3 90 deg				Rigid Surface Joint Mode, 5.4kg, J3 90 deg				Rigid Surface Straight Line 5.4kg, J3 45 to 90			
	X (J3)	Y (J1)	-Z	X	Y	-Z*	mm/sec	J1	mm/sec	J3	mm/sec	J1	mm/sec	J3	mm/sec	X	Y	-Z	mm/sec
100%	34	50	105	52	44	118	600	182	1151	98	2198				2198	130	168		600
80%	31	50	103	42	35	94	480	130	921	85	1758				1758	91	128		480
60%	26	50	94	32	26	81	360	84	691	60	1319	316	691	237	1319	82	96	510	360
40%	26	46	81	22	18	44	240	50	461	33	879	176	461	159	879	85	82	240	240
20%	26	39	71	6	5	32	120	24	230	17	440	69	230	83	440	81	81	141	120
10%	22	37	66	5	5	16	60	13	115	4	220	60	115	42	220	74	79	105	60
Speed								Free Space Joint Mode, 1.4kg, J3 90 deg				Rigid Surface Joint Mode, 1.4kg, J3 90 deg				Rigid Surface Straight Line 1.4kg, J3 45 to 90			
				2kg gage mass		*4kg gage mass		J1	mm/sec	J3	mm/sec	J1	mm/sec	J3	mm/sec	X	Y	-Z	mm/sec
100%								195	1151	98	2198				2198	108	147		600
80%								129	921	74	1758				1758	79	113		480
60%								79	691	57	1319	282	691	219	1319	86	89	438	360
40%								21	461	39	879	153	461	133	879	85	81	214	240
20%								6	230	20	440	63	230	65	440	80	77	117	120
10%								5	115	4	220	62	115	22	220	75	74	77	60

Robot Workcell Design

Introduction. The PFDD robots are always configured as a "Collaborative Robot". They are designed for applications with a payload of 6-8kg depending on the model. High speed impacts for the robots, 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, for example 150mm/sec or Speed 25%, which will not create excessive force in the event of a trapped operator.

The Collision Force Table on the previous page indicates under what speed, payload, and collision conditions the collision force may exceed the recommended ISO force limits. From the table it can be seen that collisions in free space, even with a 5.4kg payload at 100% speed should not injure an operator as long as a safe end effector is attached to the robot. However, when the robot approaches within 100mm of a rigid surface, an approach point should be taught, and the robot should be slowed down to a speed indicated by the table to avoid trapping an operator against a rigid surface at high speed.

Workcell Design Recommendations for the PFDD robots

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 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 PFDD robots are designed so that the outer link or inner link of the robot cannot move down and touch the mounting surface, thus trapping an operator's appendage. The workcell designer will be programming the robot to move workpieces from one location to a second location and back again. When moving in free space the robot may make motions at higher speeds. When approaching rigid surfaces, the operator should slow down the robot as indicated in the collision tables to avoid any possibility of injury.

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

Appendix A: Example Performance Level Evaluation for PFDDR, Update for PFDD example

Example Workcell description: A PFDD4 moves 100-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.

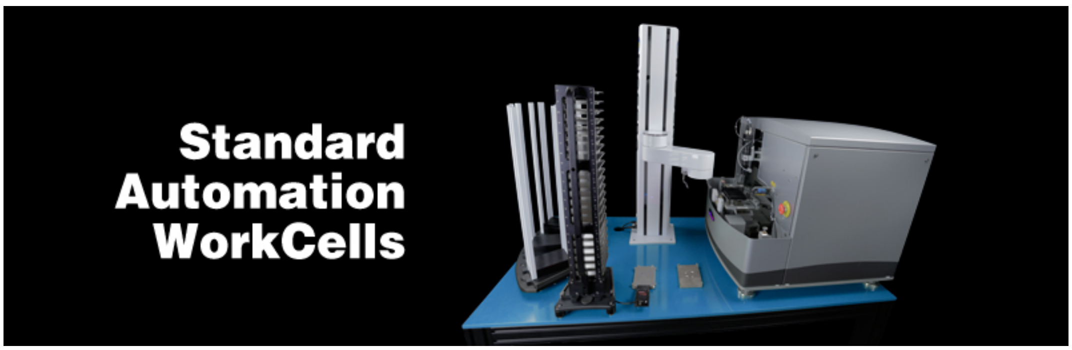


Figure 9: Example PF400 Workcell: Courtesy of Biosero

Normal Operator Interaction with robot:

Teaching locations in workcell by hand guiding or teach pendant. Maximum robot forces under manual control from PFDDR Table 1 are 105N.

Pausing robot and removing racks from workcell with 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 PFDDR Table 1 is 182N, which is below free space collision for 500ms maximum of 280N.

Untrained operator reaches into workcell while robot is moving into instrument tray and hand is trapped between robot and instrument tray. From PFDDR Table 1 max trapping force in downwards Z direction at 60mm/sec (10% of max speed of 600mm/sec) is 77N.

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: 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/cm^2	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 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*)

Table A2, Continued

Table A.2 *(continued)*

Body region	Specific body area		Quasi-static contact: Maximum permissible pressure [a] p_s N/cm²	Quasi-static contact: Maximum permissible force [b] N	Transient contact: Maximum permissible pressure multiplier [c] P_T	Transient contact: Maximum permissible force multiplier [c] F_T
Hands and fingers	17	Forefinger pad D	300	140	2	2
	18	Forefinger pad ND	270		2	
	19	Forefinger end joint D	280		2	
	20	Forefinger end joint ND	220		2	
	21	Thenar eminence	200		2	
	22	Palm D	260		2	
	23	Palm ND	260		2	
	24	Back of the hand D	200		2	
	25	Back of the hand ND	190		2	
Thighs and knees	26	Thigh muscle	250	220	2	2
	27	Kneecap	220		2	
Lower legs	28	Middle of shin	220	130	2	2
	29	Calf muscle	210		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].

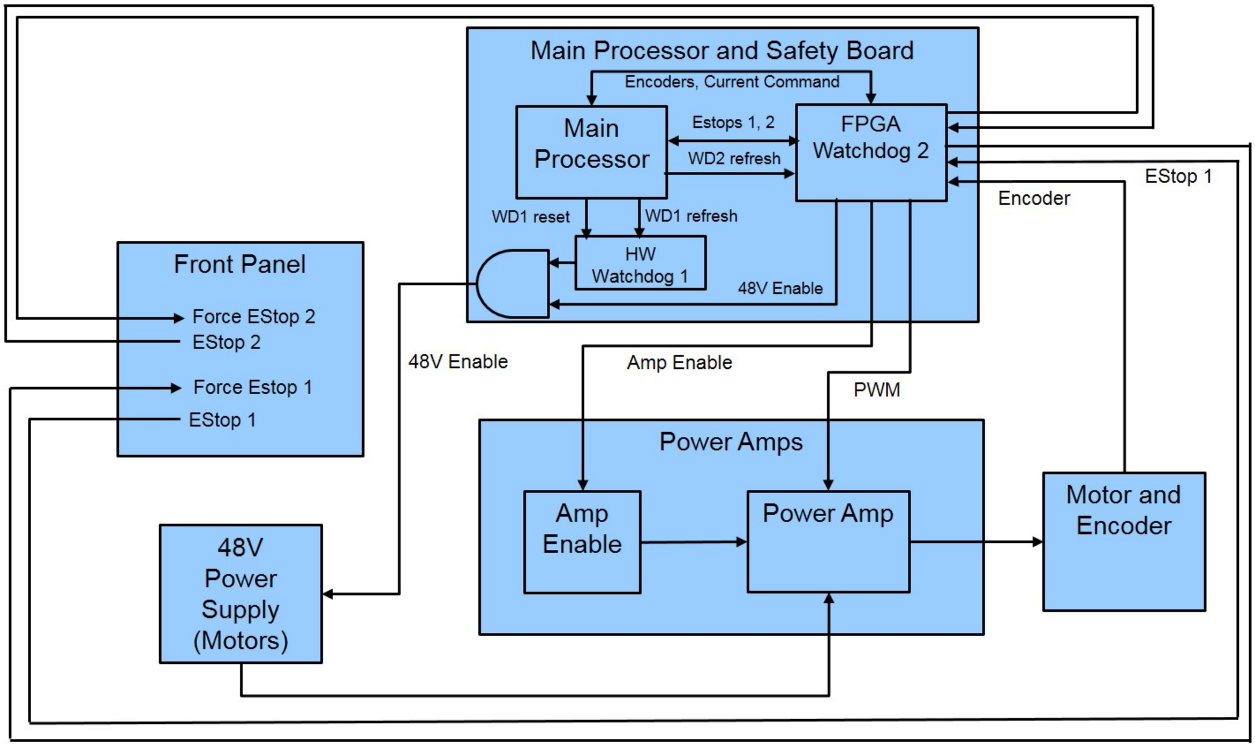
[b] The values for maximum permissible force have been derived from a study carried out by an independent organization (see Reference [6]), referring to 188 sources. These values refer only to the body regions, not to the more specific areas. The maximum permissible force is based on the lowest energy 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*)

Appendix C: Safety Circuits for PFDD Robots

14-Jun-19	PFDD Robots								
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 turn5 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



PFDDR Safety Circuits

Installation Information

Environmental Specifications

The PFDD robots must be installed in a non-condensing environment. Tape seals for the vertical column are an optional order item for environments where fluid or particles may splash against the robot. For applications where the connector panel in the base may be exposed to conductive particles or fluid, it is recommended a panel cover splash hood be added to protect the connectors. With tape seals and a connector hood the robot is rated at IP52. Without these features the robot is rated at IP11. This robot is not intended for use in a washdown or heavy spray environment. Please see the Environmental Specifications in Appendix B for specific environmental limits.

Facilities Connections

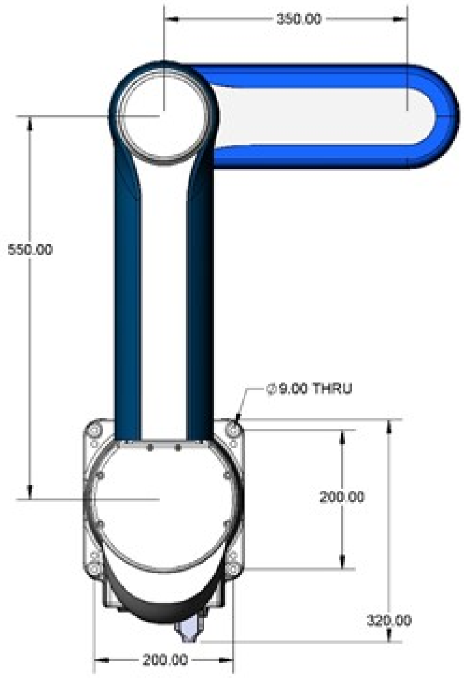
The Facilities Panel at the base of the robot (and optional linear axis end cap) includes:

- System AC input power receptacle 90 to 265VAC
- Lighted AC on/off power switch
- Connectors for controller input and output signals
- Two air fittings for 1/8in OD air hoses 70 psi max

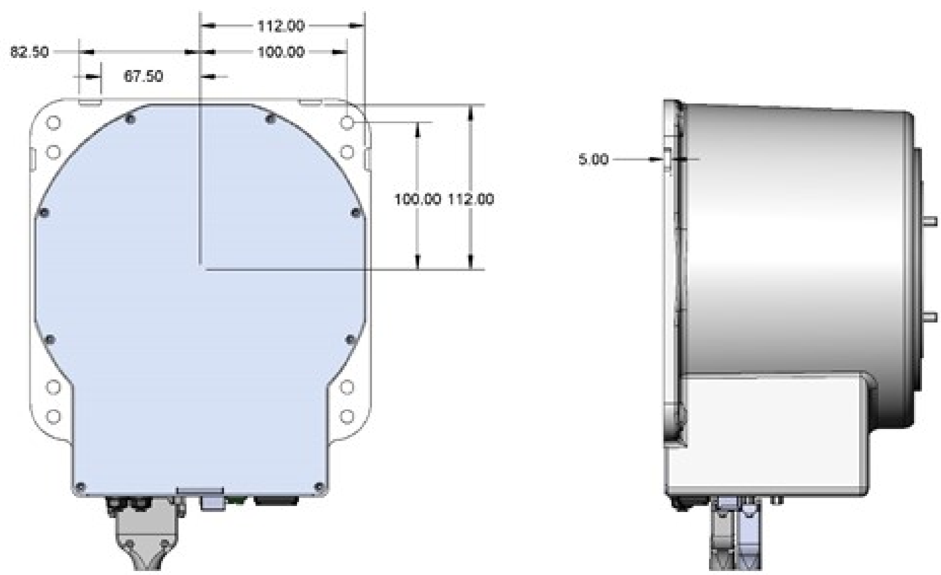
Item	Name	Description
1	9 Pin D Sub Connector	RS-232 for Pendant, 24 VDC, Dual E-Stops, Gnd, Can be used for optional teach pendant
2	25 Pin D Sub Connector	DIO, 12 inputs, 8 outputs
3	15 PIN D Sub Connector	RS-485, 48 VDC, Gnd, Belt Encoder, Cell Interlock Signals, RS-232 COM 1
4	Ethernet Connector	For Ethernet to Computer Cable
5	Power Switch	Lighted Power Switch
6	Power Entry Module	For IEC plug with Filter
7	2 Push Type Air Fittings	For 1/8in OD air hoses, to outer link

System Dimensions

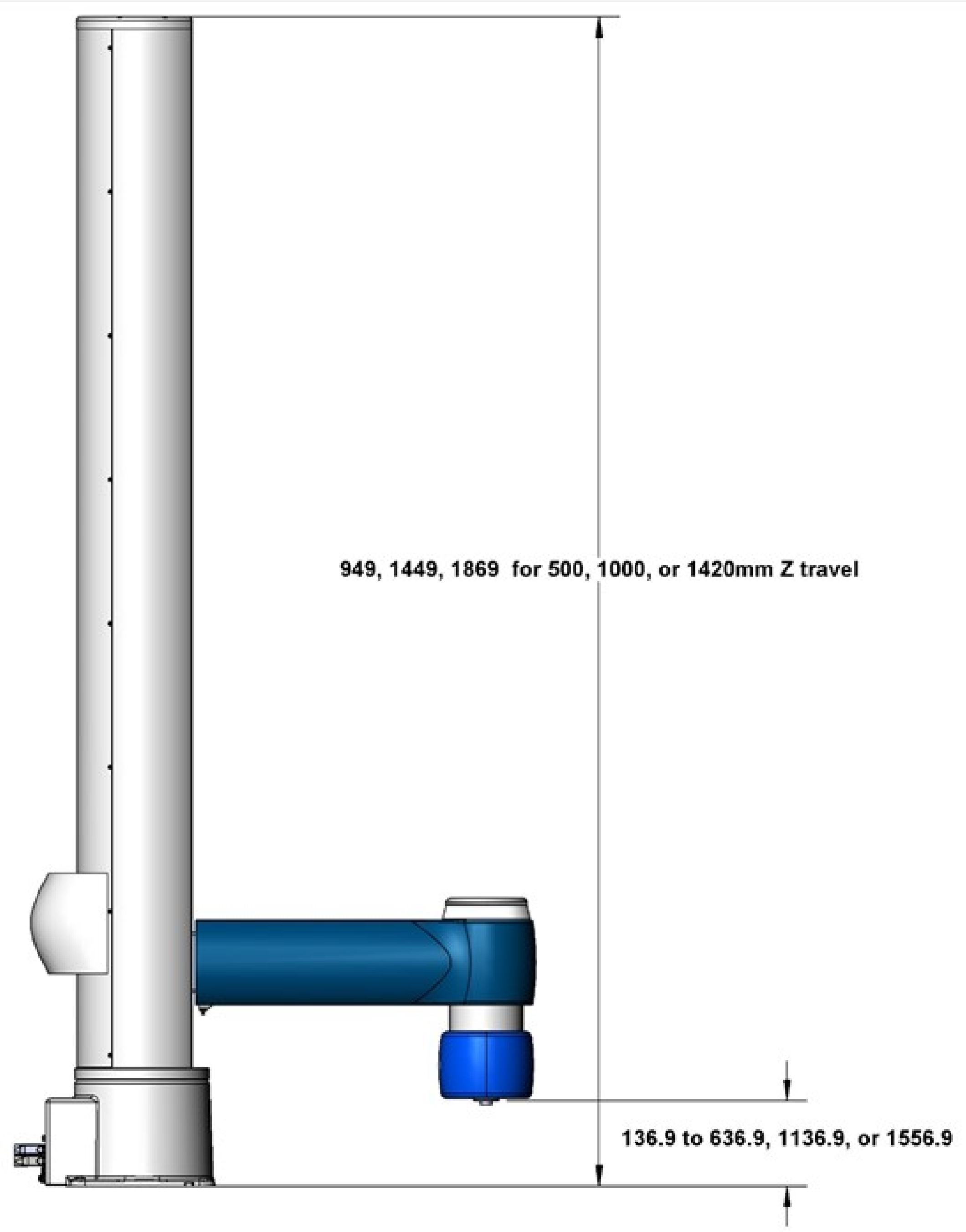
All dimensions are in millimeters.



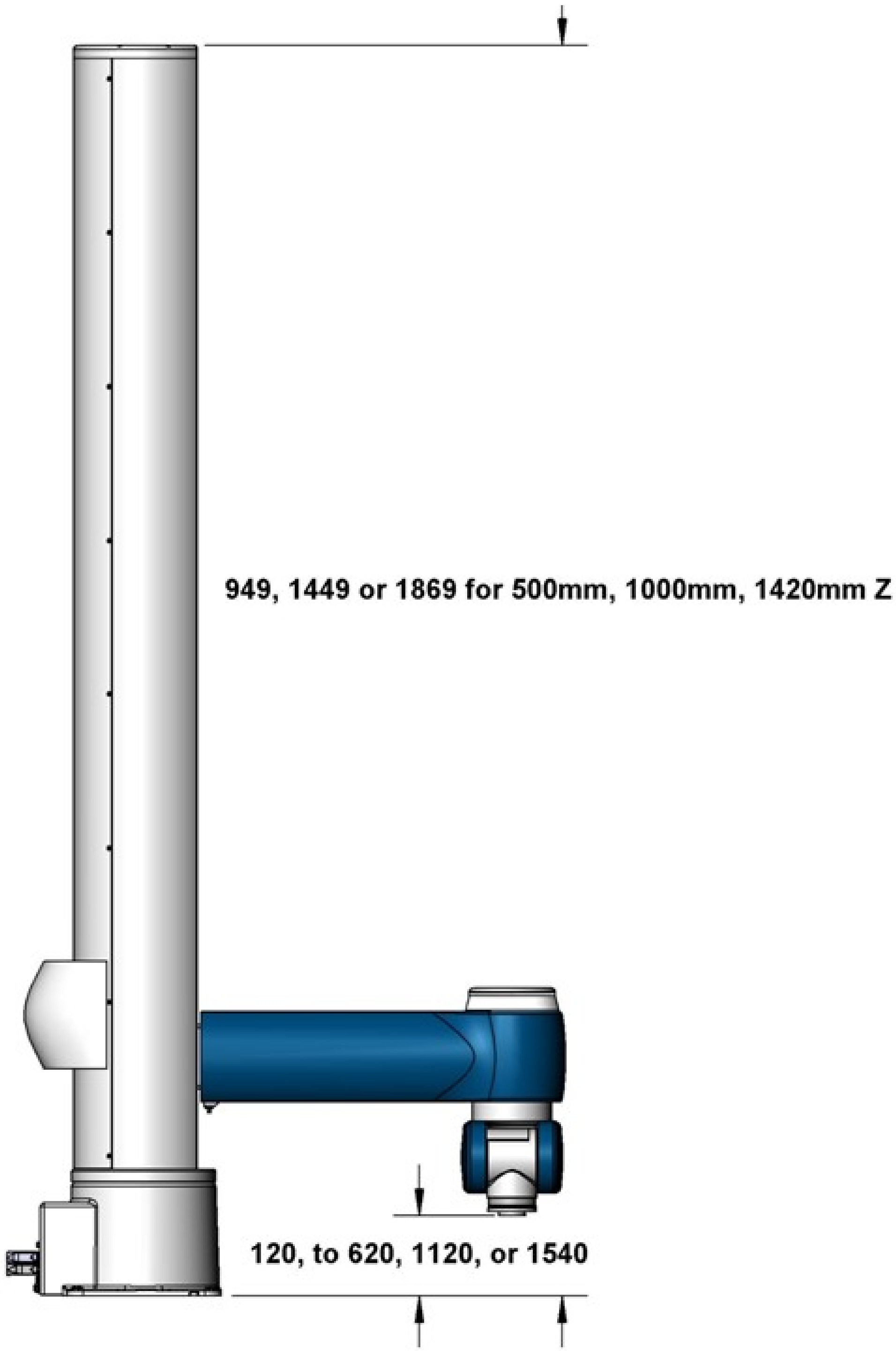
Mounting Dimensions for PFDD Robots,



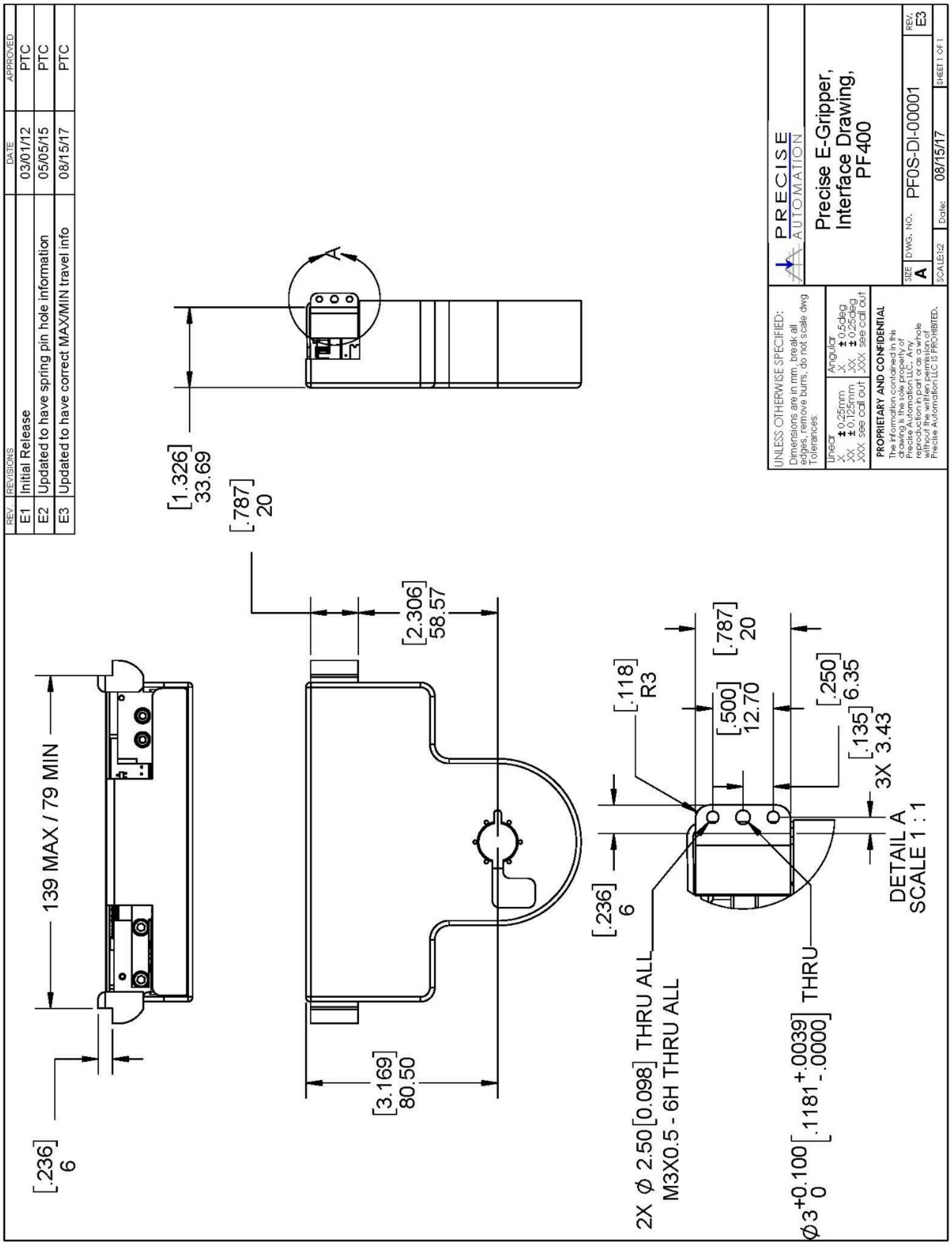
Base Alignment Notches

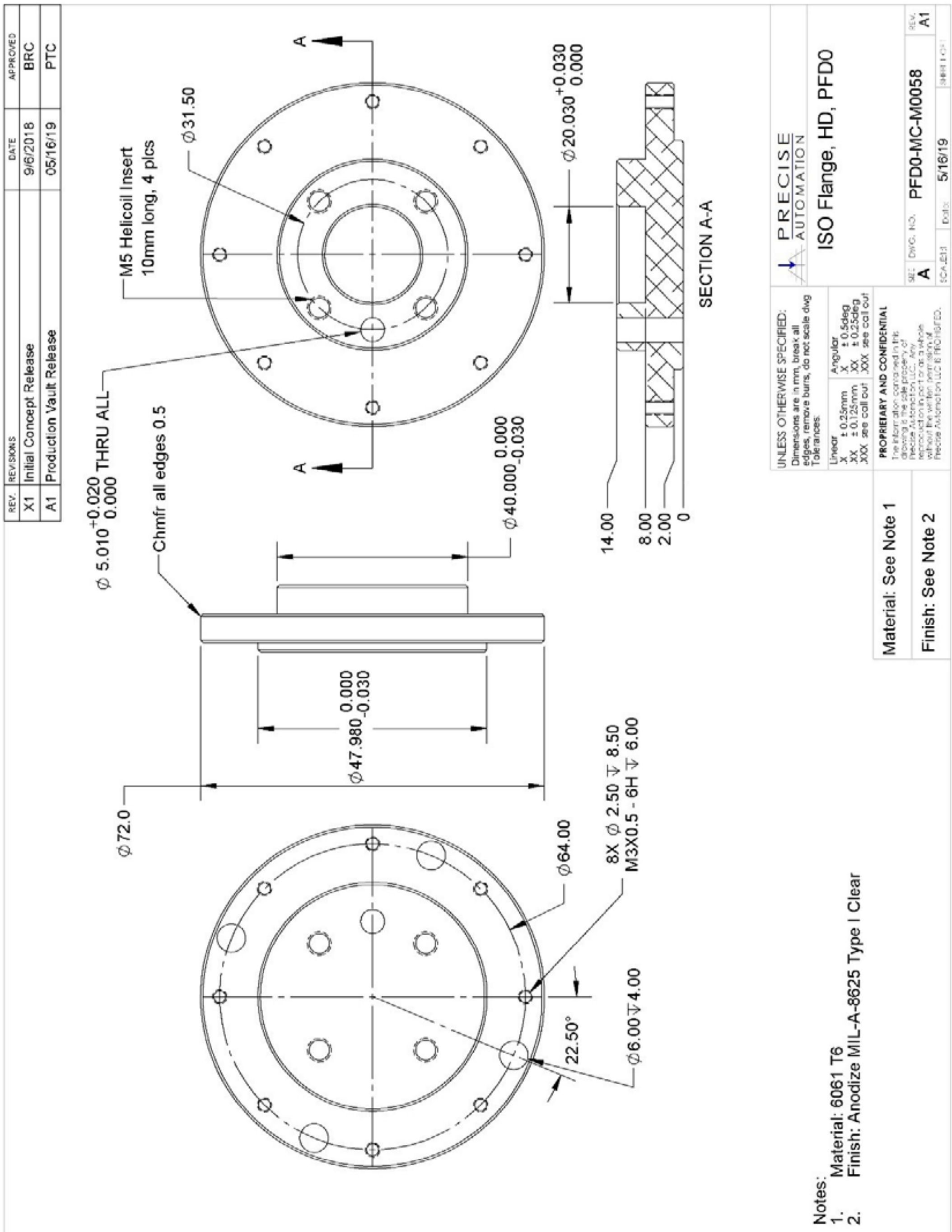


Gripper Flange Mount Height PFDD4



Gripper Flange Mount Height PFDD6


REV
REVISIONS
DATE
APPROVED
E1
Initial Release
03/01/12
PTC
E2
Updated to have spring pin hole information
05/05/15
PTC
E3
Updated to have correct MAX/MIN travel info
08/15/17
PTC
139 MAX / 79 MIN
[.236] 6
[3.169] 80.50
[2.306] 58.57
[.787] 20
[1.326] 33.69
[.118] R3
[.500] 12.70
[.250] 6.35
3X [.135] 3.43
DETAIL A
SCALE 1 : 1
2X Ø 2.50 [0.098] THRU ALL
M3X0.5 - 6H THRU ALL
THRU
A
UNLESS OTHERWISE SPECIFIED:
PROPRIETARY AND CONFIDENTIAL
PRECISE
AUTOMATION
Precise E-Gripper,
Interface Drawing,
PF400
SIZE
A
DWG. NO.
PF0S-DI-00001
REV.
E3
SCALE:1:2
Date:
08/15/17
SHEET 1 OF 1



ISO Gripper Flange

Mounting Instructions

PFDD robots must be attached to a rigid surface that can withstand lateral forces of 400 Newtons without moving or vibrating. The robot base has an integrated bolting pattern to accommodate 4 M8 SHCS mounting screws located as shown above.

Tool Mounting

PFDD Robots can be supplied with a light payload gripper with 23N of squeeze force for large workcells in life sciences. Or a third-party electric gripper or pneumatic gripper may be attached by the end user. The standard robot includes 2 1/8in OD pneumatic lines, however if pneumatic tooling is desired, the robot must be ordered with one or two pneumatic valves installed. The outer link has a flange for users to attach grippers or tooling.

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 three extra inputs and two extra outputs available for users. For 4-axis robots a slip ring is installed which routes 18 signals thru the J4 pulley, or optionally pneumatic lines and hi-flex signal wires can be routed thru the pulley. However, it should be noted that all the wires in the 18-conductor slip ring are consumed by the electric gripper, although some of these wires can be configured to route serial or Ethernet signals, depending on the slip ring model. For the 6-axis version wiring must be routed outside the robot wrist. For robots without the electric gripper, one or two solenoid valves can be driven from either the J4 or J6 motor controller, which also provides 3 24V digital inputs.

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 main controller, the cover on the base must be removed by removing 6 M3 X 6 FHCS from the base casting.

Other joint axis controllers are located in the following locations. Z axis and power supplies are located on the Z column under the Z column rear cover. The J3 controller is located on the elbow under the light tower cover. For the PFDD4 the J4 controller and servo gripper controller or solenoids are located in the top of the outer link, under the foam cover and sheet metal cover. For the PFDD6 the J4 controller is located inside the bottom of the J4 housing, which is covered by the J4 foam cover. The J5 and J6 controllers are located inside the J5 housing. Details on accessing these controllers can be found in the service section.

Power Requirements

The PFDD robots power supplies have an input range of 100 to 240 VAC, +/- 10%, 50/60 Hz. 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 700 watts RMS. Typical operating power is 150 to 300 watts RMS.

Hardware Reference

System Schematics

System Diagram and Power Supplies

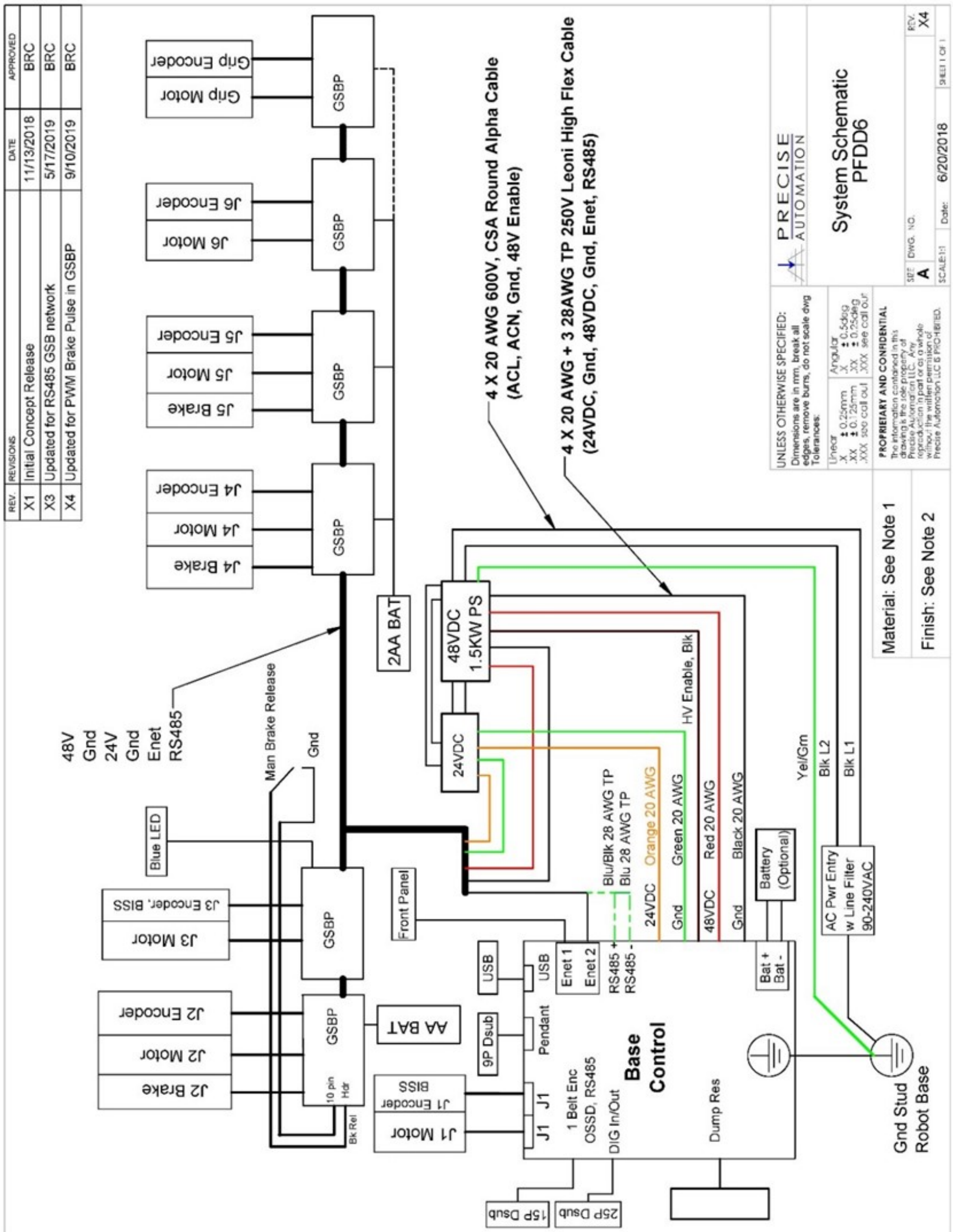
The robot has a 24VDC and 48VDC power supply located in the Z column. The power supplies have both over-current and over-voltage protection and are CSA, UL, and CE certified. The robot controller and electric gripper are powered by the 24VDC supply. The main robot motors are powered by the 48VDC supply. The 48VDC supply is protected against over voltage bus pump up by an energy dump circuit, which connects a 75-Watt dump resistor located in the base housing 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 the controllers through a ribbon cable which also contains 3 twisted pairs for RS485 (1 pair) and 100 BaseT Ethernet (2 pairs).

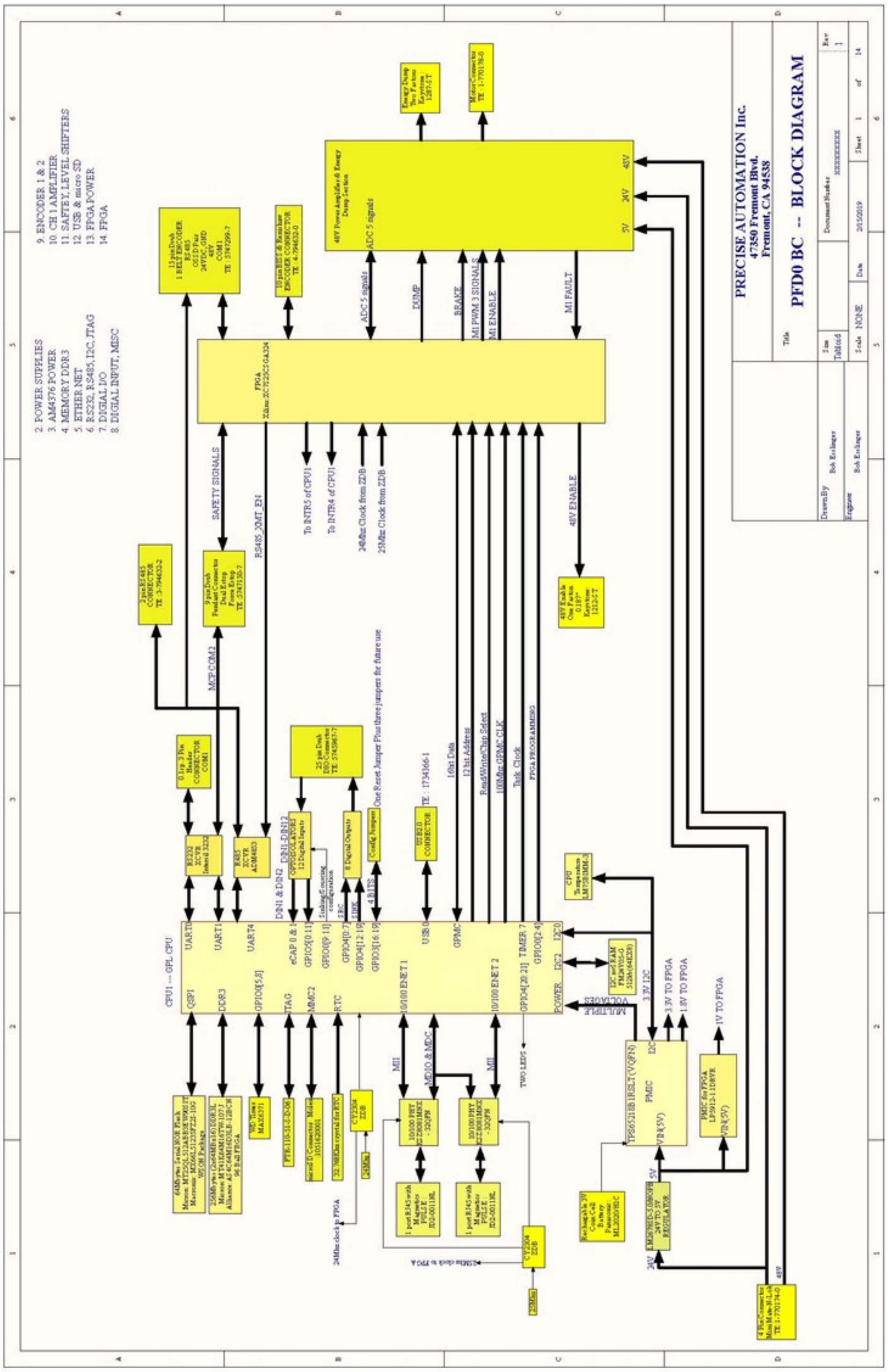
Twelve digital input and eight digital output signals from the main robot controller are available in the 25pin Dsub on the connector panel in the base. The 12 digital output signals can be individually configured as either sourcing or sinking by software settings in the Web Interface. The 8 digital input signals can be configured as either sourcing or sinking individually and the 12 digital inputs can be configured as sourcing or sinking in blocks of 4 by software settings in the Web Interface. See section on IO.

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 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. The robot is shipped with a jumper that completes the dual ESTOP circuits.

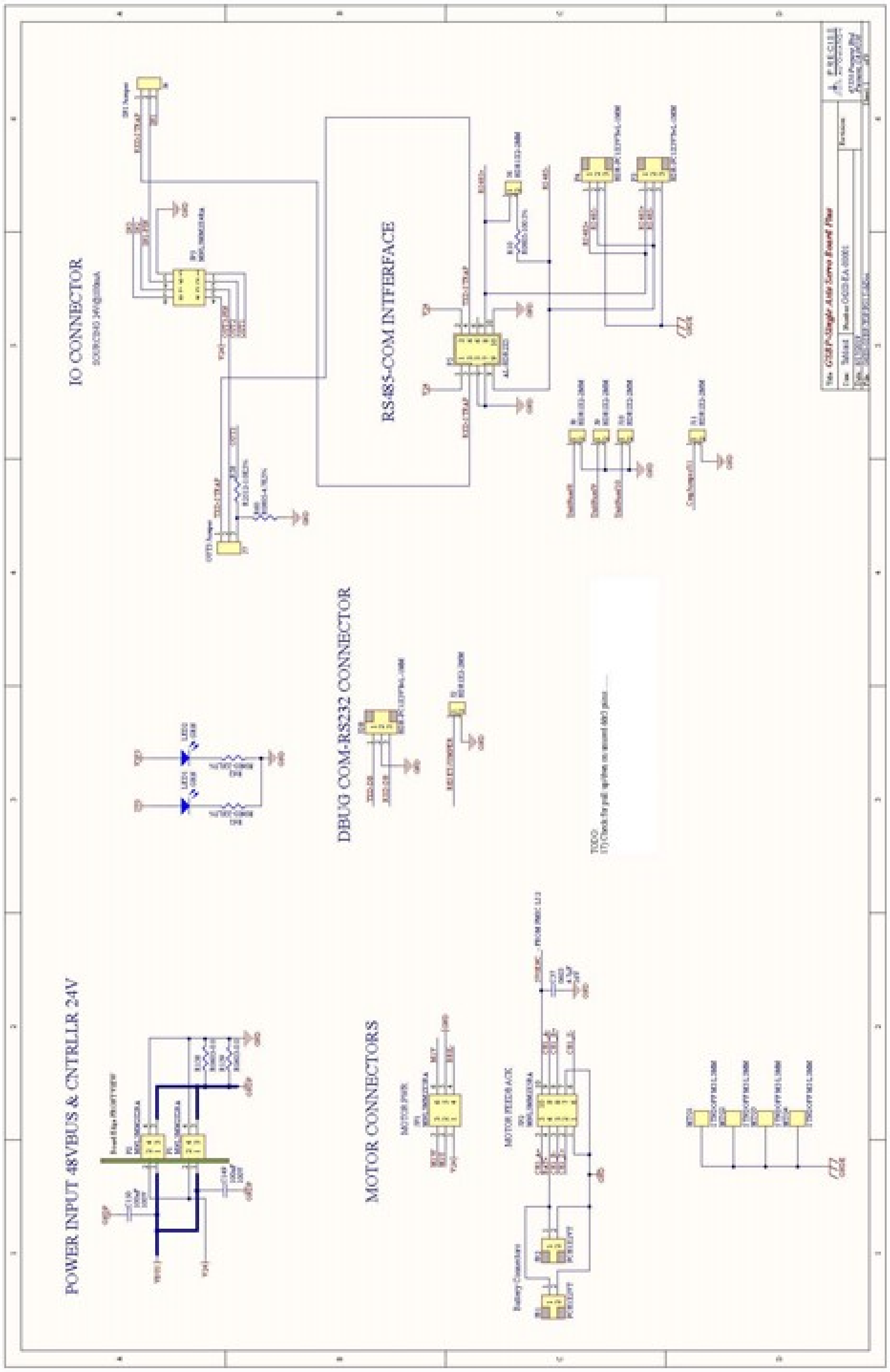
The cable from the brake release button under the Shoulder plugs into the amplifier board for the Z axis motor on the back of the Z column. This button provides a ground return from the Z column brake to ground bypassing the transistor that performs this function under computer power so that the brake can be released manually without motor power being enabled, as long as 24VDC is turned on. Care should be taken to support the links of the robot when this button is pushed as the links weigh 14kg and will drop under gravity when this button is pushed.



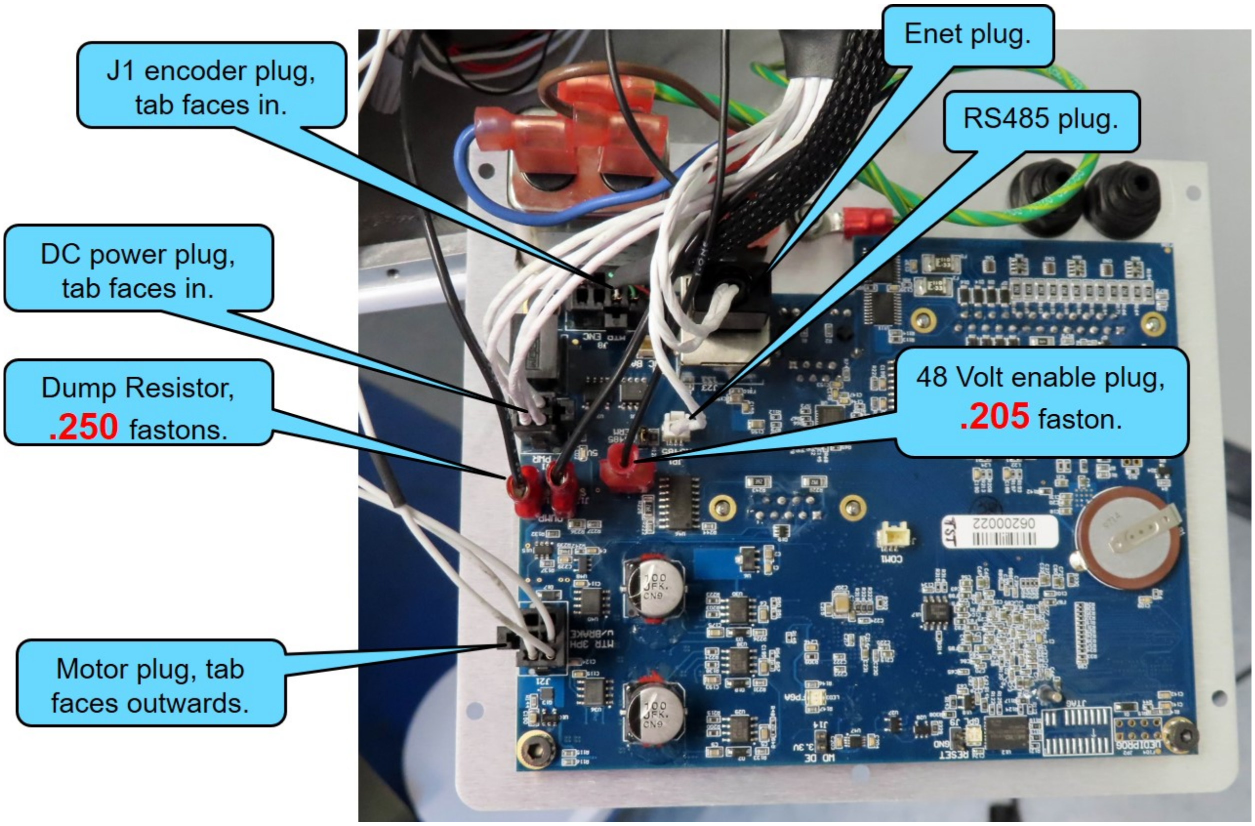
Schematic: System Overview



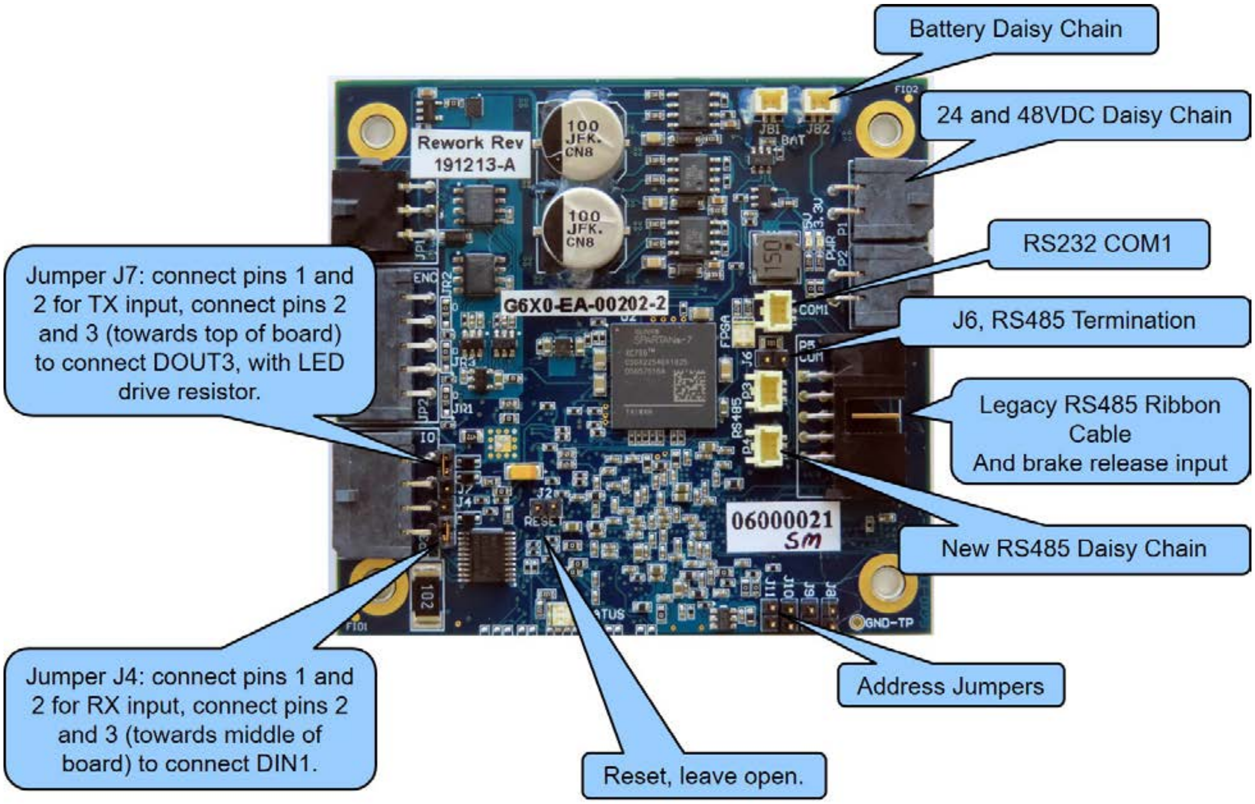
Schematic: PFD0 Base Controller Block Diagram



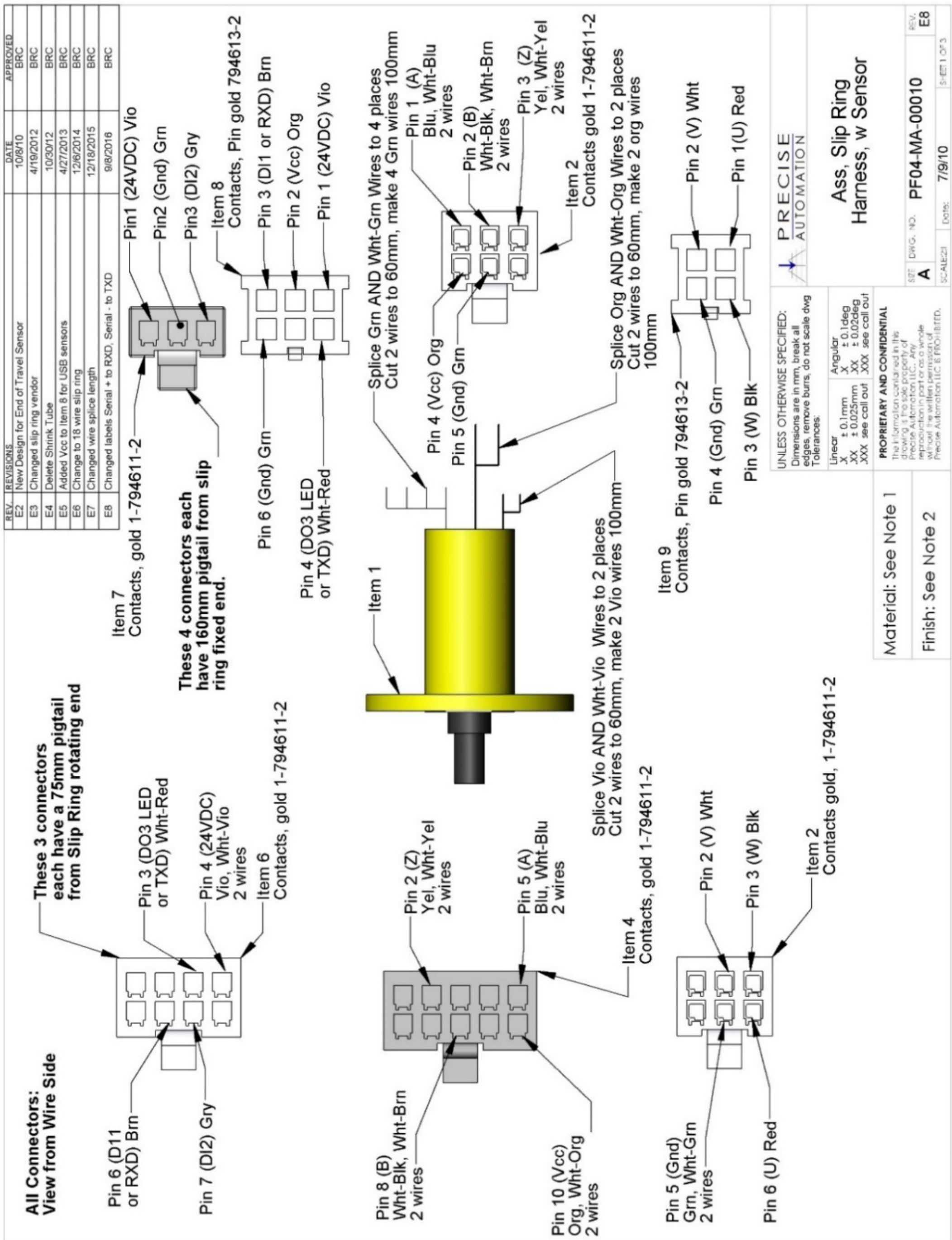
Schematic: Joint Axis Controller Connectors



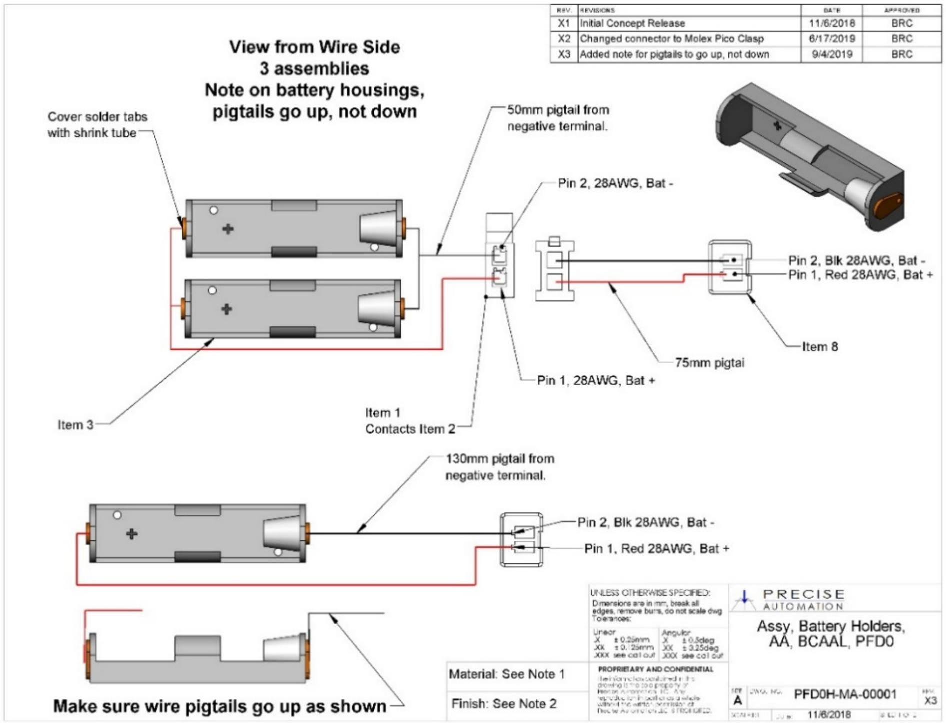
Base Controller Connectors

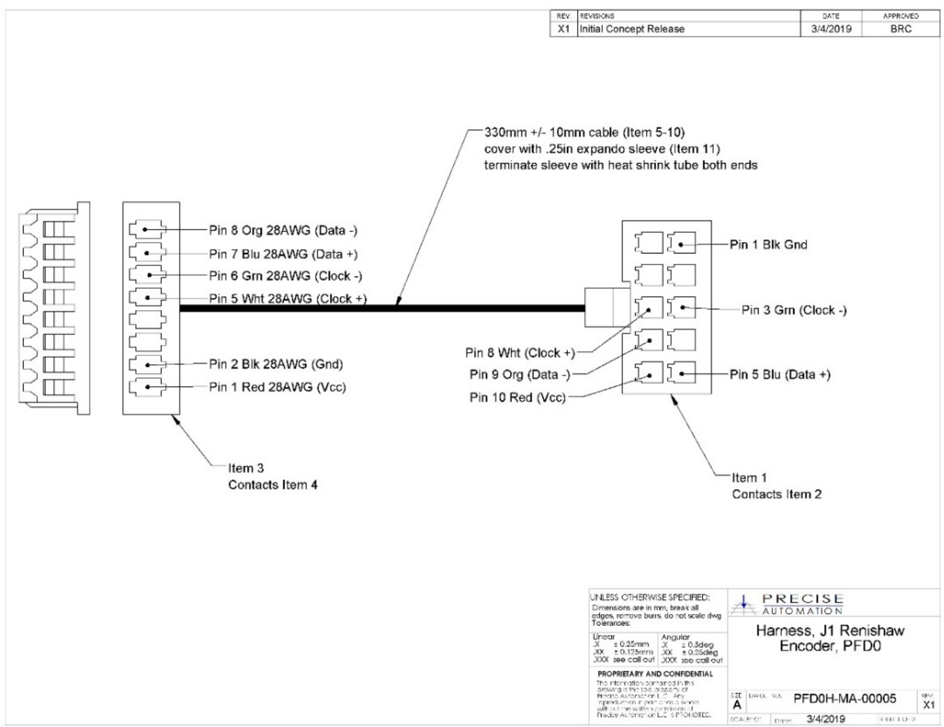


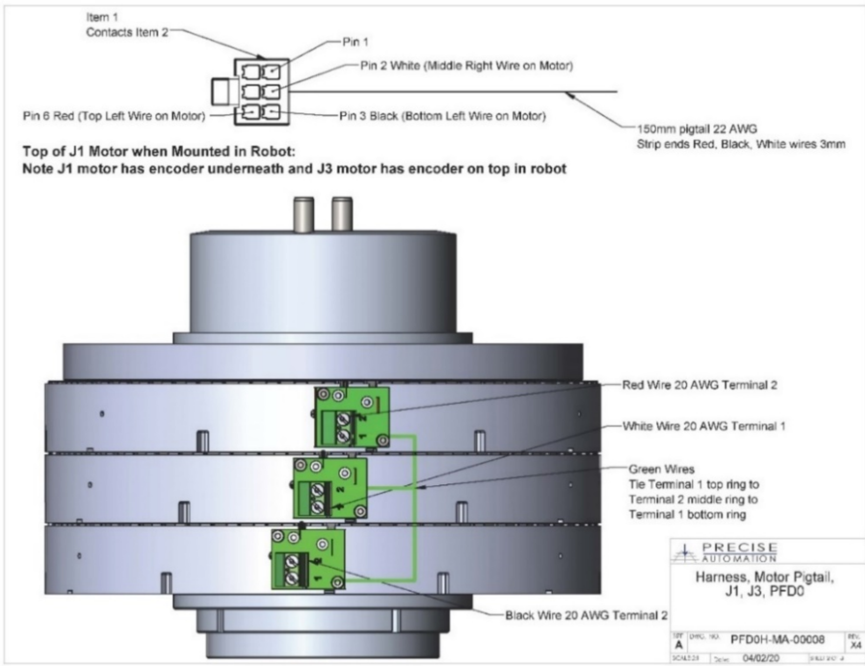
Gripper and Joint Axis Controller Connectors

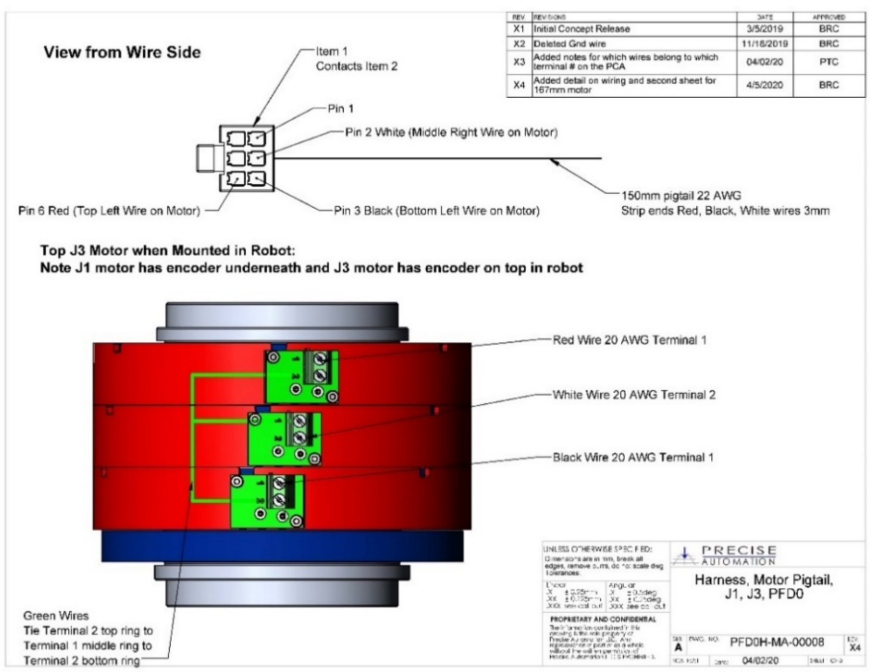


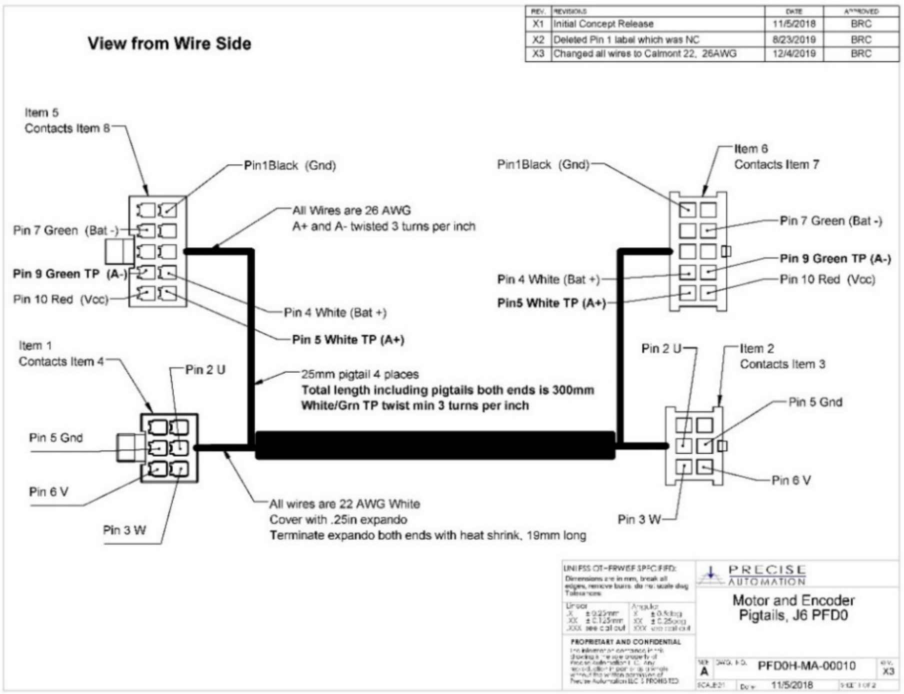
Schematic: Slip Ring for 23N Gripper

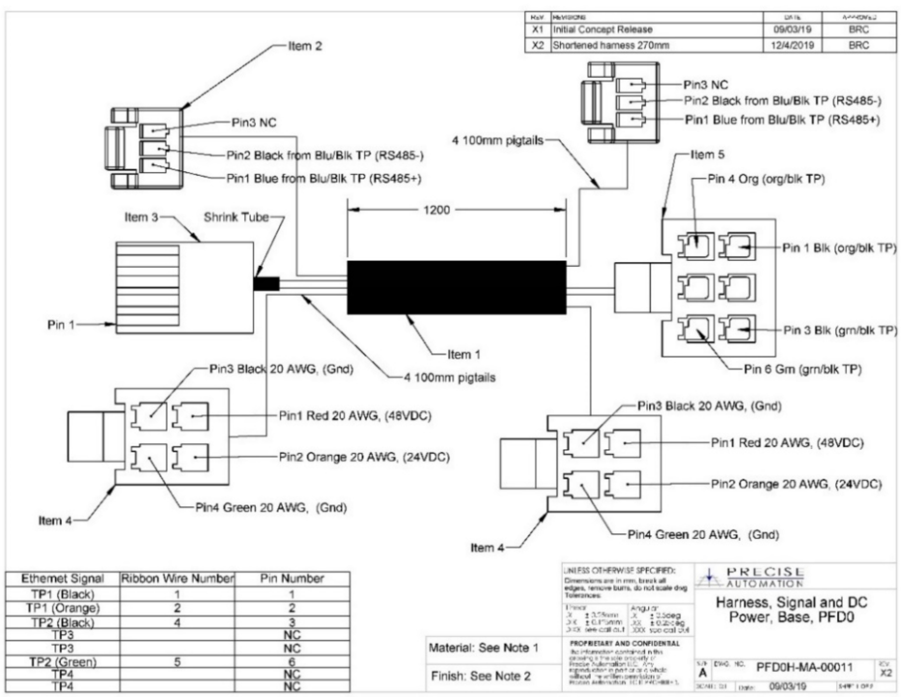

REV. REVISIONS DATE APPROVED
X1 Initial Concept Release 11/6/2018 BRC
X2 Changed connector to Molex Pico Clasp 6/17/2019 BRC
X3 Added note for pigtails to go up, not down 9/4/2019 BRC
View from Wire Side
3 assemblies
Note on battery housings,
pigtails go up, not down
Cover solder tabs with shrink tube
50mm pigtail from negative terminal.
Pin 2, 28AWG, Bat -
Pin 2, Blk 28AWG, Bat -
Pin 1, Red 28AWG, Bat +
Item 8
75mm pigtai
Pin 1, 28AWG, Bat +
Item 3
Item 1
Contacts Item 2
130mm pigtail from negative terminal.
Pin 2, Blk 28AWG, Bat -
Pin 1, Red 28AWG, Bat +
Make sure wire pigtails go up as shown
Material: See Note 1
Finish: See Note 2
UNLESS OTHERWISE SPECIFIED:
PROPRIETARY AND CONFIDENTIAL
PRECISE AUTOMATION
Assy, Battery Holders, AA, BCAAL, PFD0
A
PFD0H-MA-00001
X3
11/6/2018


REV. REVISIONS DATE APPROVED
X1 Initial Concept Release 3/4/2019 BRC
330mm +/- 10mm cable (Item 5-10)
cover with .25in expando sleeve (Item 11)
terminate sleeve with heat shrink tube both ends
Pin 8 Org 28AWG (Data -)
Pin 7 Blu 28AWG (Data +)
Pin 6 Grn 28AWG (Clock -)
Pin 5 Wht 28AWG (Clock +)
Pin 2 Blk 28AWG (Gnd)
Pin 1 Red 28AWG (Vcc)
Pin 1 Blk Gnd
Pin 3 Grn (Clock -)
Pin 8 Wht (Clock +)
Pin 9 Org (Data -)
Pin 10 Red (Vcc)
Pin 5 Blu (Data +)
Item 3
Contacts Item 4
Item 1
Contacts Item 2
UNLESS OTHERWISE SPECIFIED:
PROPRIETARY AND CONFIDENTIAL
PRECISE AUTOMATION
Harness, J1 Renishaw Encoder, PFD0
A
PFD0H-MA-00005
X1
3/4/2019

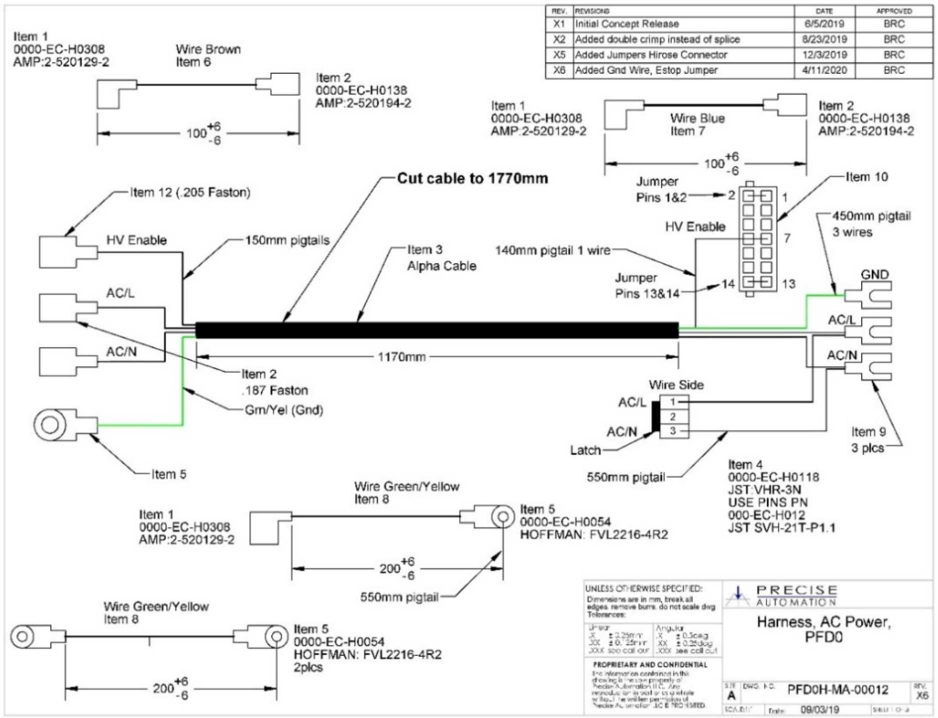

Item 1
Contacts Item 2
Pin 1
Pin 2 White (Middle Right Wire on Motor)
Pin 6 Red (Top Left Wire on Motor)
Pin 3 Black (Bottom Left Wire on Motor)
150mm pigtail 22 AWG
Strip ends Red, Black, White wires 3mm
Top of J1 Motor when Mounted in Robot:
Note J1 motor has encoder underneath and J3 motor has encoder on top in robot
Red Wire 20 AWG Terminal 2
White Wire 20 AWG Terminal 1
Green Wires
Tie Terminal 1 top ring to
Terminal 2 middle ring to
Terminal 1 bottom ring
Black Wire 20 AWG Terminal 2
PRECISE
AUTOMATION
Harness, Motor Pigtail,
J1, J3, PFD0
A
PFD0H-MA-00008
X4
04/02/20

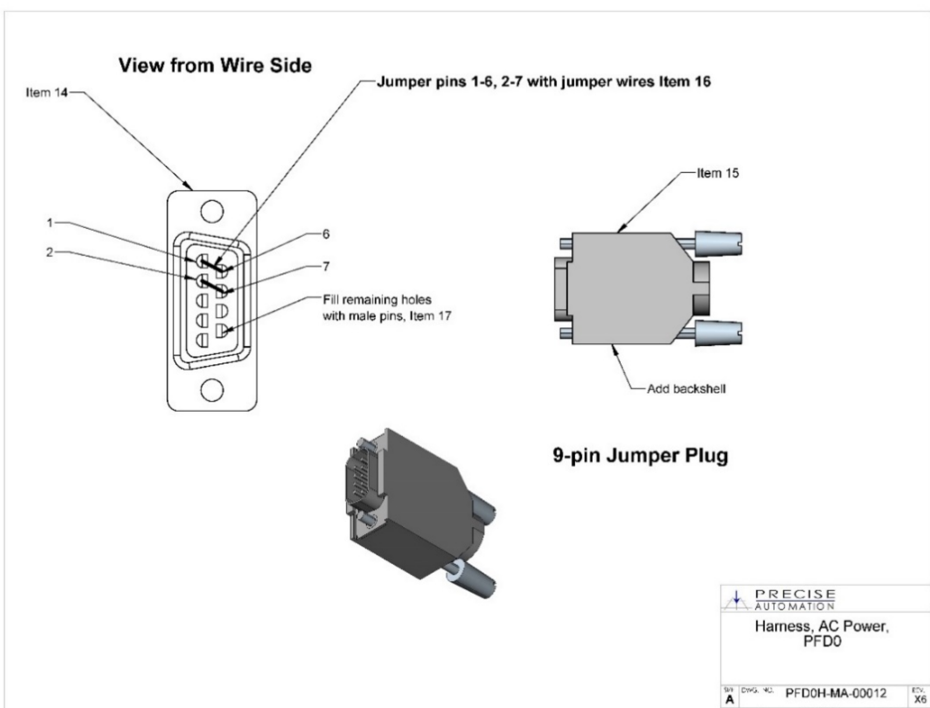

X1 Initial Concept Release 3/5/2019 BRC
X2 Deleted Gnd wire 11/16/2019 BRC
X3 Added notes for which wires belong to which terminal # on the PCA 04/02/20 PTC
X4 Added detail on wiring and second sheet for 167mm motor 4/5/2020 BRC
View from Wire Side
Item 1
Contacts Item 2
Pin 1
Pin 2 White (Middle Right Wire on Motor)
Pin 6 Red (Top Left Wire on Motor)
Pin 3 Black (Bottom Left Wire on Motor)
150mm pigtail 22 AWG
Strip ends Red, Black, White wires 3mm
Top J3 Motor when Mounted in Robot:
Note J1 motor has encoder underneath and J3 motor has encoder on top in robot
Red Wire 20 AWG Terminal 1
White Wire 20 AWG Terminal 2
Black Wire 20 AWG Terminal 1
Green Wires
Tie Terminal 2 top ring to
Terminal 1 middle ring to
Terminal 2 bottom ring
PROPRIETARY AND CONFIDENTIAL
PRECISE
AUTOMATION
Harness, Motor Pigtail,
J1, J3, PFD0
A
PFD0H-MA-00008
X4
04/02/20

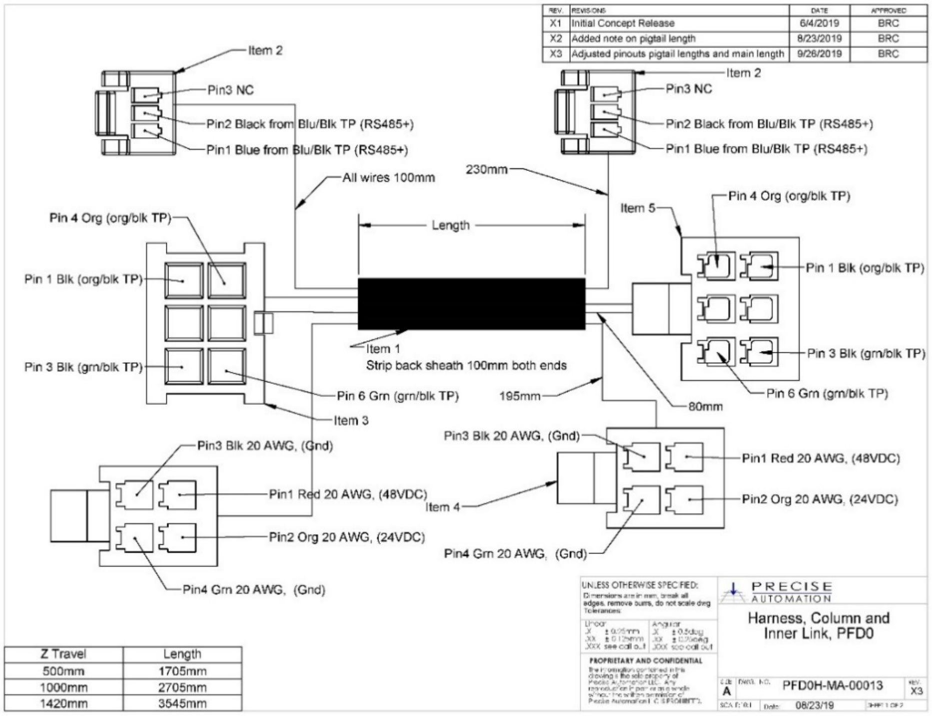


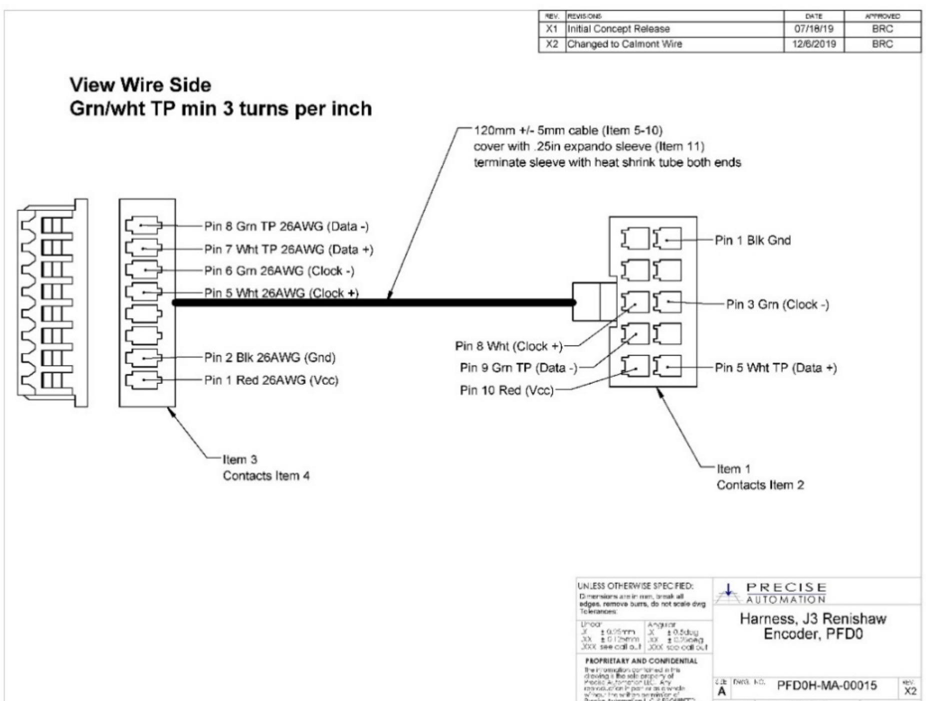


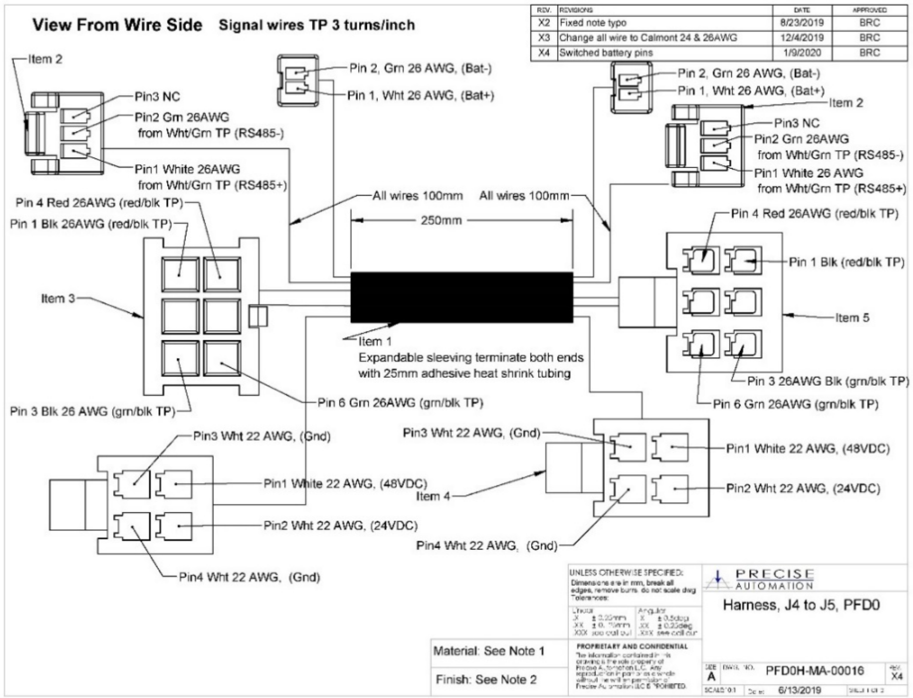
Ethernet Signal	Ribbon Wire Number	Pin Number
TP1 (Black)	1	1
TP1 (Orange)	2	2
TP2 (Black)	4	3
TP3		NC
TP3		NC
TP2 (Green)	5	6
TP4		NC
TP4		NC

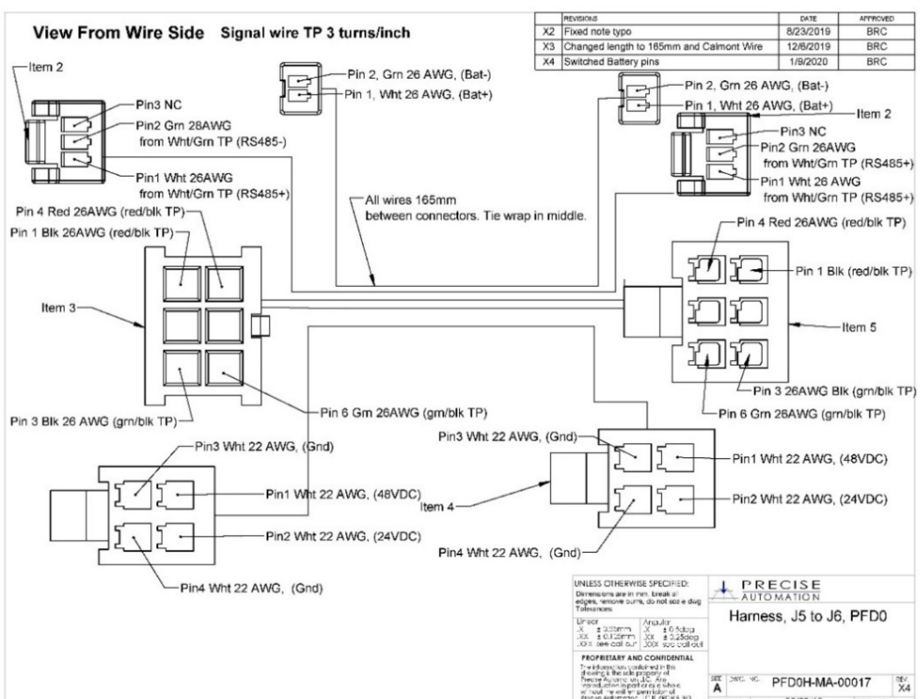

REV. REVISIONS DATE APPROVED
X1 Initial Concept Release 6/5/2019 BRC
X2 Added double crimp instead of splice 8/23/2019 BRC
X5 Added Jumpers Hirose Connector 12/3/2019 BRC
X6 Added Gnd Wire, Estop Jumper 4/11/2020 BRC
Item 1
0000-EC-H0308
AMP:2-520129-2
Wire Brown
Item 6
Item 2
0000-EC-H0138
AMP:2-520194-2
100 +6 -6
Item 1
0000-EC-H0308
AMP:2-520129-2
Wire Blue
Item 7
Item 2
0000-EC-H0138
AMP:2-520194-2
100 +6 -6
Cut cable to 1770mm
Item 12 (.205 Faston)
Jumper
Pins 1&2
Item 10
HV Enable
450mm pigtail
3 wires
HV Enable
150mm pigtails
Item 3
Alpha Cable
140mm pigtail 1 wire
Jumper
Pins 13&14
GND
AC/L
AC/L
AC/N
1170mm
AC/N
Item 2
.187 Faston
Grn/Yel (Gnd)
Wire Side
AC/L
AC/N
Latch
Item 9
3 plcs
Item 5
550mm pigtail
Item 4
0000-EC-H0118
JST:VHR-3N
USE PINS PN
000-EC-H012
JST SVH-21T-P1.1
Wire Green/Yellow
Item 8
Item 1
0000-EC-H0308
AMP:2-520129-2
Item 5
0000-EC-H0054
HOFFMAN: FVL2216-4R2
200 +6 -6
550mm pigtail
Wire Green/Yellow
Item 8
Item 5
0000-EC-H0054
HOFFMAN: FVL2216-4R2
2plcs
200 +6 -6
UNLESS OTHERWISE SPECIFIED:
PROPRIETARY AND CONFIDENTIAL
PRECISE AUTOMATION
Harness, AC Power, PFD0
A
PFD0H-MA-00012
X6
09/03/19

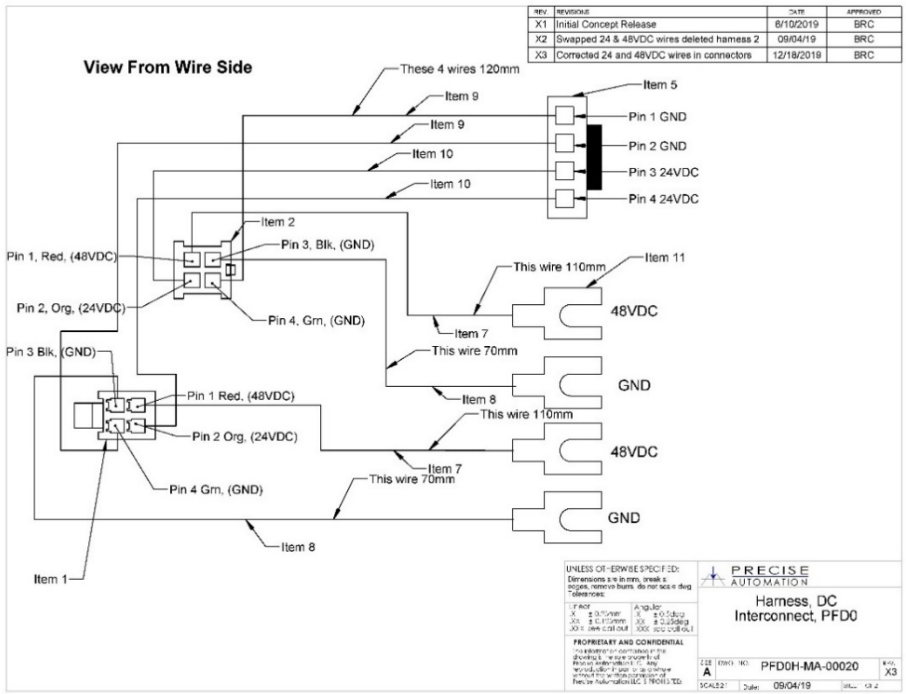

View from Wire Side
Item 14
Jumper pins 1-6, 2-7 with jumper wires Item 16
1
2
6
7
Fill remaining holes
with male pins, Item 17
Item 15
Add backshell
9-pin Jumper Plug
PRECISE AUTOMATION
Harness, AC Power, PFD0
A
PFD0H-MA-00012
X6
09/03/19

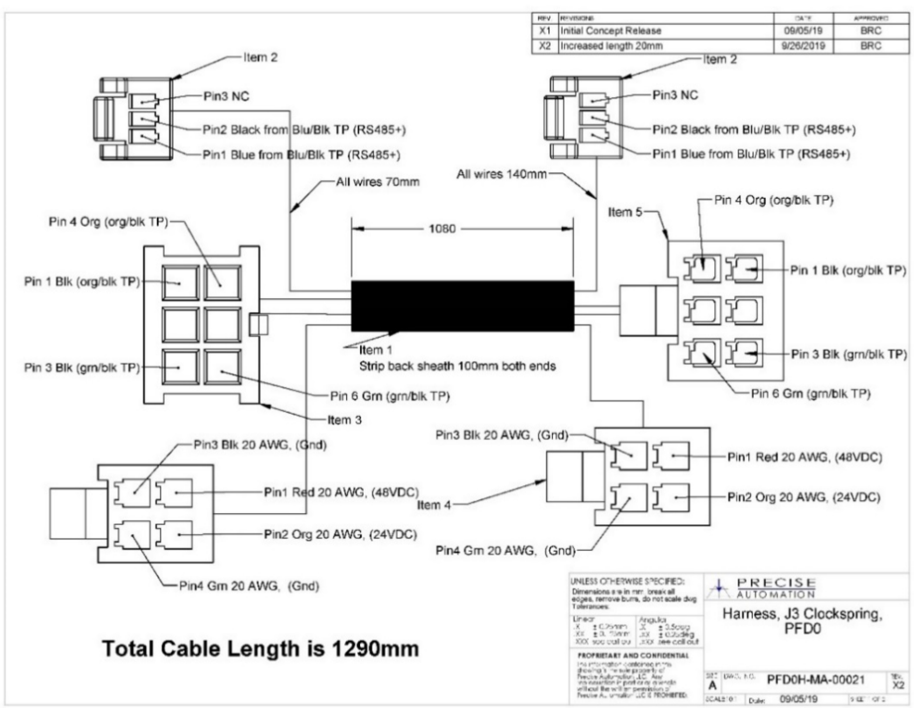

REV. REVISIONS DATE APPROVED
X1 Initial Concept Release 6/4/2019 BRC
X2 Added note on pigtail length 8/23/2019 BRC
X3 Adjusted pinouts pigtail lengths and main length 9/26/2019 BRC
Item 2
Pin3 NC
Pin2 Black from Blu/Blk TP (RS485+)
Pin1 Blue from Blu/Blk TP (RS485+)
All wires 100mm
230mm
Item 5
Pin 4 Org (org/blk TP)
Length
Pin 1 Blk (org/blk TP)
Pin 3 Blk (grn/blk TP)
Item 1
Strip back sheath 100mm both ends
Pin 6 Grn (grn/blk TP)
195mm
80mm
Item 3
Pin3 Blk 20 AWG, (Gnd)
Pin1 Red 20 AWG, (48VDC)
Pin2 Org 20 AWG, (24VDC)
Pin4 Grn 20 AWG, (Gnd)
Item 4
PRECISE AUTOMATION
Harness, Column and Inner Link, PFD0
PFD0H-MA-00013
X3
08/23/19
Z Travel | Length
500mm | 1705mm
1000mm | 2705mm
1420mm | 3545mm

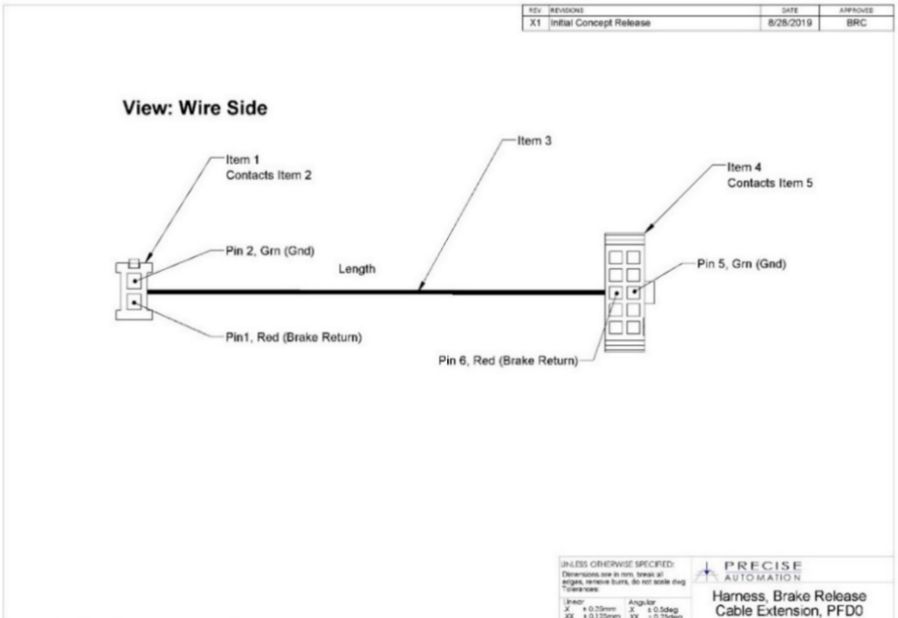

REV. REVISIONS DATE APPROVED
X1 Initial Concept Release 07/18/19 BRC
X2 Changed to Calmont Wire 12/6/2019 BRC
View Wire Side
Grn/wht TP min 3 turns per inch
120mm +/- 5mm cable (Item 5-10)
cover with .25in expando sleeve (Item 11)
terminate sleeve with heat shrink tube both ends
Pin 8 Grn TP 26AWG (Data -)
Pin 7 Wht TP 26AWG (Data +)
Pin 6 Grn 26AWG (Clock -)
Pin 5 Wht 26AWG (Clock +)
Pin 2 Blk 26AWG (Gnd)
Pin 1 Red 26AWG (Vcc)
Pin 1 Blk Gnd
Pin 3 Grn (Clock -)
Pin 8 Wht (Clock +)
Pin 9 Grn TP (Data -)
Pin 10 Red (Vcc)
Pin 5 Wht TP (Data +)
Item 3
Contacts Item 4
Item 1
Contacts Item 2
PRECISE AUTOMATION
Harness, J3 Renishaw Encoder, PFD0
PFD0H-MA-00015
X2
07/18/19


View From Wire Side
Signal wires TP 3 turns/inch
X2 Fixed note typo 8/23/2019 BRC
X3 Change all wire to Calmont 24 & 26AWG 12/4/2019 BRC
X4 Switched battery pins 1/9/2020 BRC
Item 2
Pin3 NC
Pin2 Grn 26AWG from Wht/Grn TP (RS485-)
Pin1 White 26AWG from Wht/Grn TP (RS485+)
Pin 2, Grn 26 AWG, (Bat-)
Pin 1, Wht 26 AWG, (Bat+)
Pin 4 Red 26AWG (red/blk TP)
Pin 1 Blk 26AWG (red/blk TP)
All wires 100mm
250mm
Item 3
Item 1
Expandable sleeving terminate both ends with 25mm adhesive heat shrink tubing
Pin 1 Blk (red/blk TP)
Item 5
Pin 3 26AWG Blk (grn/blk TP)
Pin 6 Grn 26AWG (grn/blk TP)
Pin 3 Blk 26 AWG (grn/blk TP)
Pin3 Wht 22 AWG, (Gnd)
Pin1 White 22 AWG, (48VDC)
Item 4
Pin2 Wht 22 AWG, (24VDC)
Pin4 Wht 22 AWG, (Gnd)
PRECISE AUTOMATION
Harness, J4 to J5, PFD0
Material: See Note 1
Finish: See Note 2
PFD0H-MA-00016
X4
6/13/2019

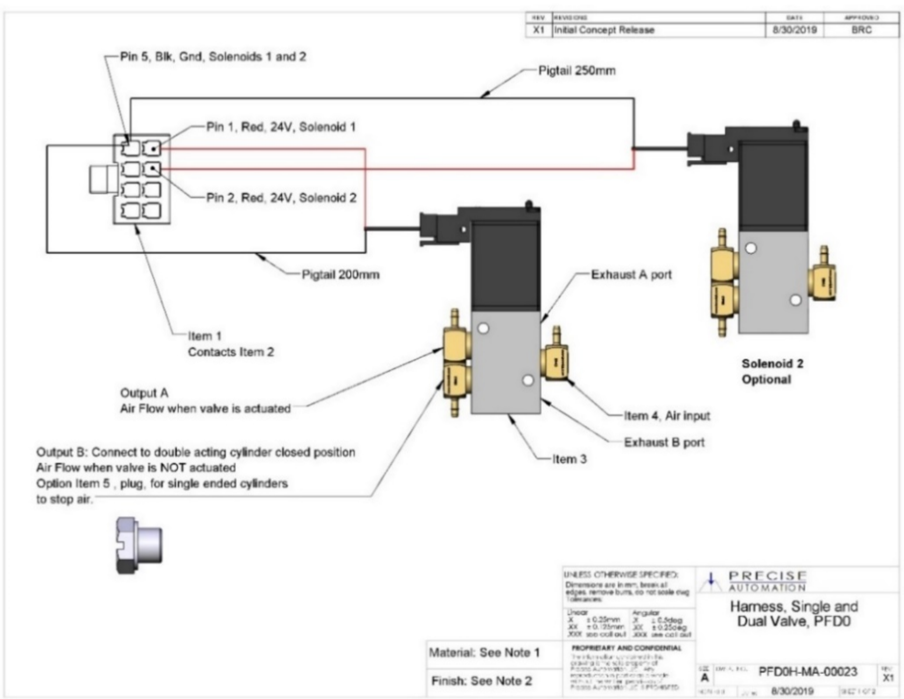

View From Wire Side
Signal wire TP 3 turns/inch
X2 Fixed note typo 8/23/2019 BRC
X3 Changed length to 165mm and Calmont Wire 12/6/2019 BRC
X4 Switched Battery pins 1/9/2020 BRC
Item 2
Pin3 NC
Pin2 Grn 26AWG from Wht/Grn TP (RS485-)
Pin1 Wht 26AWG from Wht/Grn TP (RS485+)
Pin 2, Grn 26 AWG, (Bat-)
Pin 1, Wht 26 AWG, (Bat+)
Pin2 Grn 26AWG from Wht/Grn TP (RS485+)
Pin1 Wht 26 AWG from Wht/Grn TP (RS485+)
All wires 165mm between connectors. Tie wrap in middle.
Pin 4 Red 26AWG (red/blk TP)
Pin 1 Blk 26AWG (red/blk TP)
Item 3
Pin 1 Blk (red/blk TP)
Item 5
Pin 3 26AWG Blk (grn/blk TP)
Pin 6 Grn 26AWG (grn/blk TP)
Pin 3 Blk 26 AWG (grn/blk TP)
Pin3 Wht 22 AWG, (Gnd)
Pin1 Wht 22 AWG, (48VDC)
Item 4
Pin2 Wht 22 AWG, (24VDC)
Pin4 Wht 22 AWG, (Gnd)
PRECISE AUTOMATION
Harness, J5 to J6, PFD0
PFD0H-MA-00017
X4
08/23/19

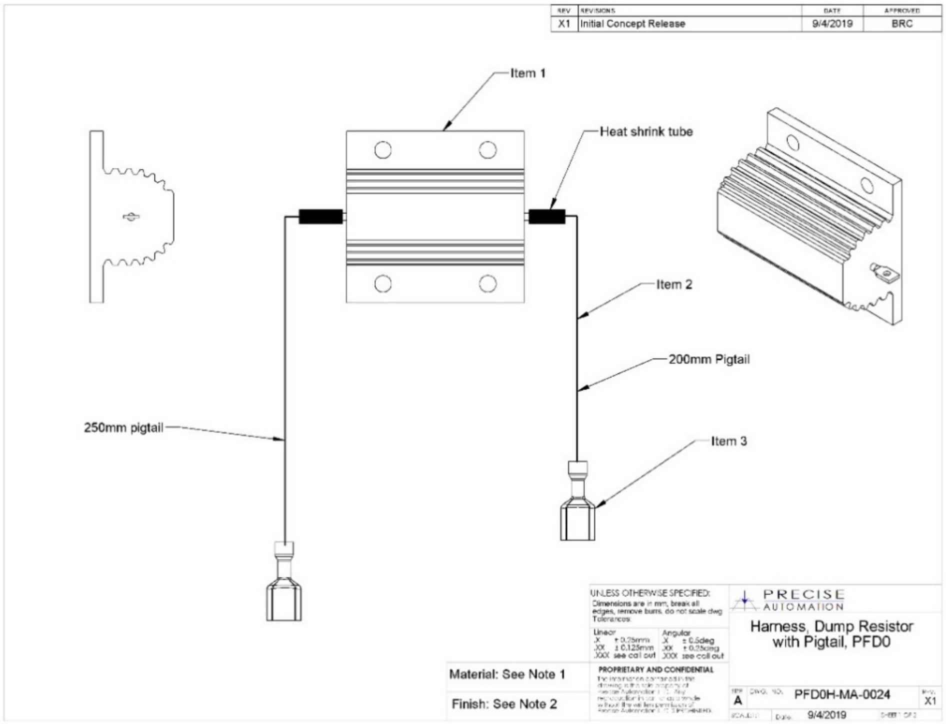

REV. REVISIONS DATE APPROVED
X1 Initial Concept Release 6/10/2019 BRC
X2 Swapped 24 & 48VDC wires deleted harness 2 09/04/19 BRC
X3 Corrected 24 and 48VDC wires in connectors 12/18/2019 BRC
View From Wire Side
These 4 wires 120mm
Item 9
Item 9
Item 10
Item 10
Item 5
Pin 1 GND
Pin 2 GND
Pin 3 24VDC
Pin 4 24VDC
Item 2
Pin 3, Blk, (GND)
Pin 1, Red, (48VDC)
Pin 2, Org, (24VDC)
Pin 4, Grn, (GND)
This wire 110mm
Item 11
48VDC
Item 7
This wire 70mm
GND
Item 8
Pin 3 Blk, (GND)
Pin 1 Red, (48VDC)
Pin 2 Org, (24VDC)
This wire 110mm
48VDC
Item 7
This wire 70mm
Pin 4 Grn, (GND)
GND
Item 8
Item 1
UNLESS OTHERWISE SPECIFIED:
PROPRIETARY AND CONFIDENTIAL
PRECISE AUTOMATION
Harness, DC Interconnect, PFD0
A
PFD0H-MA-00020
X3
09/04/19

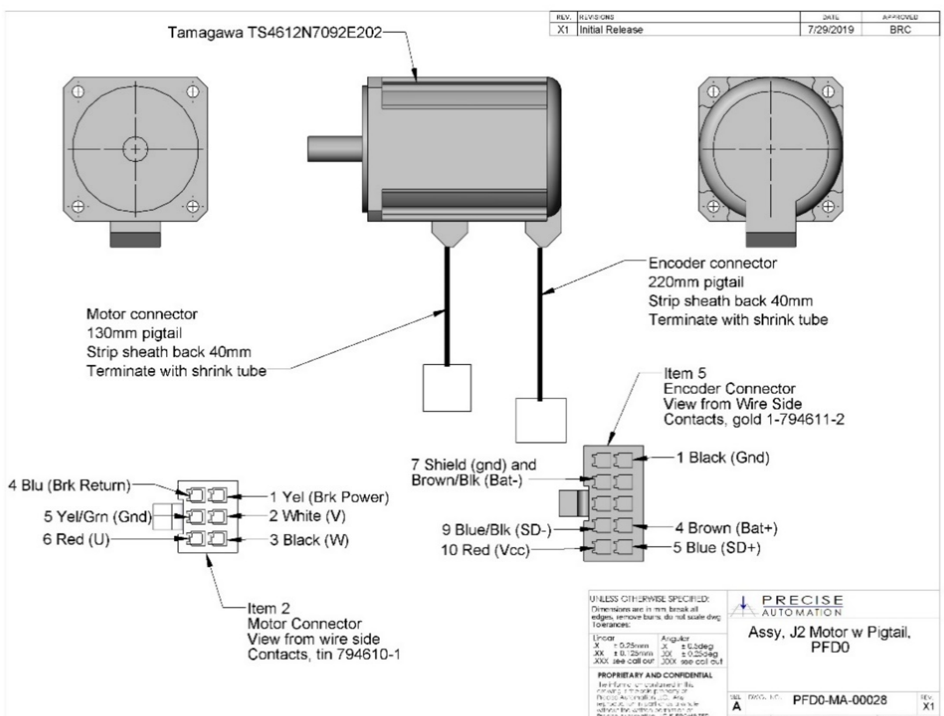

REV. REVISIONS DATE APPROVED
X1 Initial Concept Release 09/05/19 BRC
X2 Increased length 20mm 9/26/2019 BRC
Item 2
Pin3 NC
Pin2 Black from Blu/Blk TP (RS485+)
Pin1 Blue from Blu/Blk TP (RS485+)
Item 2
Pin3 NC
Pin2 Black from Blu/Blk TP (RS485+)
Pin1 Blue from Blu/Blk TP (RS485+)
All wires 70mm
All wires 140mm
Item 5
Pin 4 Org (org/blk TP)
1080
Pin 4 Org (org/blk TP)
Pin 1 Blk (org/blk TP)
Pin 1 Blk (org/blk TP)
Pin 3 Blk (grn/blk TP)
Pin 3 Blk (grn/blk TP)
Item 1
Strip back sheath 100mm both ends
Pin 6 Grn (grn/blk TP)
Pin 6 Grn (grn/blk TP)
Item 3
Pin3 Blk 20 AWG, (Gnd)
Pin3 Blk 20 AWG, (Gnd)
Pin1 Red 20 AWG, (48VDC)
Pin1 Red 20 AWG, (48VDC)
Item 4
Pin2 Org 20 AWG, (24VDC)
Pin2 Org 20 AWG, (24VDC)
Pin4 Grn 20 AWG, (Gnd)
Pin4 Grn 20 AWG, (Gnd)
Total Cable Length is 1290mm
UNLESS OTHERWISE SPECIFIED:
PROPRIETARY AND CONFIDENTIAL
PRECISE AUTOMATION
Harness, J3 Clockspring, PFD0
A
PFD0H-MA-00021
X2
09/05/19

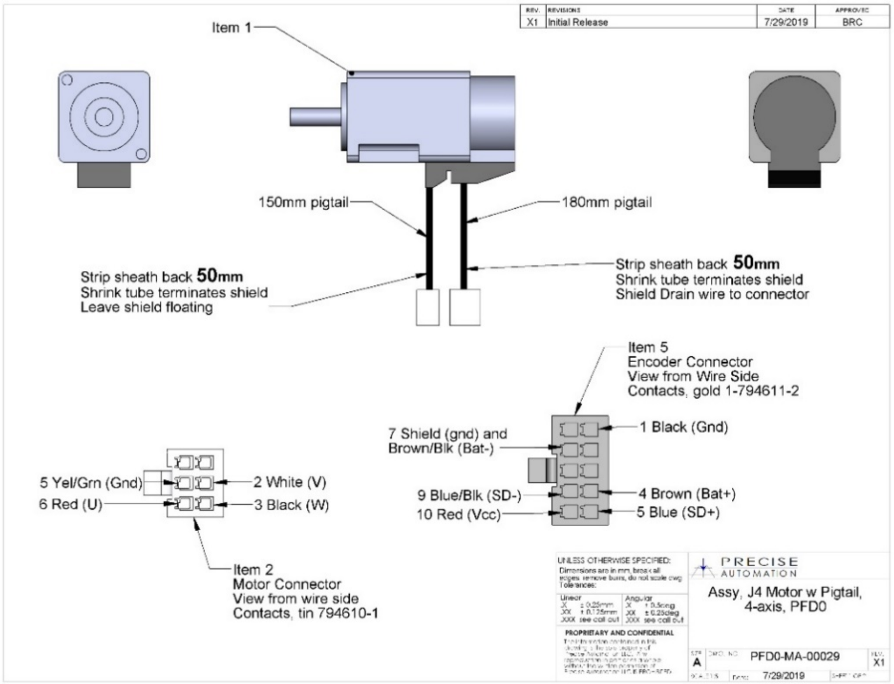


Z Travel	Length
500mm	1600
1000mm	2600
1420mm	3440

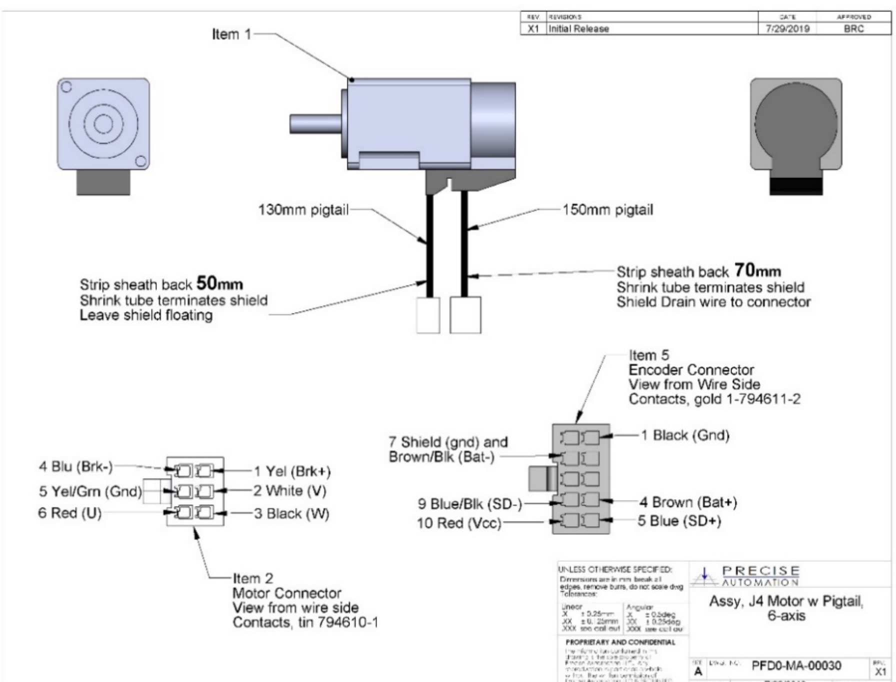



REV
REVISIONS
DATE
APPROVED
X1
Initial Concept Release
9/4/2019
BRC
Item 1
Heat shrink tube
Item 2
200mm Pigtail
250mm pigtail
Item 3
UNLESS OTHERWISE SPECIFIED:
Linear
Angular
PROPRIETARY AND CONFIDENTIAL
PRECISE
AUTOMATION
Harness, Dump Resistor with Pigtail, PFD0
Material: See Note 1
Finish: See Note 2
A
PFD0H-MA-0024
X1
9/4/2019

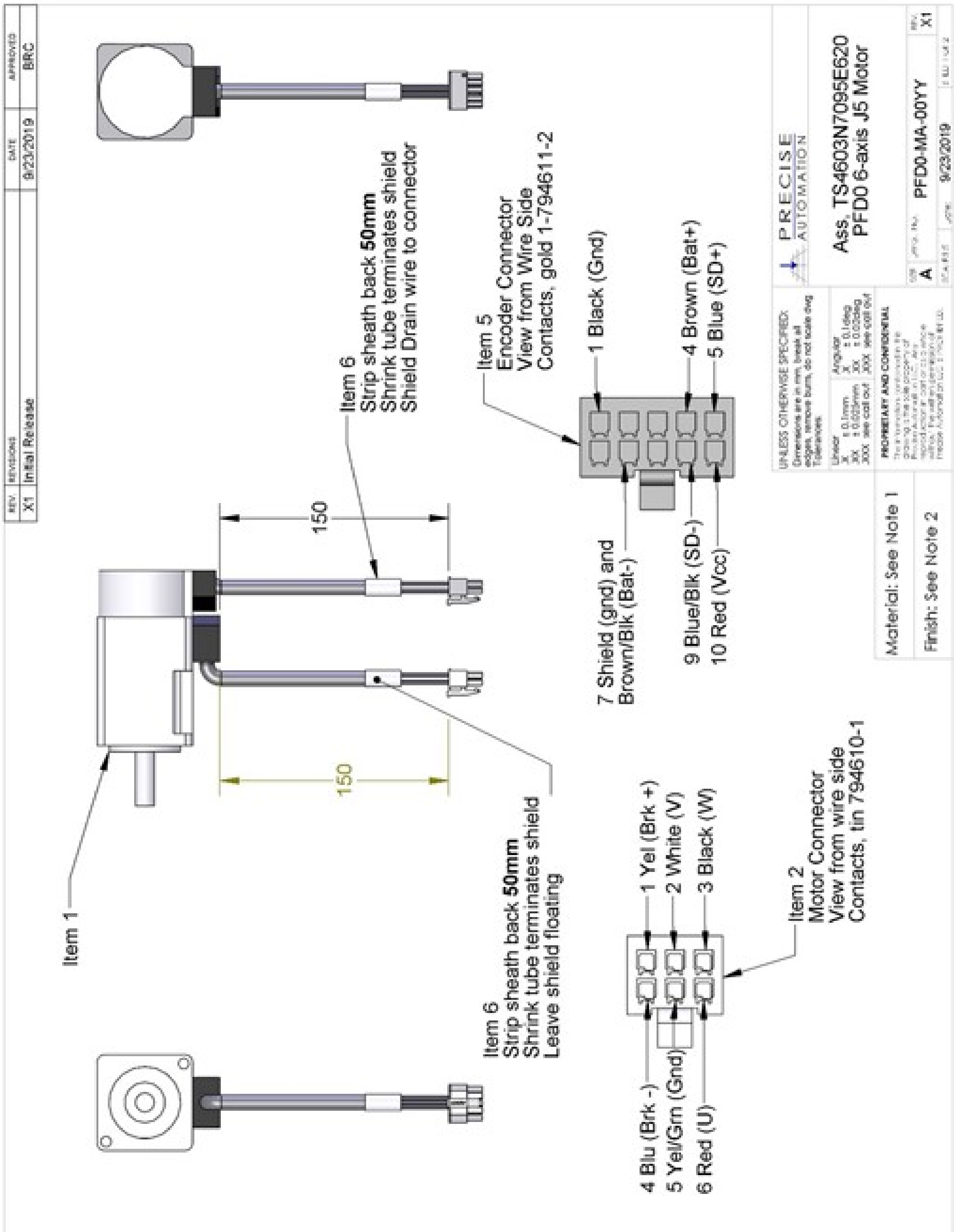

REV.
REVISIONS
DATE
APPROVED
X1
Initial Release
7/29/2019
BRC
Tamagawa TS4612N7092E202
Encoder connector
220mm pigtail
Strip sheath back 40mm
Terminate with shrink tube
Motor connector
130mm pigtail
Strip sheath back 40mm
Terminate with shrink tube
Item 5
Encoder Connector
View from Wire Side
Contacts, gold 1-794611-2
1 Black (Gnd)
7 Shield (gnd) and
Brown/Blk (Bat-)
4 Blu (Brk Return)
1 Yel (Brk Power)
5 Yel/Grn (Gnd)
2 White (V)
6 Red (U)
3 Black (W)
9 Blue/Blk (SD-)
4 Brown (Bat+)
10 Red (Vcc)
5 Blue (SD+)
Item 2
Motor Connector
View from wire side
Contacts, tin 794610-1
UNLESS OTHERWISE SPECIFIED:
PROPRIETARY AND CONFIDENTIAL
PRECISE
AUTOMATION
Assy, J2 Motor w Pigtail, PFD0
A
PFD0-MA-00028
X1
9/3/2019



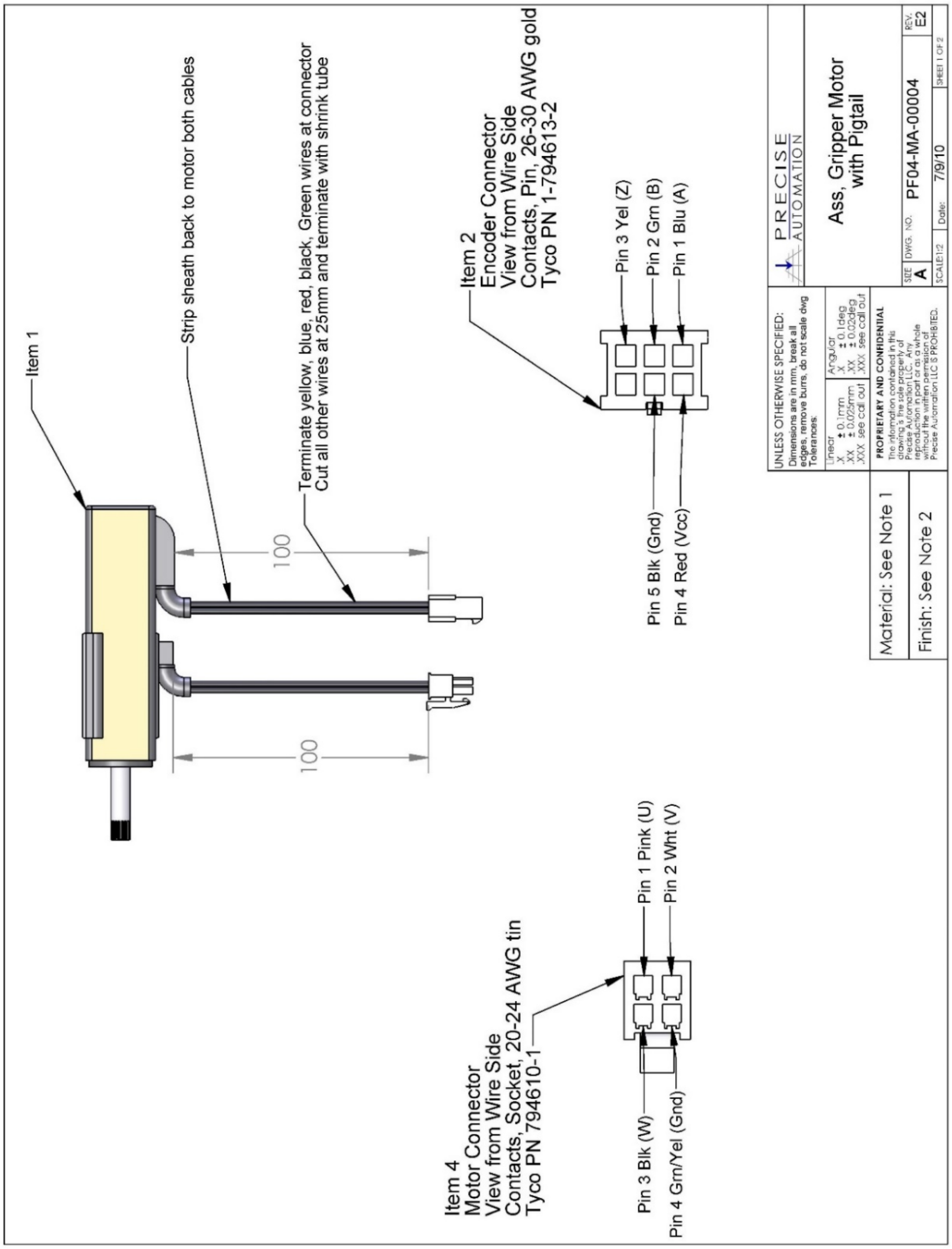
J4 Motor, PFDD4



J4 Motor, PFDD6



Wiring for J5, J6 motors, 6-axis PFD0
(Note J6 motor is 50WT, no brake

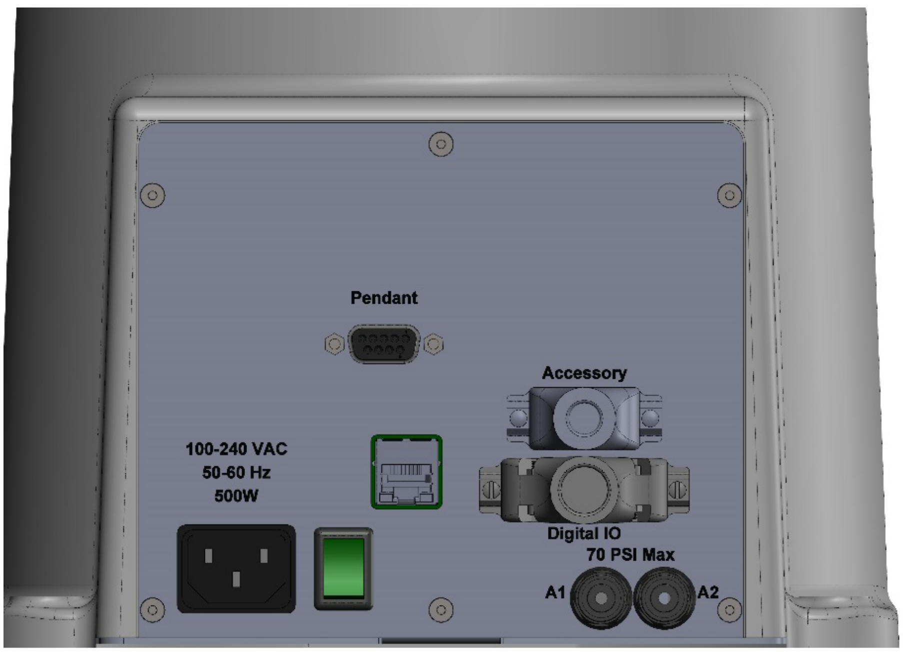


Motor, 23Nm Servo Gripper

Facilities Panel

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

- System AC input power receptacle 90 to 265VAC
- Lighted AC on/off power switch
- Connectors for controller input and output signals
- Two air fittings for 1/8in OD air hoses 75 psi max



Item	Name	Description
1	9 Pin D Sub Connector	RS-232 for Pendant, 24 VDC, Dual E-Stops, Gnd, Can be used for optional teach pendant
2	25 Pin D Sub Connector	DIO, 12 inputs, 8 outputs
3	15 PIN D Sub Connector	RS-485, 48 VDC, Gnd, Belt Encoder, Cell Interlock Signals, RS-232 COM 1
4	Ethernet Connector	For Ethernet to Computer Cable
5	Power Switch	Lighted Power Switch
6	Power Entry Module	For IEC plug with Filter
7	2 Push Type Air Fittings	For 1/8in OD air hoses, to outer link

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

- Digital input signals
- Digital output signals
- Ethernet port
- MCP / E-Stop/ RS232
- RS-485, Belt Encoder, OSSD (Output Safety Switching Device)

Each of these interfaces is described in detail in the following sections. In addition, the robot's slave controllers, which are mounted near the motors of the robot, may contain additional interfaces (e.g. inputs or outputs). Please refer to the *PreciseFlex™ GSBP Controllers, Hardware Introduction and Reference Manual* for additional information.

DANGER: 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 Rear Z column cover is removed.**

If the pneumatic gripper option is ordered two air lines are routed through the interior of the robot. At the Facilities Panel, these air lines are presented in one-touch push-to-release fittings on the facilities panel. The other end of these lines exit in the Outer Link. When using these lines, clean, dry external air should be provided.

CAUTION: The maximum air pressure that can be conveyed by the air lines through the robot is **70 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

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 9 pin D-Sub connector in the connector panel in the base casting. The E-Stop box completes a circuit from Pin 1 (Estop 1) to Pin 6 (FE Out 1) and from Pin 2 (Estop 2) to Pin 7 (FE Out2) in this connector. If this circuit is not completed it is not possible to enable motor power to the robot. The FE Out signals allow each Estop circuit to be toggled during the CAT3 startup sequence to make sure both circuits are working. If no E-Stop box or Manual Control Pendant is connected, jumpers must be connected between these four 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 robot is shipped with 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 E-Stop circuits.

MCP / E-Stop Interface

The MCP interface includes the signals necessary to connect a Manual Control Pendant, or E-Stop box. These signals are provided in a DB9 female connector mounted on the robot’s Facilities Panel.

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

Pin	Description
1	ESTOP_L1
2	ESTOP_L2
3	RS232 RXD (Com 2)
4	24VDC
5	NC
6	FORCE ESTOP_L1 (Toggles ESTOP Low at Start Up, Then High)
7	FORCE ESTOP_L2 (Toggles ESTOP Low at Start Up, Then High)
8	RS232 (Com2)
9	Gnd
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

15 Pin D-Sub Signals

Pin	Description
1	24VDC
2	48VDC
3	GND

4	RS232 TXD (Com1)
5	OSSD1 (Output Signal Switching Device for Safety Devices)
6	RS485+
7	A+ (Belt)
8	B+ (Belt)
9	48VDC
10	GND
11	RS232 RXD (Com1)
12	OSSD2 (Output Signal Switching Device for Safety Devices)
13	RS485-
14	A- (Belt)
15	B- (Belt)
Interface Panel Connector Part No	DB15 Female Connector AMP 5747299-7
User Plug Part No	DB15 Male Plug Amp 1658656-1 (crimp) Pins 22-26AWG 745254-6

Digital Input and Output Signals

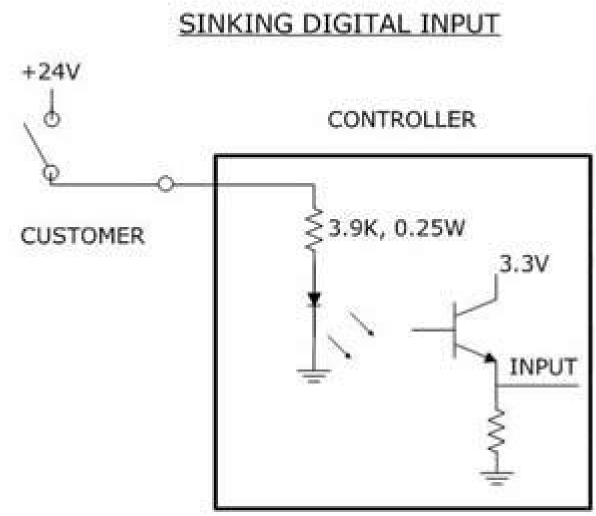
Digital Input Signals

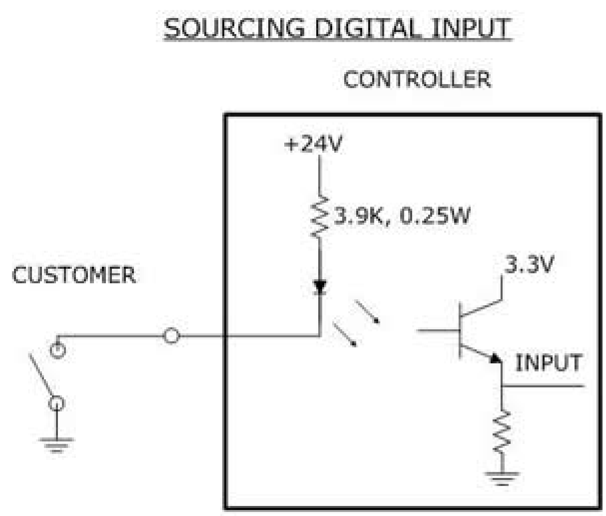
The standard PFDD robots provides 12 general purpose optically isolated digital input signals at the Facilities Panel (in addition to those signals that are available at the Gripper Control Board).

The input signals can be configured as "sinking" or "sourcing" in blocks of 4 by means of a software configuration setting. Set DataID 531 "DIN sink mode 1-4, 5-8, 9-12" to configure source vs. sink for digital input groups. 0 means sourcing, 1 means sinking.

Output signals can be configured individually. Set DataID 530 "DOUT sink mode 1, 2, 3, 4, 5, 6, 7, 8" to configure source vs. sink for digital outputs. 0 means sourcing, 1 means sinking. Changing any of these values clears all 8 digital outputs.

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”.

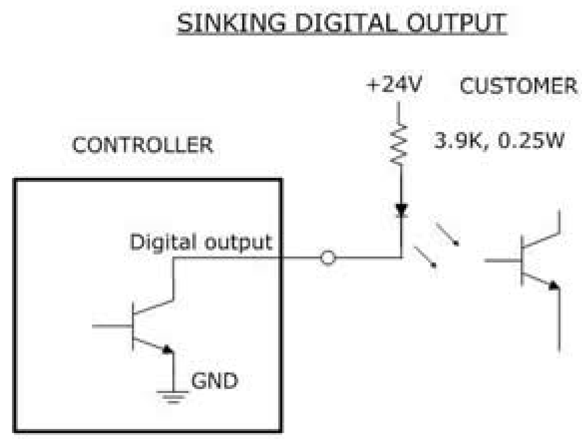




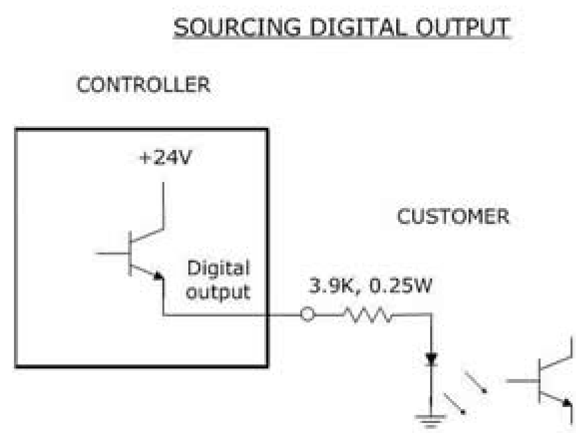
Digital Output Signals

The PFDD robot provides 8 general-purpose optically isolated digital output signals in the 25-pin D-Sub connector on the facilities panel.

These output signals can be individually configured as "sinking" or "sourcing" by means of a software setting. (See above.) ***As shipped from the factory, the output signals are configured as "sourcing"***, i.e. the external equipment must <u>pull down an output pin to ground</u> and the controller pulls this pin to 24VDC when the signal is asserted as true.



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



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

25 Pin D-Sub Signals

Pin	GPL Signal Number	Description
1		GND
2	10001	Digital Input 1
3	10003	Digital Input 3
4	10005	Digital Input 5
5	10007	Digital Input 7
6	10009	Digital Input 9
7	10011	Digital Input 11
8		24VDC
9	13	Digital Output 1
10	15	Digital Output 3
11	17	Digital Output 5
12	19	Digital Output 7
13		24VDC
14		GND
15	10002	Digital Input 2
16	10004	Digital Input 4
17	10006	Digital Input 6
18	10008	Digital Input 8
19	10010	Digital Input 10
20	10012	Digital Input 12
21		24VDC
22	14	Digital Output 2
23	16	Digital Output 4
24	18	Digital Output 6
25	20	Digital Output 8
User Plug Part No		Amp 1658657-1, (crimp) Pins 22-26AWG 745254-6

Slave Amplifier (GSBP) Digital Inputs and Outputs

For each motor other the base motor, there is a slave amplifier which includes 3 sinking analog/digital inputs and 3 sourcing digital outputs. One digital output is dedicated for an LED light and has a 1,000 ohm resistor in series to limit the current. Three inputs and two outputs are available for application use. The digital inputs are each connected directly to Analog to Digital Converter inputs in the CPU, so they can be set by SW for 0-10VDC analog inputs (future feature) or 24VDC digital inputs (current release).

Pin	GPL Signal Number	Description
1	200013	Digital Output 1
2	200014	Digital Output 2
3	200015	Digital Output 3:LED driver (LED Out 3 Jumper Pins 2&3) OR TXD (Out 3 Jumper Pins 1&2)
4		24 VDC output
5		GND
6	210001	Digital/Analog Input 1 (IN1 Jumper Pins 2&3) OR RXD (IN1 Jumper Pins 1 &2)
7	210002	Digital/Analog Input 2
8	210003	Digital/Analog Input 3
User Plug Part No		TE 794617-8, Pins 794610-1 (20-24AWG Tin)

Ethernet Interface

PFDD 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.

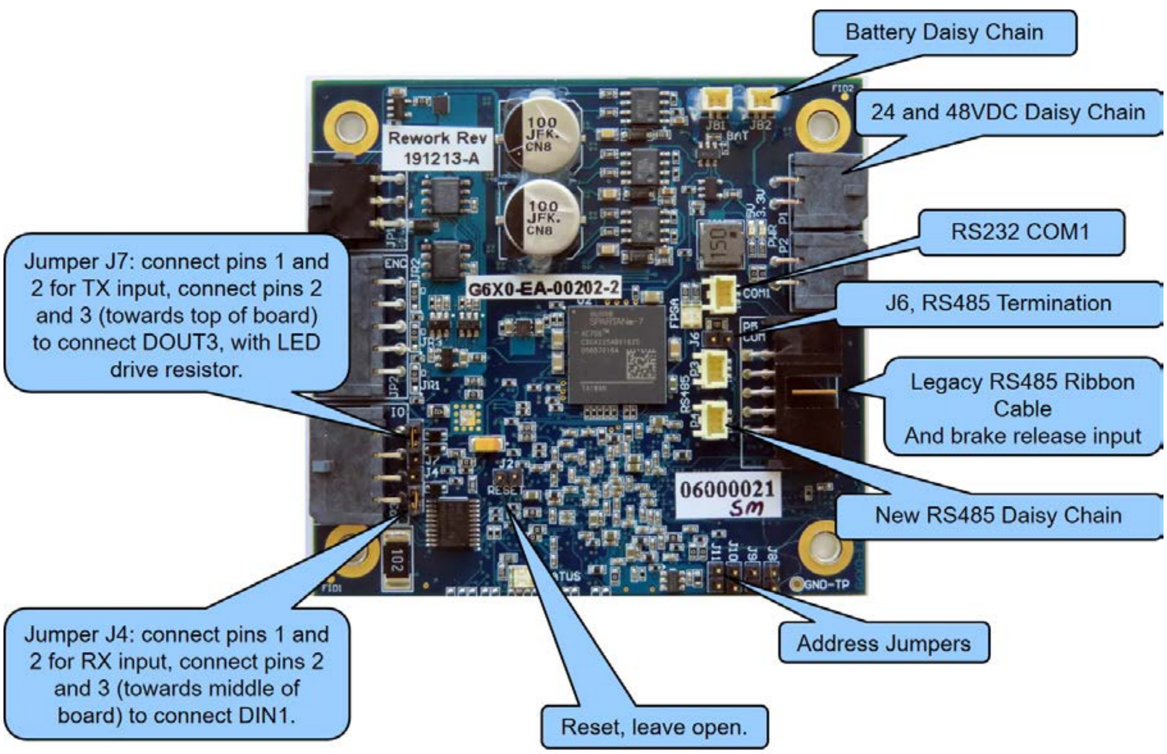
See the *Setup and Operation Quick Start Guide* for instructions on setting the IP address for the controller.

RS-232 Serial Interface

The PFDD robot includes a standard RS-232 serial line equipped with hardware or software flow control. This port is available on the 15-pin D-sub connector on the connector panel in the base of the robot as COM1. 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).

Gripper Serial Interface (for Bar Code and other RS232 devices in Gripper)

It is possible to connect a bar code reader or other RS232 serial device to the slip ring located in the robot gripper. In the GSBP gripper two IO pins have optional assignments based on jumpers. For J4 connect pins 2 and 3 to connect Digital Input 1 to pin 6 and connect pins 1 and 2 to connect pin 6 to a line that goes back to a CPU serial input where it is multiplexed onto RS485 to connect back the main controller COM1 input. For J7 connect pins 2 and 3 to connect Digital Output 3 to pin 3 and connect pins 1 and 2 to connect pin 3 to a line that goes back to a CPU serial input where it is multiplexed onto RS485 to connect back the main controller COM1 input. Serial data rate is limited to 9600 baud. (Not available in beta units)



J4 and J7 on GSB Board

Refer to Slip Ring drawings in Hardware Reference Section for the slip ring connector pin assignments inside the grippers. The mating connector is TE (Amp) Micro Mate N Lok PN 794617-6 with contacts PN 1-794611-2. It is recommended that 24V bar code readers be used as the 5V supply is very limited.

Several bar code readers that have been successfully implemented with Precise Robots are the following:

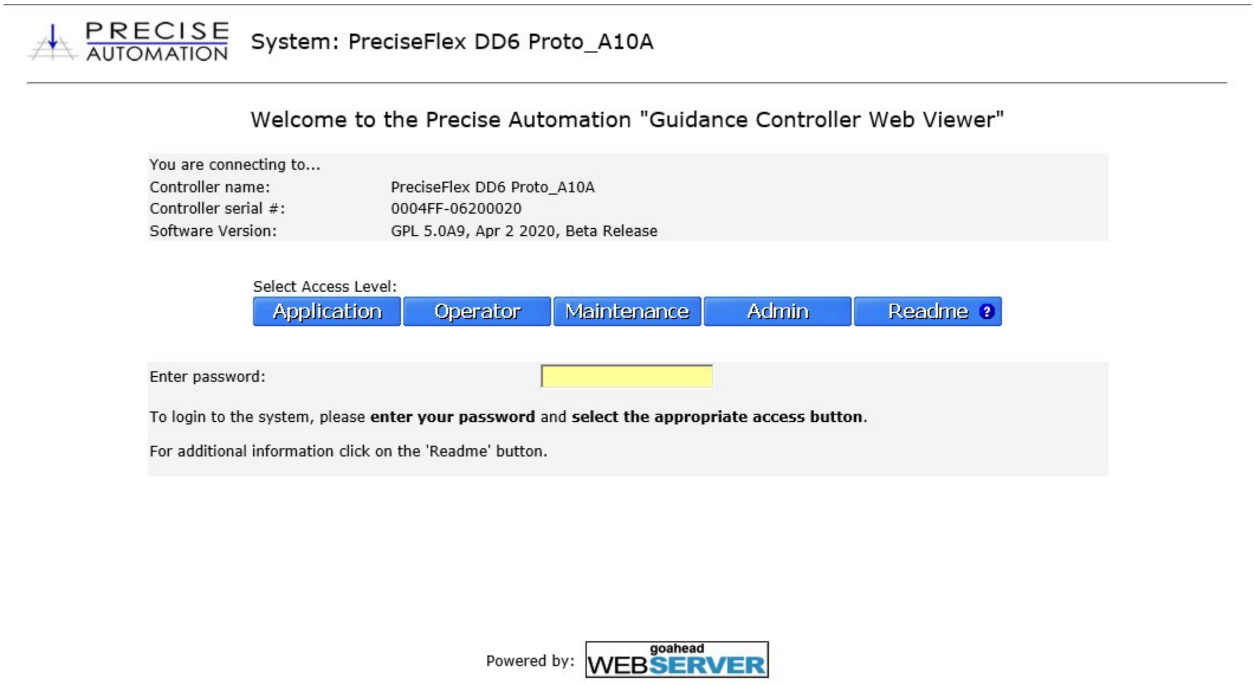
1. Keyence SR750, 1D and 2D, 24VDC supply, 200ma, 60mm distance.
2. Cognex DM50, DM60, DM70, 24VDC supply, 500ma, 45 to 110mm distance
3. Omron/Microscan MiniHawk, 1D and 2D, 5VDC supply, need converter from 24VDC

Software Reference

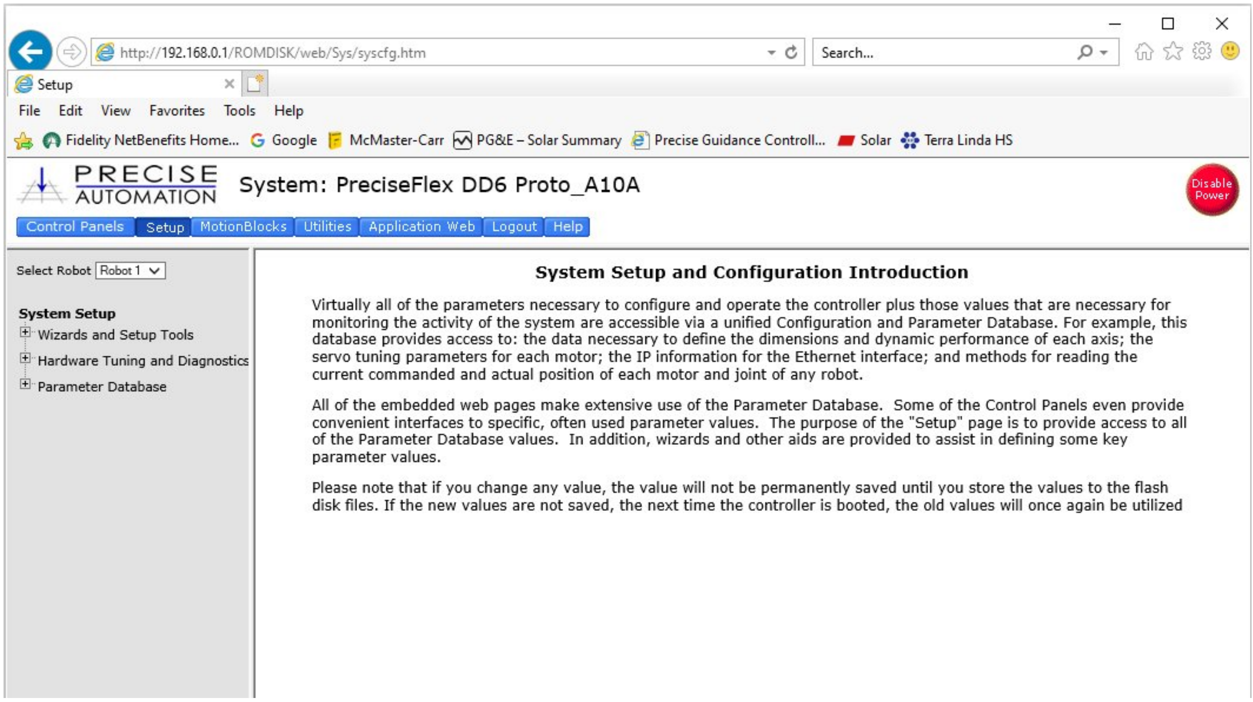
Accessing the Web Server

Many OEM customers run Precise Robots 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.

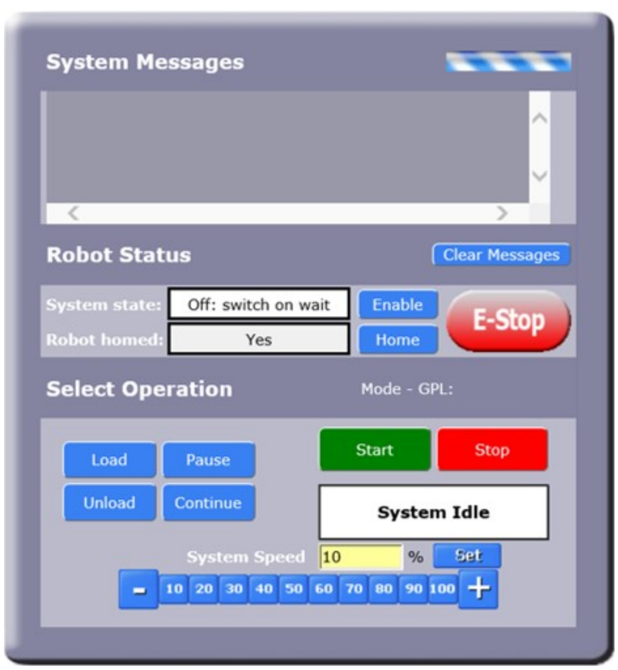
The Web Server Interface may be addressed by opening a browser (such as Internet Explorer) in a PC that is connected to the robot via Ethernet. You must know the IP address of the robot controller. Two common IP addresses are 192.168.0.1 and 192.168.0.10. The PC LAN interface address must be configured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



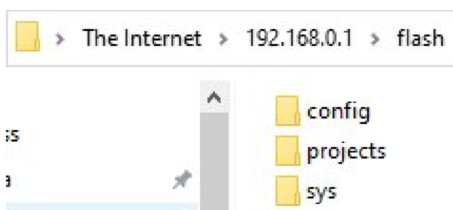
If an application is running, the “System Running” panel will display in green. In order to run diagnostics, you must stop the application from running. Click “Stop”. This will stop the application from running. You should click the “Disable Power” button to be sure motor power is off. If you need to load a new project (for example CAL_PP) you will need to click on “Unload” and then “Load” 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 via ftp. Previous generations of GPL supported this process directly from the GPL Web Server, but Windows 10 and Edge no longer allow this. Therefore, the procedures listed below must be used.

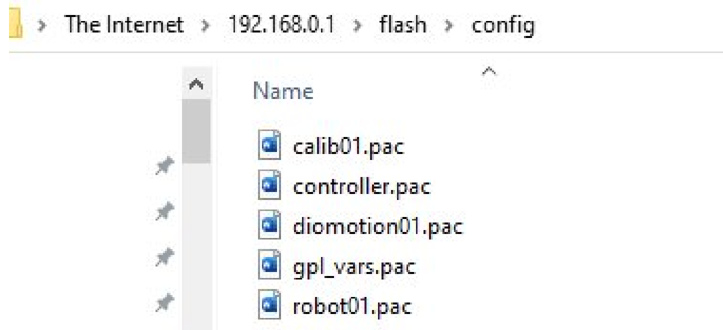
1. Use the Windows 10 File Explorer (NOT the Web Explorer) to access the flash directly. For example, type "ftp://192.168.0.1/flash" in the File Explorer address line if your controller is set to the default address 192.168.0.1. Otherwise use your controller IP address. This should bring up a window with the following files.



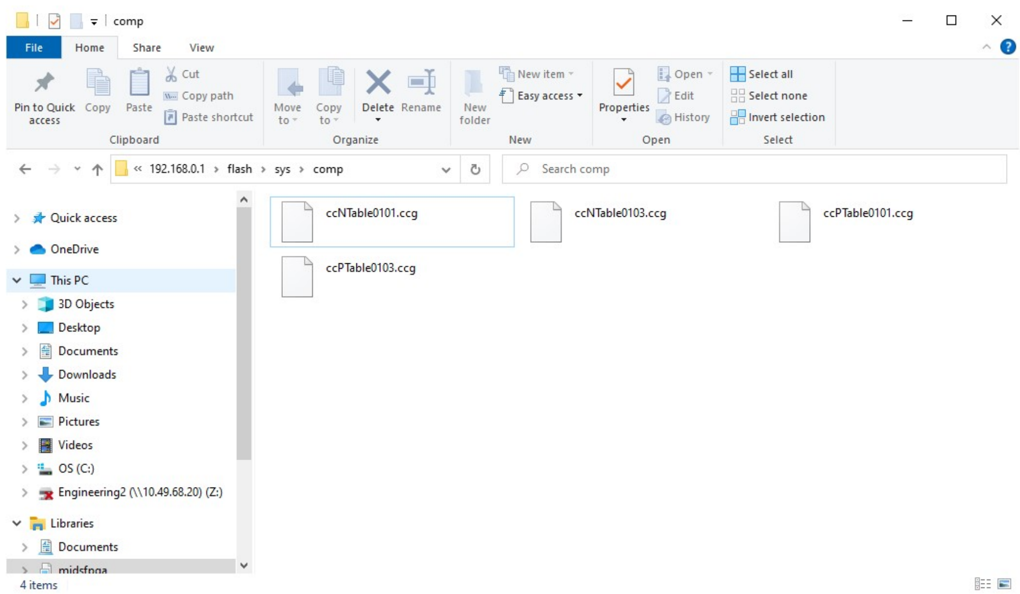
2. To load a GPL Project, such as CALPP, Open the “Projects” folder and paste the Project folder into this area. There may be several other projects (programs) loaded into this folder, which is stored in flash ram in the controller. A project folder is a software folder than may have several files inside it. You must load the entire folder, not just the files inside.

3. 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.

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. Wait at least 15 seconds after the copy is complete before turning off the controller. ***The robot must be re-booted after new PAC files are installed for them to take effect.***



5. If you wish to update the DDR motor cogging compensation tables, go back up to the top-level directory and open the FLASH file, then open the sys file, then open the comp file. Paste the new cogging compensation tables into the comp file, wait 15 seconds and then reboot the controller.



Updating GPL (System Software and Firmware)

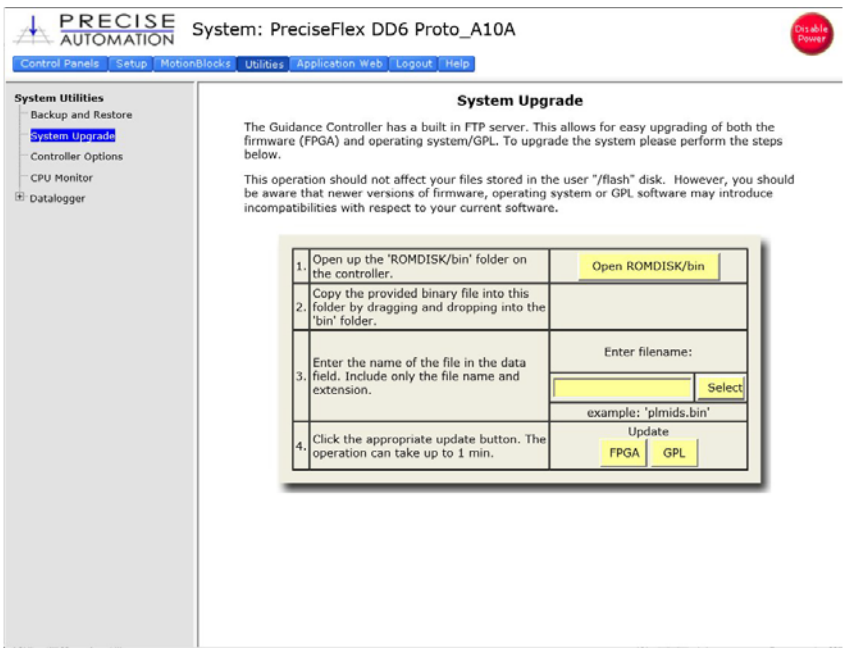
GPL (the system software and firmware are now a single file in GPL 5.0 and later) may be upgraded in the field. To perform an upgrade:

1. Obtain the appropriate upgrade software from Precise, in the form of a .gz file.

2. Use the Windows 10 File Explorer (NOT the Web Explorer) to access the ROMDISK GPL storage area directly. Type "ftp://192.168.0.1/ROMDISK/bin" in the File Explorer address line.

3. Paste the new GPL system file into this folder.

4. Using the Web Interface, under “Utilities”, click on “System Upgrade”.



5. Ignore the Open ROMDISK/bin button, this is for older versions of Windows. In box 3, click the Select button. A pop-up window will open showing the contents of the ROMDISK/bin folder. Highlight the GPL file and click again on Select in the pop-up window.

6. In box 4 click on update GPL. Wait until you see the “Update Complete” pop up. Then wait 15 seconds for the flash to store the data, then reboot the controller for the new version of GPL to take effect.

Recovering from Corrupted PAC Files

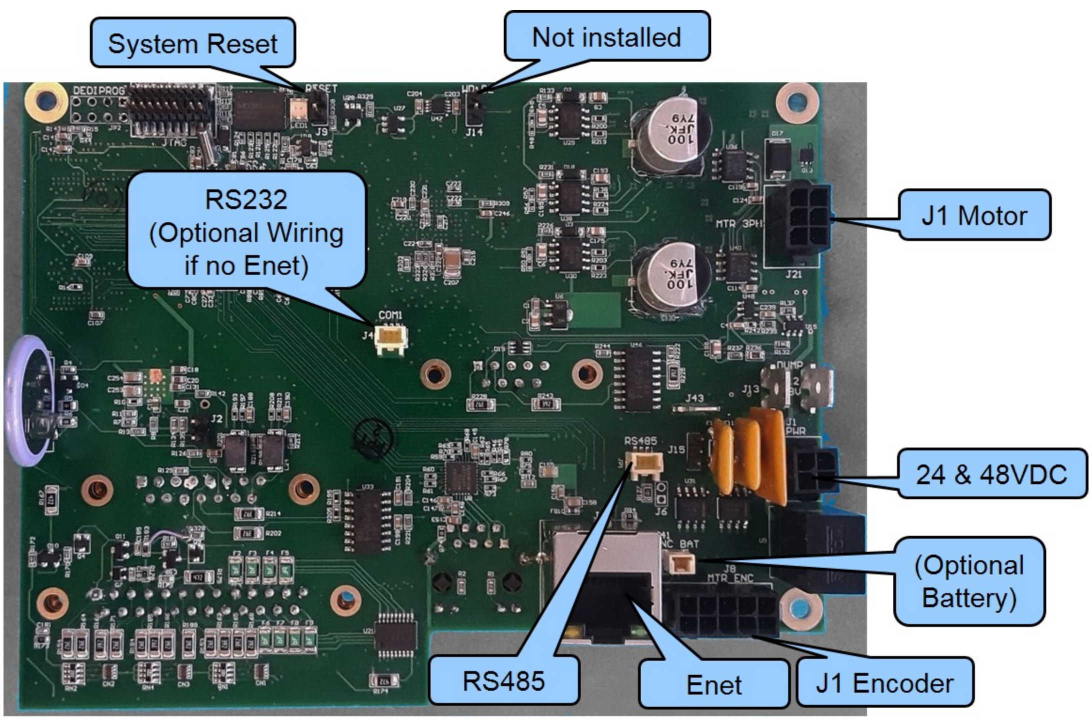
PAC files are configuration files that determine the configuration of the robot for the software, including the robot factory calibration data. These files are stored in Flash RAM. Flash RAM is also used to store robot programs. The Flash RAM requires some time for a complete write cycle. During the 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 and fails to wait a sufficient amount of time for the flash to be saved before turning off power.

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 backup 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 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 screws holding the connector panel in the base of the robot to access the PCA.
3. Move Jumper J9 (System Reset) 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. Follow the procedure above for updating PAC files.

Gripper Support

Gripper Introduction

This section discusses adding grippers to the PFDD4 and PFDD6 robots. For the PFDD4, there is a hollow output pulley in J4. For some electric grippers a slip ring is installed in this pulley. For other grippers pneumatic tubes, or a high-flex wire pigtail can be routed up through this hollow pulley, which allows all the gripper wiring to be kept inside the robot.

For the PFDD6, the 6th axis has a harmonic drive and motor installed, and there is not a wire path through the axis. Therefore, all gripper wiring must go through an external service loop from the gripper into a port on the J5 side cover. Since the gripper will rotate on J6, care should be taken to be sure the gripper pigtail has enough length to wrap around J6 as it rotates, but is not so long that it catches on items in the workcell. For some applications, helical coiled pneumatic tubing or even a helical coiled electrical pigtail may be desirable.

For the PFDD4 at least one customer has requested the Precise 23N Micro-titer plate handing gripper. This is a light duty gripper with 70mm of travel that is optimized to handle micro-titer plates for laboratory automation applications. It is designed for very light payloads typically 500 grams or less. It is controlled by a dedicated slave amplifier, the GSBP amp, which is connected through a slip ring in the J4 pulley.

Other commercial grippers can be attached to the PFDD4 and PFDD6 robots. These may be pneumatic or electric grippers. They may be interfaced in several ways. For pneumatic grippers and DIO controlled 24VDC electric grippers, they may be controlled by the IO available on either the J4 or J6 slave amplifier. See below for details.

The PFDD robots also have 100Mb Ethernet available for gripper control or camera interfacing. 24VDC is available at the IO connector on the slave amplifiers.

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 1000ms 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.

Software Revision

The Spring Gripper functionality is fully supported by GPL version 5.0 or later and PAC files PreciseFlex™ DD6 Proto_A10A May 2021 or later.

Controlling the 23N spring 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.

Gripper Squeeze (Simple Method)

The 23N gripper 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 are adequate to prevent dropping light payloads 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.

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 23N gripper 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 when the gripper is 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.

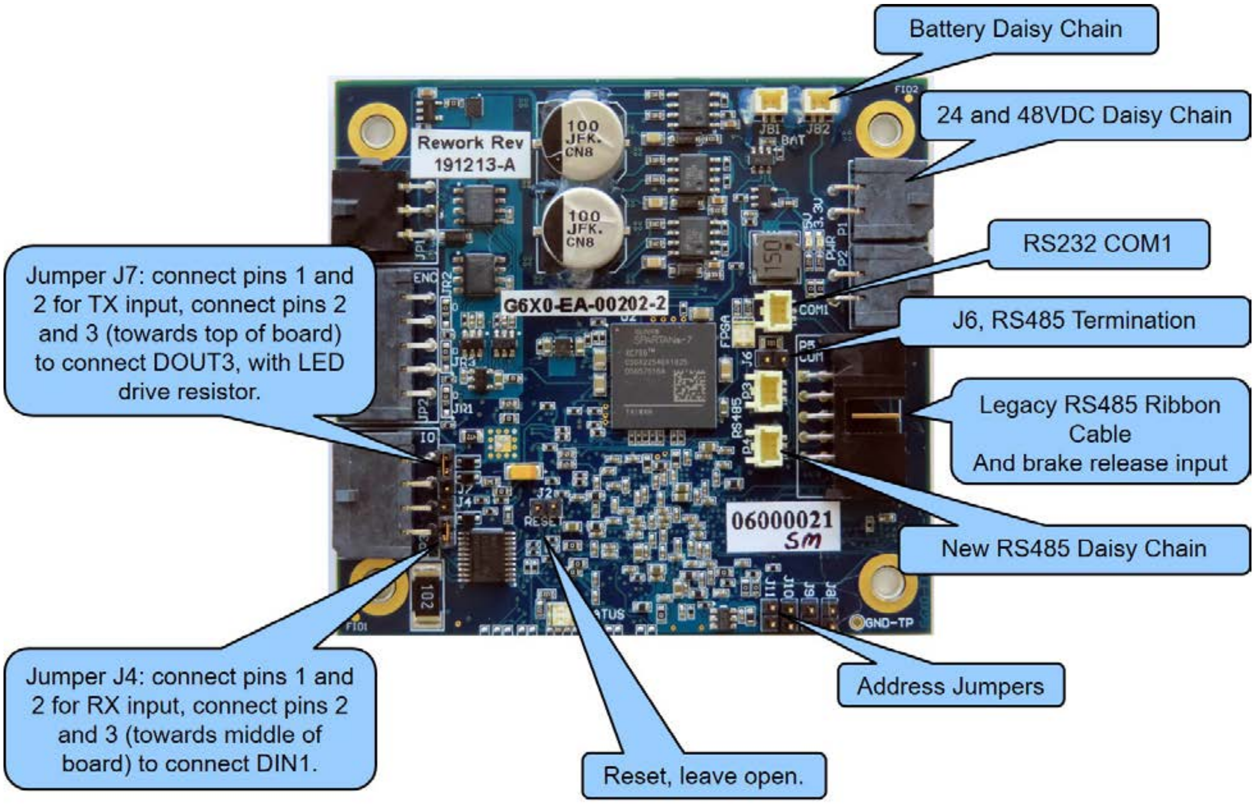
Grip Test and Squeeze Check

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 (GSBP) adds 3 general optically isolated digital outputs and 3 general optically isolated digital inputs to the standard digital I/O found on the PreciseFlex™ 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. Digital output 3 has a 1,000ohm resistor in series with the output to limit current to LED indicator lights.

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 two IO pins have optional assignments based on jumpers. For J4 connect pins 2 and 3 to connect Digital Input 1 to pin 6 and connect pins 1 and 2 to connect pin 6 to a line that goes back to the controller RS232 RXD input. For J7 connect pins 2 and 3 to connect Digital Output 3 to pin 3 and connect pins 1 and 2 to connect pin 3 to a line that goes back to the controller RS232 TXD input.



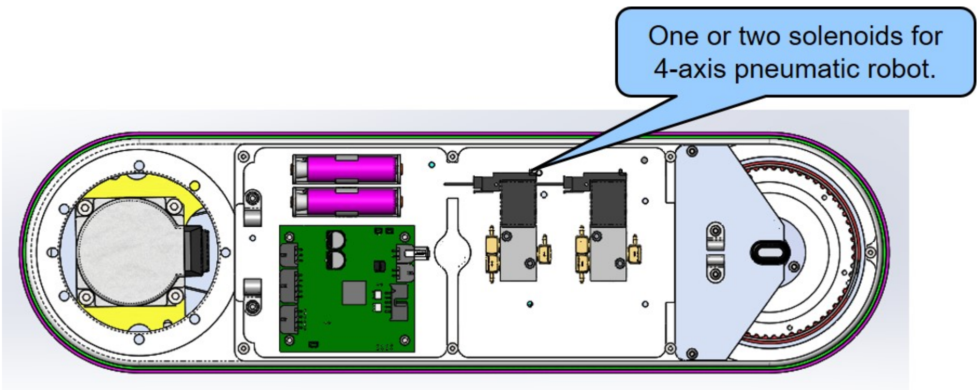
J4 and J7 on GSBP Board

The GSB I/O signals are shown in the table below for a 4-axis robot without the 5th GSBP for the 23N servo gripper. If the 23N servo gripper is installed, the addresses start with a “5” instead of a “4”. For the PFDD6, if a pneumatic or simple DIO controlled electrical gripper is installed and connected to the J6 GDBP, the addresses below start with a “6”.

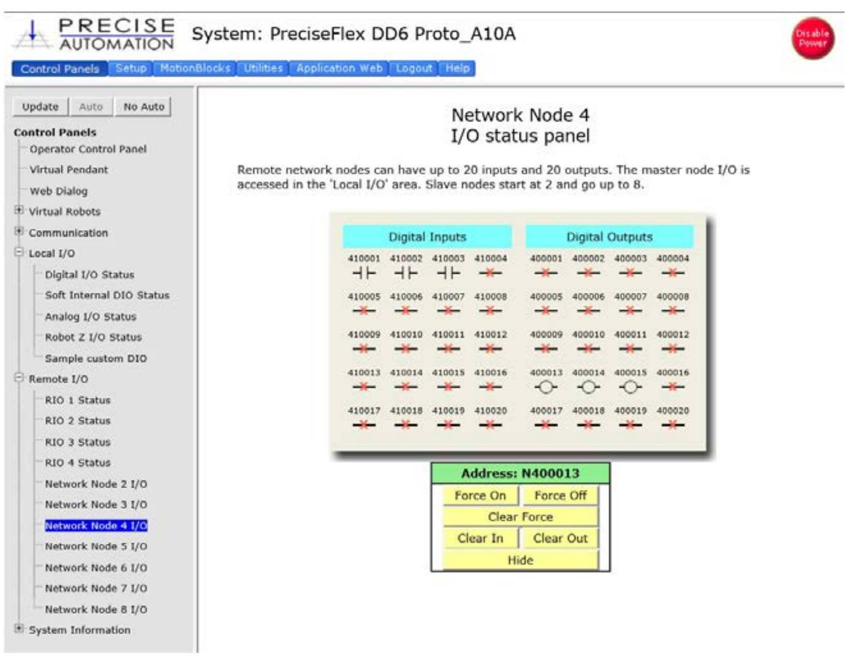
Pin	GPL Signal Number	Description
1	400013	Digital Output 1
2	400014	Digital Output 2
3	400015	Digital Output 3 (LED Output or TXD, select with J7)
4		24 VDC output
5		GND
6	410001	Digital Input 1 (Pushbutton on some Electric Grippers or RXD, select with J4)
7	410002	Digital Input 2 (End of travel sensor option)
8	410003	Digital Input 3

Optional Pneumatic or Vacuum Gripper

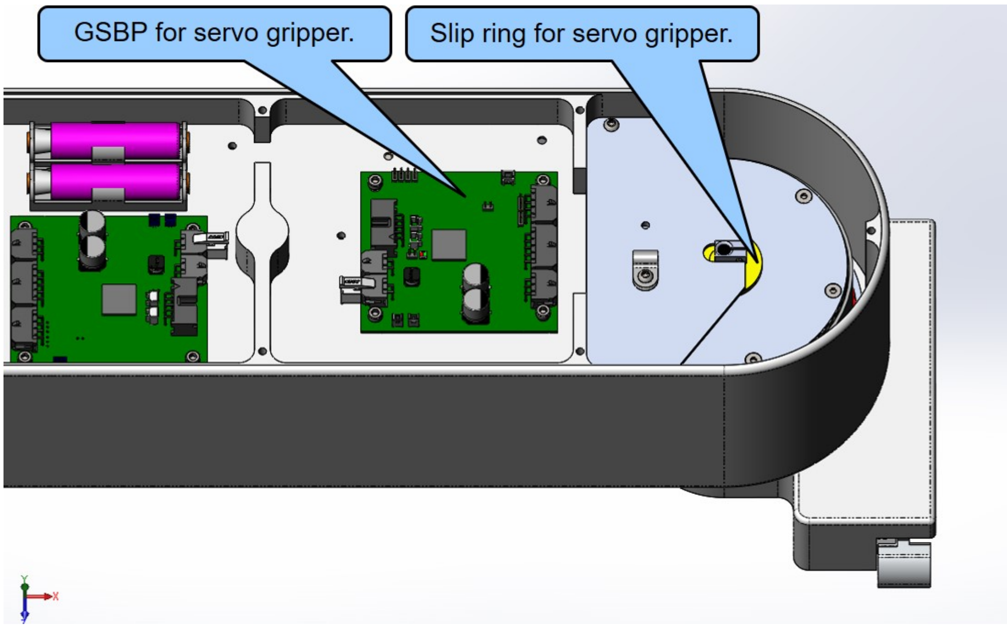
Note it is possible to order robots with or without a servo gripper. ***However, when changing from a servo gripper to a pneumatic or vacuum gripper the PAC files in the robot MUST be changed to remove the servo gripper control configuration.*** Contact Precise application support. Then, the cabling must be changed per below to support the IO signals to drive pneumatic or vacuum solenoids.



The default gripper configuration for the PFDD4 and PFDD6 is tubing installed to support two solenoids, with a single solenoid installed. For the PFDD4 this solenoid is installed in the outer link and wired to the J4 GSBP local motor controller digital output 1. The address for digital output 1 on this controller is 400013. It can be toggled manually from the operator interface as shown below by clicking on the radio button, which will bring up the IO control panel shown below. In GPL it may be controlled with the Signal.DIO command. See the schematics section for solenoid wiring.



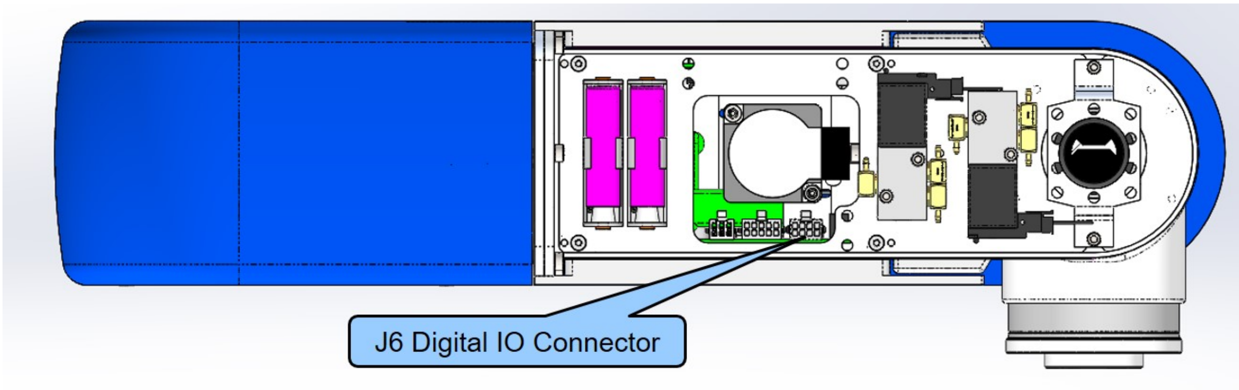
For the PFDD4 with the 23N servo gripper option, the solenoid(s) are replaced by an additional GSBP controller for the servo gripper, which is connected through a slip ring.

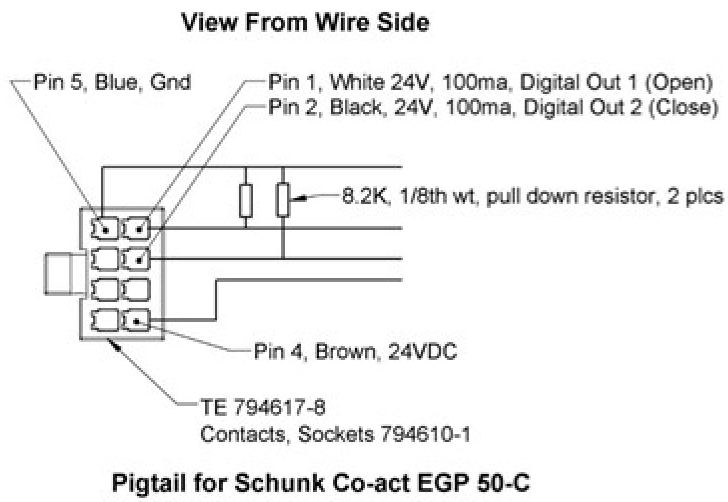


For applications with heavier payloads where an electric gripper is preferred to a pneumatic gripper, there are third-party electric grippers available which can be attached to the ISO flange with a bracket. Some of these are similar in performance to a pneumatic gripper; they have a limited travel of 6-12mm, are powered by 24VDC, and toggled open or closed by a digital signal. For example, the Schunk Co-act EGP 64 has 4 grip force settings, 65N, 110N, 170N, and 230N, runs on 24V, max 2A, and can accommodate fingers up to 50mm in length. This gripper can be interfaced to the J4 GSBP controller by using the IO connector on the J4 or J6 GSBP for 24VDC, Gnd, Digital Output 1 and Digital Output 2 to open and close the gripper. The EMI MPPM3210 gripper is similar but only requires a single digital output. The IO connector can supply a maximum of 2.5A for 24VDC. Contact Precise applications for application notes on interfacing these grippers.

For the PFDD6, the access to the solenoids and J6 GSBP controller is under the foam side cover, which is attached with Velcro. The side cover can be easily removed, and pneumatic lines attached to one or both solenoid valves, then routed out through the harness bracket and hole in the foam side cover. In this case the address to toggle the valve is 600013, as the valve is controlled from the J6 controller.

In a similar manner to the 4-axis robot, simple electric grippers can be attached to the output flange of the 6-axis robot, by plugging into the DIO connector.





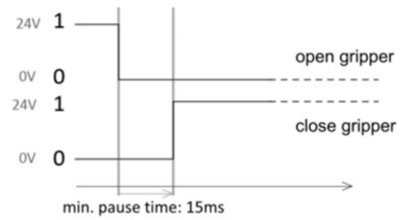
Electric Gripper Pigtail

Mounting Bracket

A flange adapter may be required to attach various grippers to the DIN ISO 9409 flange on the DDR robots. Contact Precise Application Engineering for drawings and models for several grippers. In particular the Schunk Grippers have a pigtail coming out the side of the gripper. When mounting these grippers on a PFDD4, a special flange adapter with a notch to route the gripper cable back inside the J4 output pulley is required in order to route the cable up to the J4 controller in the PFDD4 outer link.

Electrical Instructions (DIO truth table)

Function	Pin 2 (WTE)	Pin 4 (BLK)
Gripper drive de-energized (standstill; the motor is short circuited)	0	0
Gripper open	1	0
Gripper closed	0	1
Reset error (standstill; the motor is short circuited)	1	1



Pause time between two commands (from Schunk document). For more information, see the EGP Electrical Specifications document.

Software Methods

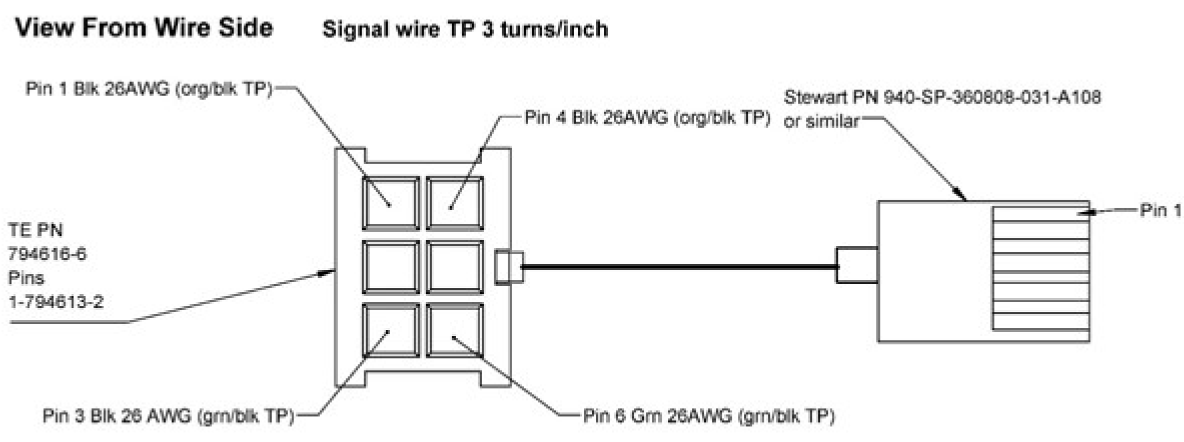
Opening and closing the gripper is as simple as triggering the proper outputs as indicated in the DIO truth table above. The following GPL subroutines were used during testing.

```
Const Dim OpenSignal As Integer = 400013 (4 axis) or 600013 (6 axis)
Const Dim CloseSignal As Integer = 400014 (4 axis) or 600014 (6 axis)
Public Sub SchunkOpen
    Move.WaitForEOM()
    Signal.DIO(CloseSignal) = False
    Thread.Sleep(80)
    Signal.DIO(OpenSignal) = True
    Thread.Sleep(500)
End Sub

Public Sub SchunkClose
    Move.WaitForEOM()
    Signal.DIO(OpenSignal) = False
    Thread.Sleep(80)
    Signal.DIO(CloseSignal) = True
    Thread.Sleep(500)
End Sub

Public Sub SchunkReset
    Signal.DIO(OpenSignal) = True
    Thread.Sleep(80)
    Signal.DIO(CloseSignal) = True
    Thread.Sleep(2000)
    Signal.DIO(OpenSignal) = False
    Thread.Sleep(80)
```

```
    Signal.DIO(CloseSignal) = False
    Thread.Sleep(80)
End Sub

Public Sub SchunkDeenergize
    Signal.DIO(OpenSignal) = False
    Thread.Sleep(80)
    Signal.DIO(CloseSignal) = False
    Thread.Sleep(80)
End Sub
```

Ethernet Connector in the Outer Links

Both the PFDD4 and the PFDD6 have an Ethernet connector available in the outer link. This 6 pin connector contains two twisted pairs that bring 100BaseT Ethernet from the main control board in the base of the robot to the outer link. Users may wish to connect a standard Ethernet connector to the Ethernet Pigtail. Connection details are given below for the mating connector.



Ethernet Signal	Enet Conn Number	TE Pin Number
TP1 (Black)	1	1
TP1 (Orange)	2	2
TP2 (Black)	4	3
TP3		NC
TP3		NC
TP2 (Green)	5	6
TP4		NC
TP4		NC

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. Metric ball end hex drivers, 4.0mm and 5.0mm for M5 and M6 SHCS.
5. A pair of tweezers or needle nose pliers.
6. A pair of side angle cutters.
7. Small flat bladed screw driver, with 1.5mm wide blade typical

Trouble Shooting

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

Symptom	Recommended Action
System error message generated	
“ESTOP not Enabled”	Check 9 pin Dsub for Estop jumpers.
“Encoder Battery Low”	Replace absolute encoder battery on back of column or outer link
“Encoder Battery Down”	If encoder cable has been disconnected, recalibrate robot. If battery voltage has dropped below 2.5V replace encoder battery and recalibrate robot.
“Encoder Operation Error”	Joint rotated too quickly with power off. See Procedure below.
“Encoder Data, Accel/decel Limit Error”	Encoder cable may be damaged and encoder is getting intermittent communication, causing apparent jumps in position. Check encoder connectors. Replace motor/encoder or encoder only on DD axes.

“Encoder Communication Error”	Check encoder connectors. 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”	Check energy dump resistor is connected. 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, check for free motion, if OK replace slip ring.
“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.

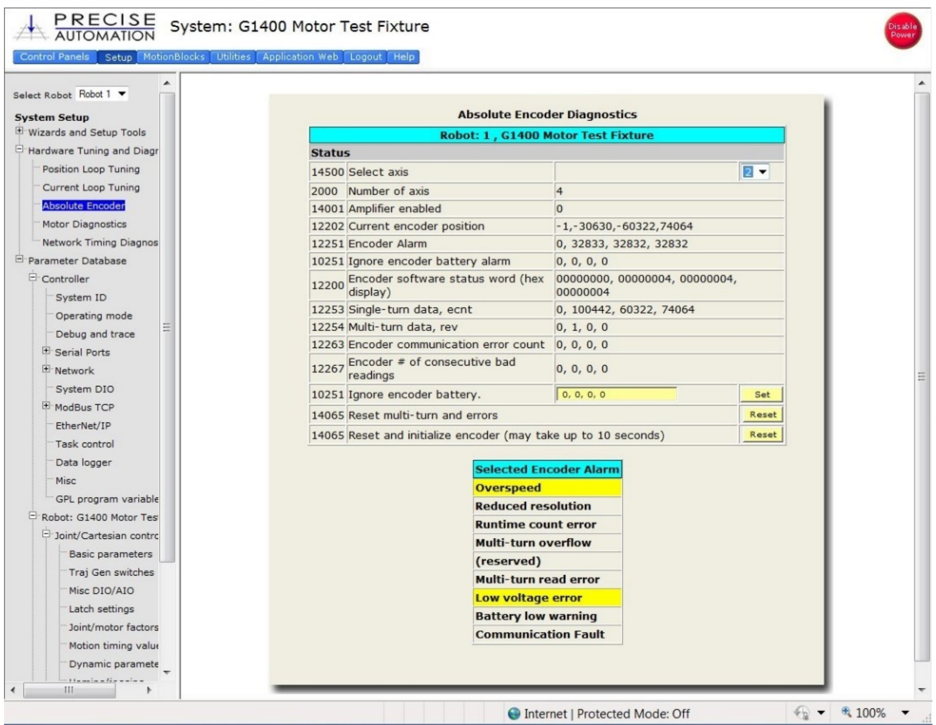
Encoder Operation Error

The PFDD robots are equipped with absolute encoders that keep track of the robot position even when AC power to the robot is disconnected. ***<u>There are batteries in the back of the Z column of the robot and outer link that provides standby power to the encoders for the Z axis and outer link motors. J1 and J3 axes have single turn absolute encoders and do not require standby batteries</u>***. 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. See the Calibration Procedure below for the joint angles in the Calibration Position.

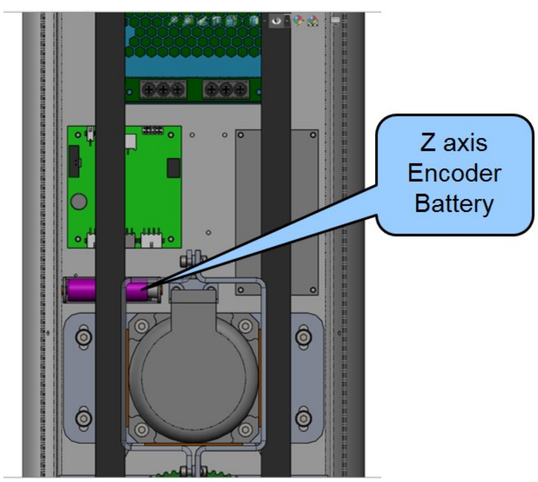
If the robot joints after this procedure followed by homing are different from the above, then the robot needs to be re-calibrated. See procedure below.

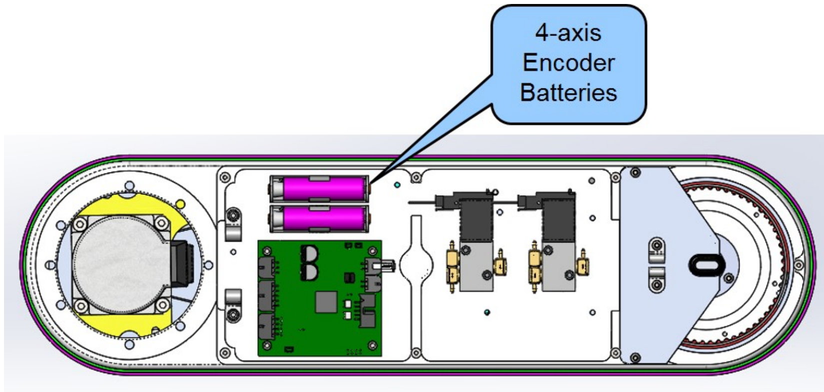
Replacing the Encoder Batteries

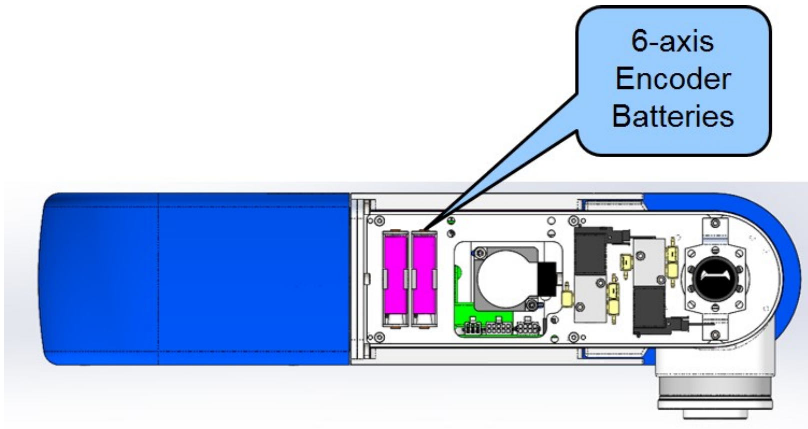
DANGER: Before replacing the encoder battery, the AC power should be disconnected. Removing the front cover allows access to the AC power terminals.

The Encoder Batteries are 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. 2.0mm hex driver or hex L wrench

Parts Required:

New Encoder Battery PN G1S0-EC-X0007

To replace the Encoder Battery for the Z axis the user must:

1. Turn off power to the robot and remove the AC power plug.
2. Remove the curved back cover from the Z column.
3. Replace the battery.
4. Replace the curved back cover on the Z column.

To replace the Encoder Battery in the 4-axis outer link the user must:

1. Remove the outer link foam cover from the sides of the outer link. It is attached with Velcro.
2. Remove the outer link top foam cover. It is attached with Velcro.

3. Remove the outer link top sheet metal cover.
4. Replace the two batteries.
5. Replace the covers.

To replace the Encoder Battery in the 6-axis outer link the user must:

1. Remove the outer link foam cover from the side of the of the outer link with the cable grommet. It is attached with Velcro.
2. Replace the two batteries.
3. Replace the cover.

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

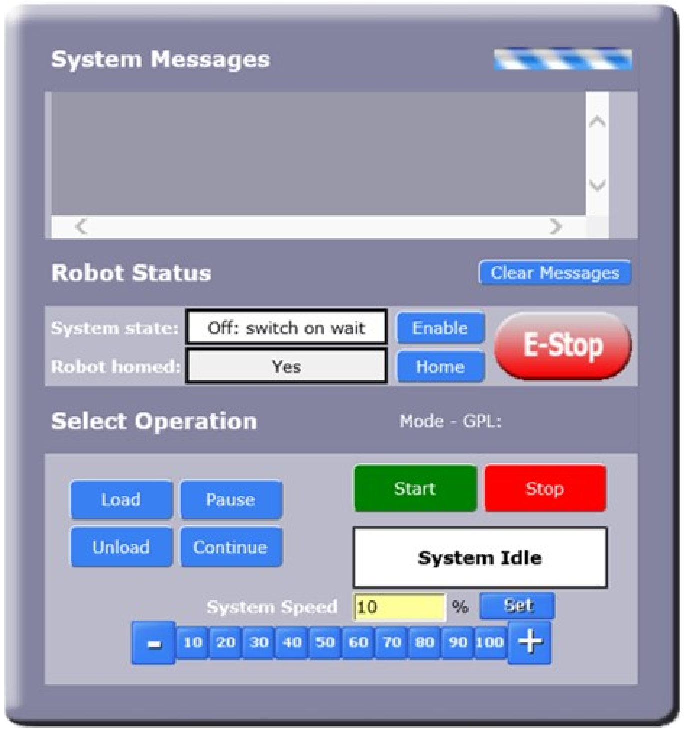
Cal_PP is a service program that must be run to set the zero positions of the absolute encoders on each motor. The zero positions must be re-established if any of the motors are replaced, their cables disconnected for a long duration, or the encoder backup battery has been disconnected.

Cal_PP is supplied on the flash drive of the robot and is available in the Support area of the Precise website. 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).

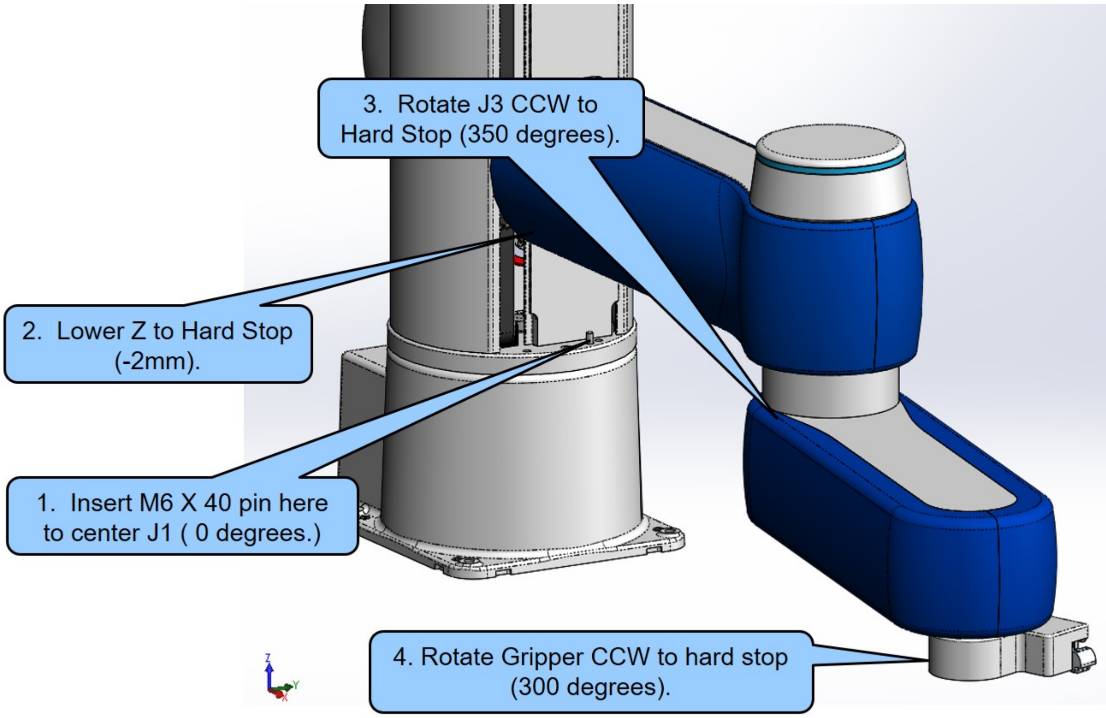
Tools Required: Calibration Kit with M6 X 40mm dowel, 2 M5 X 45mm Socket Head Cap Screws, and 2 M5 jam nuts.

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

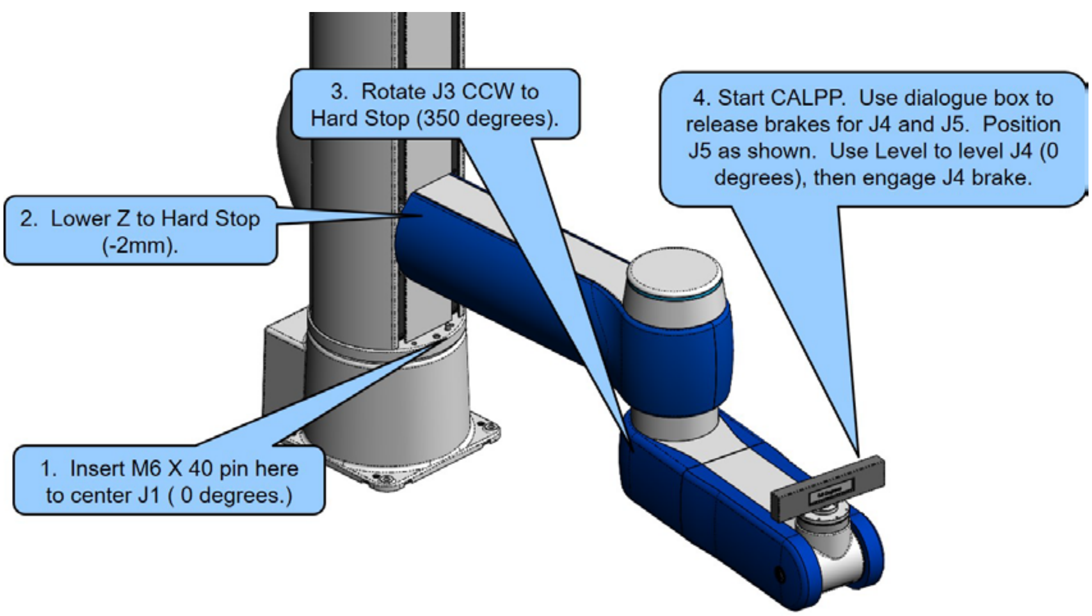
1. Enable power to the robot’s controller, but do not turn on power to the motors. (This procedure should be executed with motor power off. The robot does not move.)
2. The CALPP program is typically installed at the factory and should be loaded into flash memory. Using the Web based Operator Control Panel first unload any currently loaded programs. Press ***"UnLoad".*** This ensures that no GPL project is currently selected for execution. Press the "***Load***" button. This displays a popup list of Projects that are in the flash disk and available for execution. In the popup display, click on CALPP_RevXX. When you are ready to execute the Project, press "***Start***". 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.



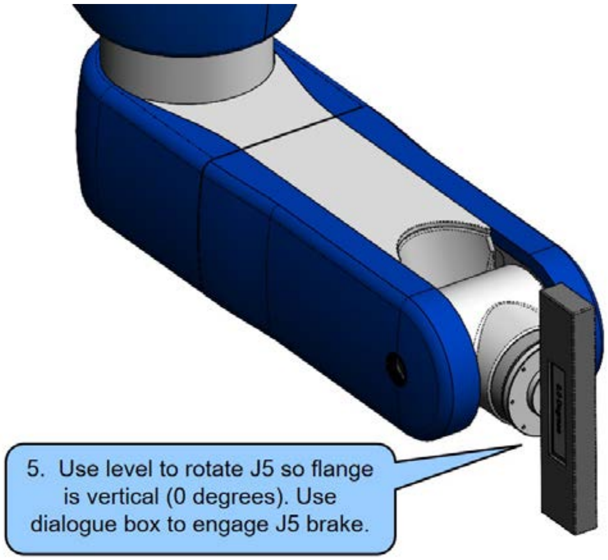
3. Manually move the robot into the configuration shown below.
4. Ensure Z-axis is resting on the lower hard stop by releasing the Z axis brake by pushing on the brake release button under the inner link while supporting the robot arm with your hand, and lowering the robot arm gently until it rests on the lower hard stop.
5. Install an M6 X 40mm Calibration Pin in the base platter as shown.
6. Rotate J3 CCW when viewed looking down until its hard stop.
7. Start CAL_PP_XX
8. For the PFDD4 Rotate J4 CCW when viewed looking down until its hard stop.
9. For the PFDD6 position the robot following the steps below.



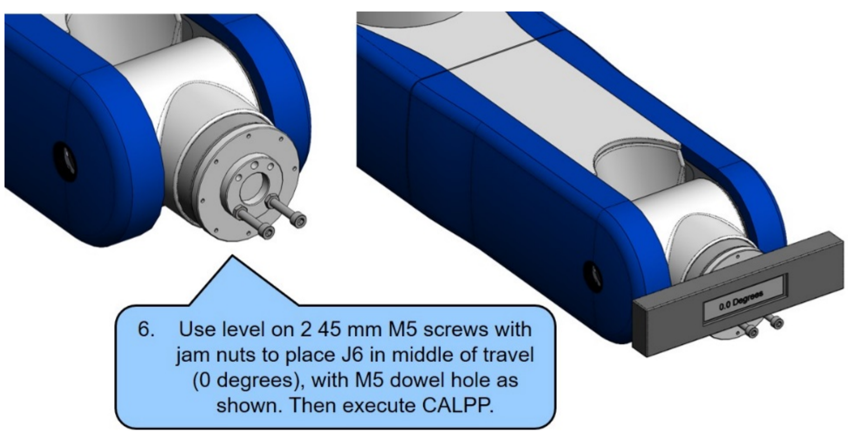
CALPP Position PFDD4



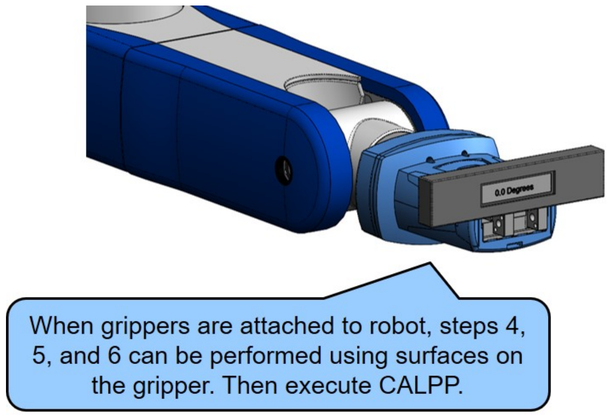
CALPP Position PFDD6 Step One



CALPP Position PFDD6 Step Two

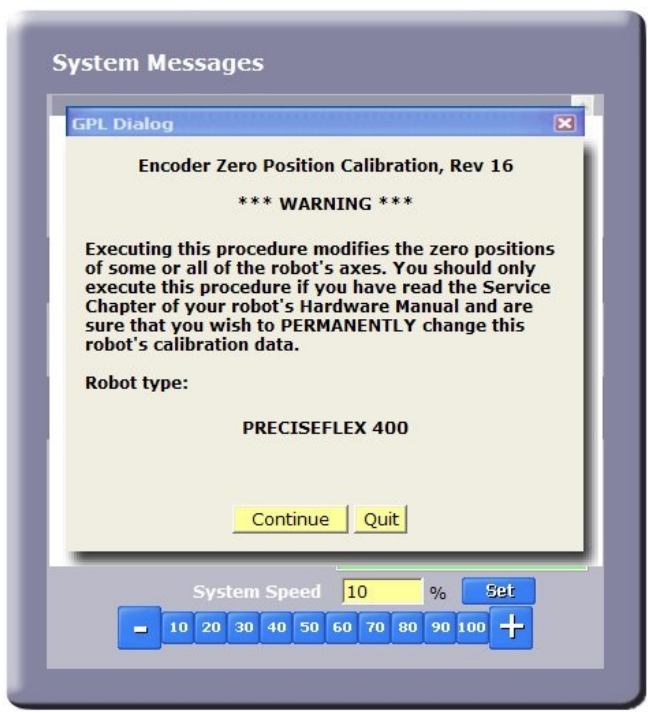


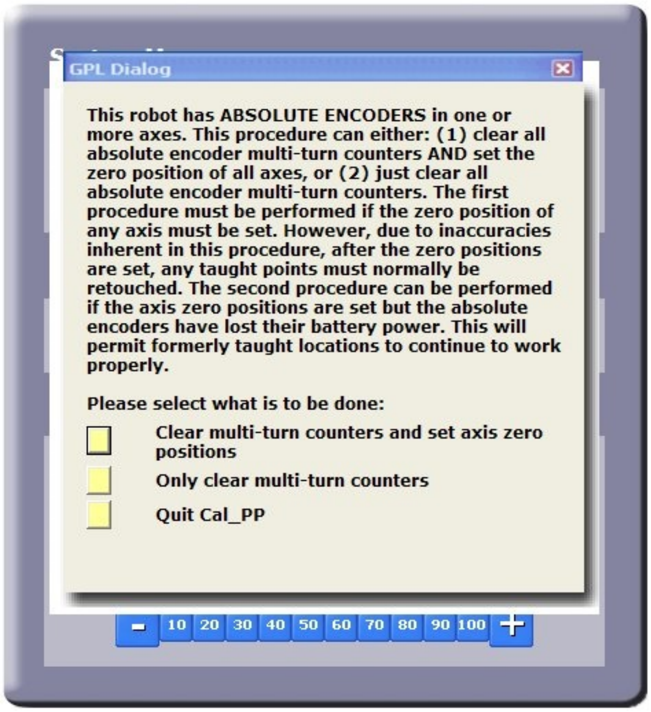
CALPP Position PFDD6 Step Three



CALPP Position PFDD6 With Gripper

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





b. A dialogue box will appear that allows the J4 and J5 brake to be released for PFDD6 to allow it to be positioned correctly for CALPP. After the robot is correctly positioned, execute CALPP.
c. The CALPP application takes about 1 minute to run.

11. After calibration is complete, use the brake release button and move the Z axis a few millimeters away 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 pin is removed from the base rotation plate.**
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 harmonic drives may need service after 20,000 hours, depending on the payload and duty cycle. The 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 in this manual for replacing belts and motors, only experienced service technicians should attempt these procedures.

General Belt Tensioning

The PFDD robots have been designed to make belt tensioning very simple. See Appendix D for belt tension specifications.

Tensioning or Replacing the J2 (Z Column) Belts

Tensioning the 1st Stage Belt

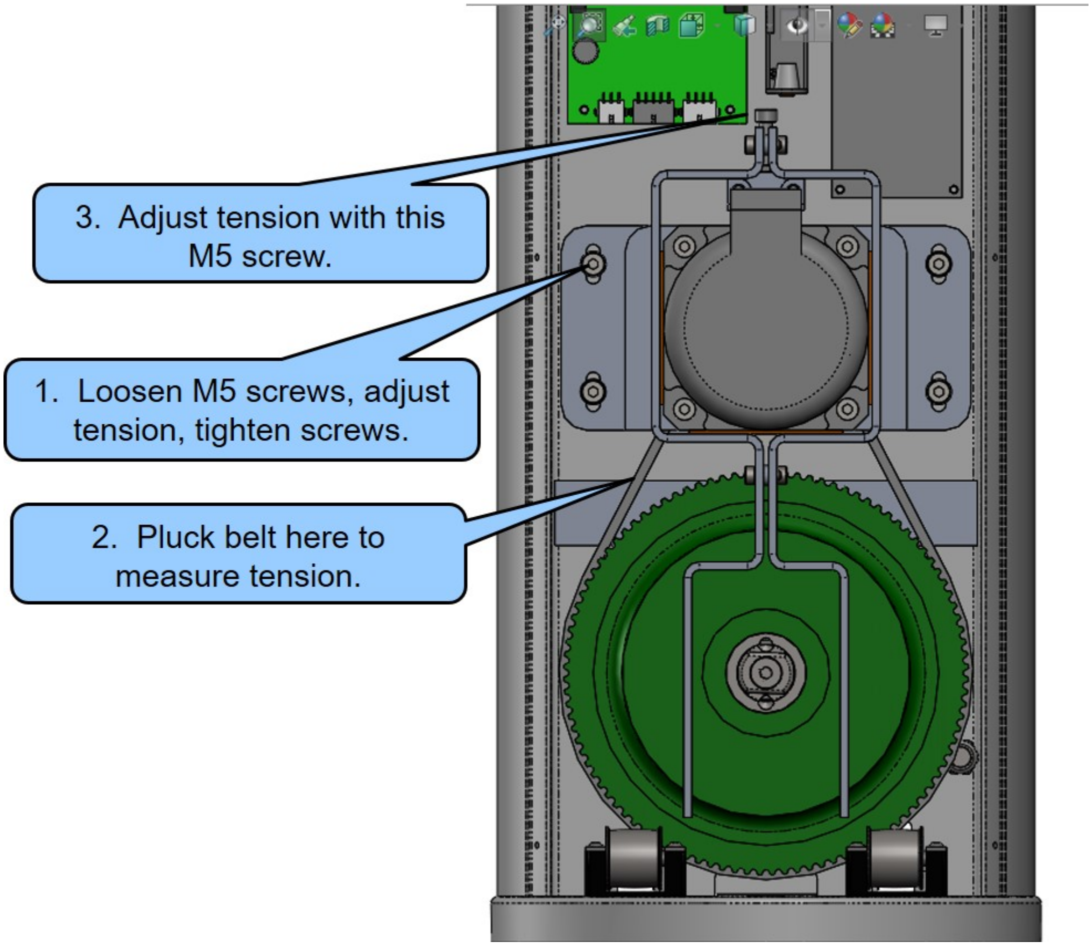
DANGER: Before tensioning the timing belts or replacing any motors, the AC power should be disconnected. Removing the rear cover allows access to the AC power terminals.

Tools Required:

1. Gates Sonic Belt Tension Meter, Model 508C
2. 2.0mm hex driver or hex L wrench
3. 4.0mm hex ball end driver

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 curved rear cover of the robot.
3. Loosen the 4 M5 locking screws on the J1 Motor Mount Bracket to allow the Mount Bracket to slide up and down.
4. Measure the tension with the belt tension meter as described in Appendix E.
5. Adjust the M5 Tension Screw.
6. After adjusting the Tension Screw, the M5 locking screws should be tightened to lock the assembly in place and the Rear Cover should be replaced.



Tensioning the 2nd Stage Belt

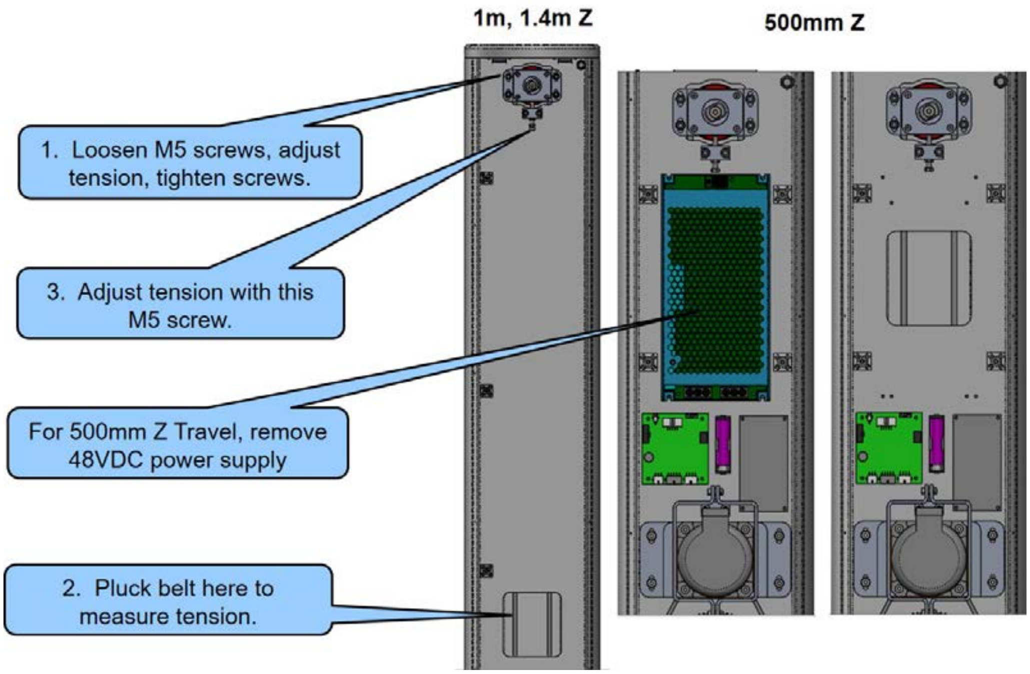
DANGER: Before tensioning the timing belts or replacing any motors, the AC power should be disconnected. Removing the rear cover allows access to the AC power terminals.

Tools Required:

1. Gates Sonic Belt Tension Meter, Model 508C
2. 2.0mm hex driver or hex L wrench
3. 3.0mm hex driver
4. 4.0mm ball end hex

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 curved rear cover of from the Z column.
3. Loosen the 4 M5 locking screws on the Z idler block.



4. For the 1.42m and 1.0m Z travel robots, the tension screw and belt tension access hole can be accessed at this point. For the 500mm Z travel robot it is necessary to remove the 48VDC power supply in order to access the belt tension access hole and the tension screw. As an alternative, the top cover and front cover may be removed to access the stage 2 timing belt from the front of the robot. This is the easier method if tape seals are not installed.
5. Adjust the second stage Z belt tension per Appendix E, tighten clamping screws and replace parts. It may be helpful to move the carriage upwards on the taller robots so that the distance from the top idler pulley to belt attachment on the Z carriage is 500mm, in order to get a higher frequency on the belt, which can be easier to measure with the tension meter. Use the 500mm span in this case.

Replacing the Z column Stage One Timing Belt

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

Tools Required:

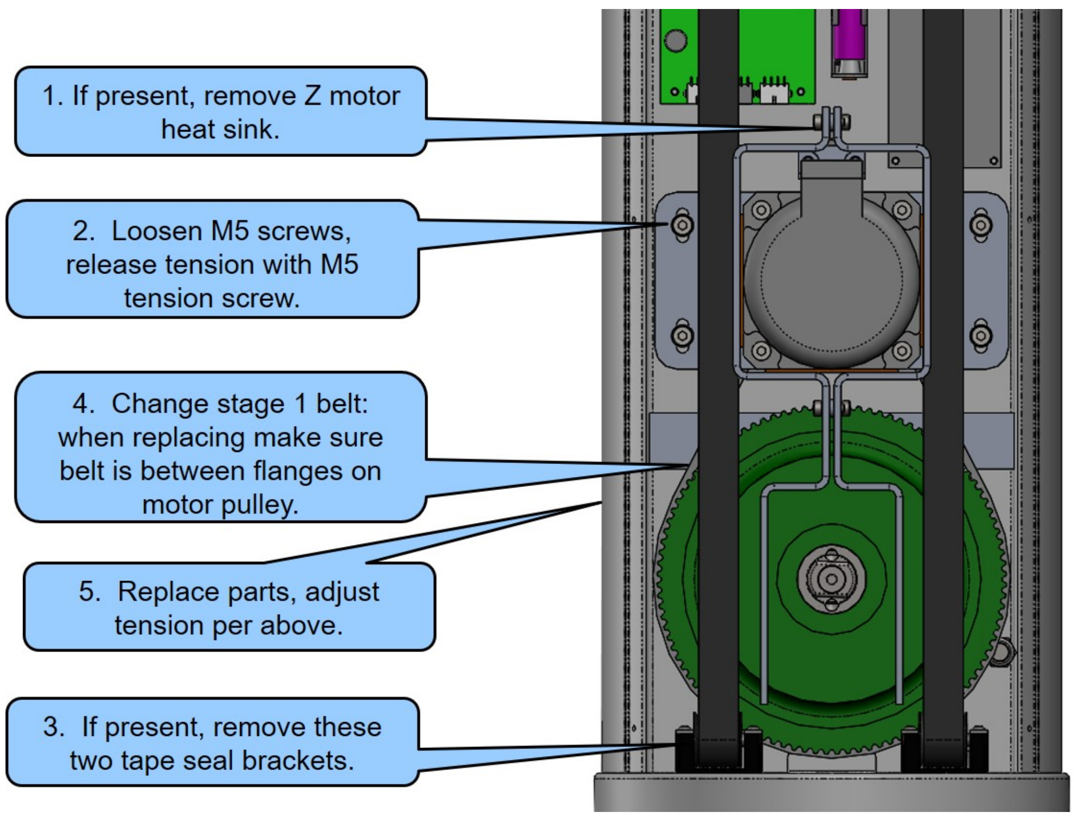
1. 2.0mm hex driver
2. 4.0mm ball end hex driver
3. 2.5mm hex driver or hex L wrench

Spare Parts Required:

1. J2 Stage One Belt, PN PFD0-MC-X0006.

The user must:

1. Turn off the robot power and remove the AC power cord.
2. Remove the curved rear cover from the Z column.
3. Remove the Z motor heat sink if installed.



4. Loosen the M5 Z motor bracket clamping screws and release the tension on belt with the M5 tension screw.
4. If present, remove the tape seal brackets. It may be necessary to release the tension on the tape seals first. In this case, slide the top plate laterally after removing screws from the top plate and front cover to release the tension on the tape seals

and allow the front cover to be removed. It is not necessary to remove the tape seal tension brackets from the top of the Z carriage.

5. Replace the Z stage one belt. When hooking the belt around the Z motor pulley, make sure the belt is inside the flanges on the Z motor pulley.
6. Adjust belt tension per above, replace parts.
7. Recalibrate robot.

Replacing the Z column Stage Two Timing Belt

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

Tools Required:

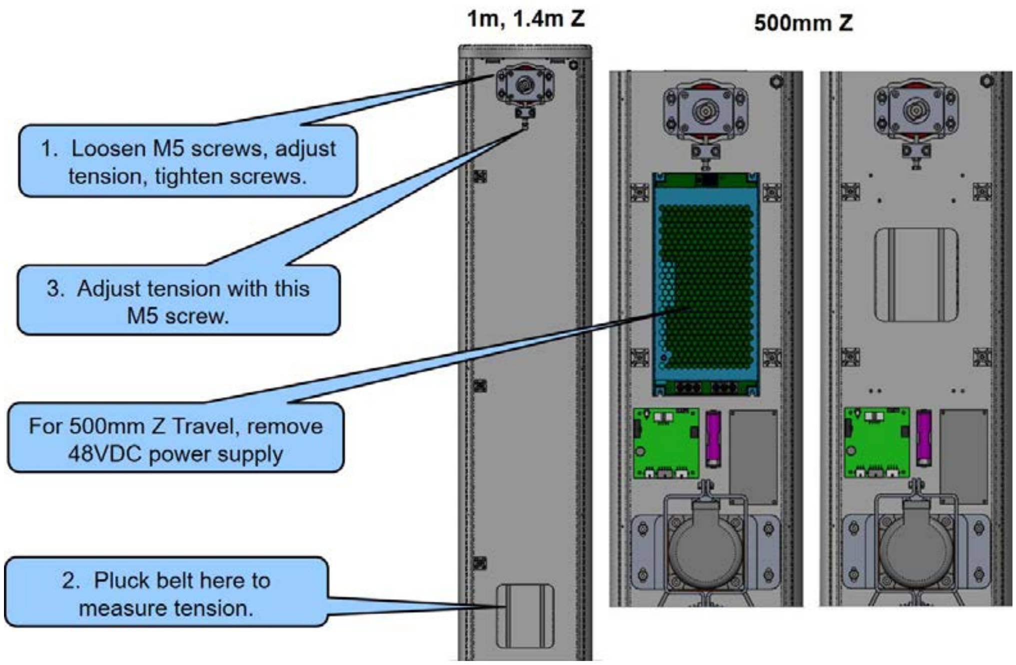
1. 2.0mm hex driver
2. 3.0mm hex L wrench
3. 3.0mm hex driver
4. 4.0mm ball end hex driver

Spare Parts Required:

1. J2 Stage One Belt, PN PFD0-MC-X0003 (500mm, 1000mm, 1420mm stroke).

The user must:

1. Move the Z carriage to 640mm height for the 1000mm and 1420mm Z travel robots, or 380mm height for the 500mm Z travel robot.
2. Turn off the robot power and remove the AC power cord.
3. Remove the curved rear cover from the Z column.



5. Remove the top plate and front Z cover. If tape seals are present, slide the top plate laterally after removing screws from the top plate and front cover to release the tension on the tape seals and allow the front cover to be removed. It is not necessary to remove the tape seal tension brackets from the top of the Z carriage.
6. Support the Z carriage and links with a stick, boxes, or other means to prevent it from dropping when the belt clamp is removed.
7. For the 500mm Z travel robot, remove the 48VDC power supply.
8. Remove the Z belt clamp which should be accessible through the access cutout in the Z extrusion, change the Z belt, and replace the clamp.
9. Tension the Z belt per above.
8. Replace parts.
9. Recalibrate robot.

Tensioning or Replacing the Belts in the PFDD4

Tensioning the Belts in the PFDD4 Outer Link

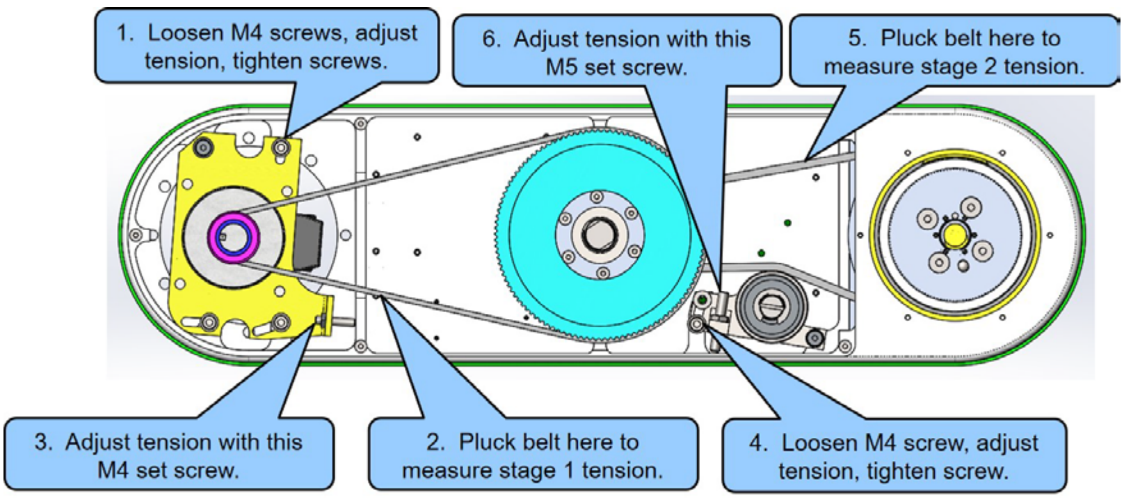
DANGER: Before tensioning the timing belts, the AC power should be disconnected. Removing the front cover allows access to the AC power terminals.

Tools Required:

1. Gates Sonic Belt Tension Meter, Model 508C
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 J4 stage 1 Timing Belt, the user must:

1. Move the robot arm to a convenient height to allow access to the outer link of the robot.
2. Turn off the robot power and remove the AC power cord.
3. Remove the foam side cover on the outer link and the foam bottom cover. These are attached with Velcro.
4. Remove the sheet metal bottom cover.



5. For stage 1, loosen the 3 M4 clamping screws, and the locknut on the tension set screw, adjust tension per Appendix E, and tighten screws.
6. For stage 2, loosen the M4 clamping screw and locknut on the tension screw, adjust tension per Appendix E, and tighten screws.
7. Replace the covers.

Replacing the Belts in the PFDD4 Outer Link

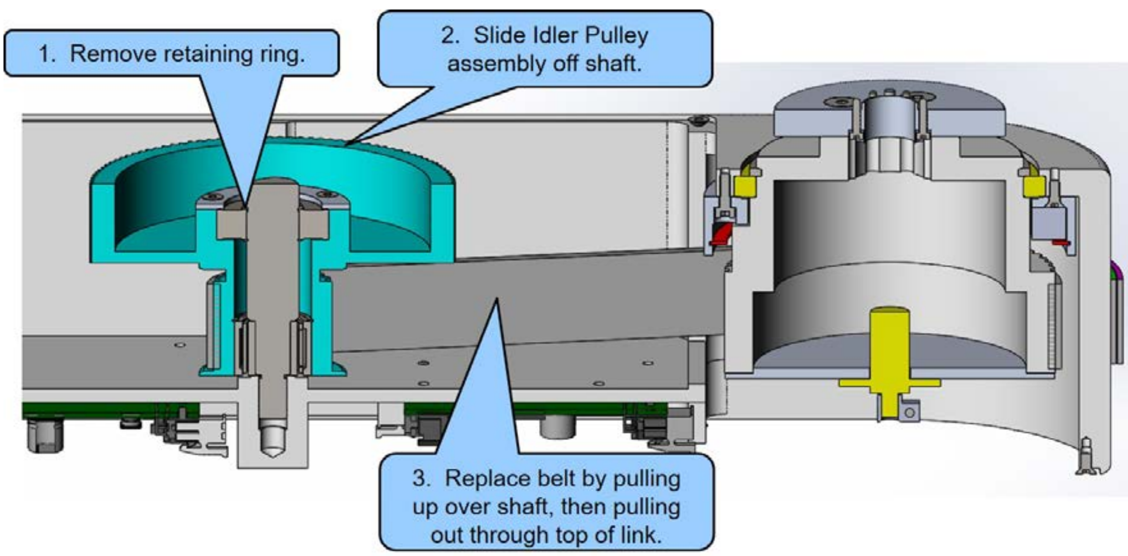
DANGER: Before replacing the timing belts, the AC power should be disconnected. Removing the front cover allows access to the AC power terminals.

Spare Parts Required:

1. J4 Stage One Belt, PN Gates GT3 Belt 3mm pitch, 564-3M, 15mm wide (PFD0-MC-X0050)
2. J4 Stage Two Belt, PN Gates GT3 Belt 5mm pitch, 3MR-564, 25mm wide (PFD0-MC-X0051)

The user must

1. Remove the top and bottom covers per above to access the belts.
2. For the Stage One Belt, loosen the M4 clamping screws, release the belt tension with the tension set screw, and replace the belt.
3. For the Stage Two Belt, remove the Stage One Belt per above, then release the belt tension.
4. Remove the retaining ring that retains the large idler pulley, remove the idler pulley.
5. Pulley the Stage Two Belt up over the idler pully shaft, then remove by pulling out thru the top of the outer link over the output pulley.
6. Replace parts, re-tension the belts, replace covers.
7. Recalibrate the robot.



Replacing the Outer Link Motors or Harmonic Drives in the PFDD6

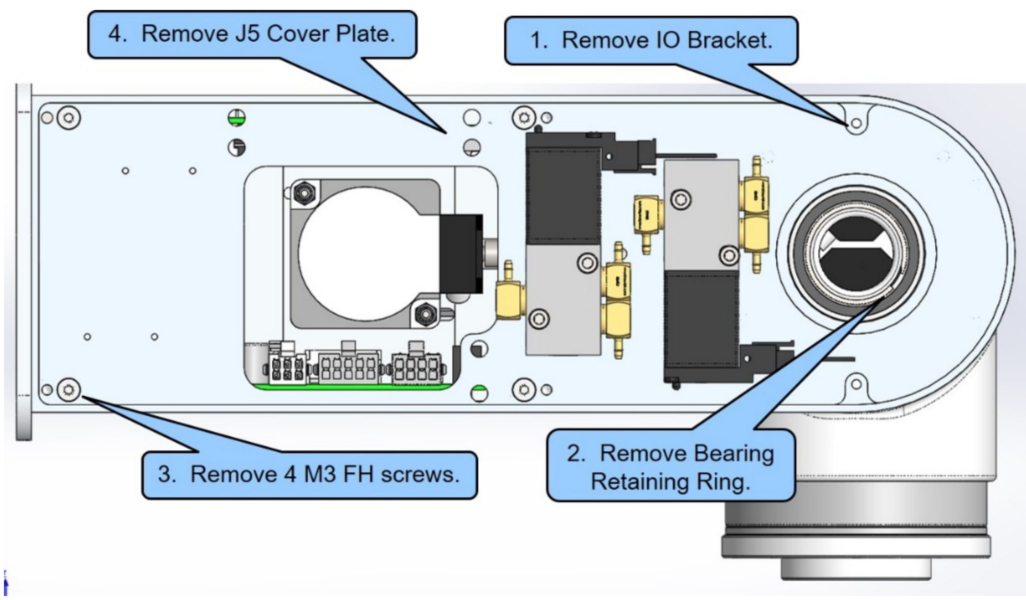
DANGER: Before replacing any parts, the AC power should be disconnected. Removing the front cover allows access to the AC power terminals.

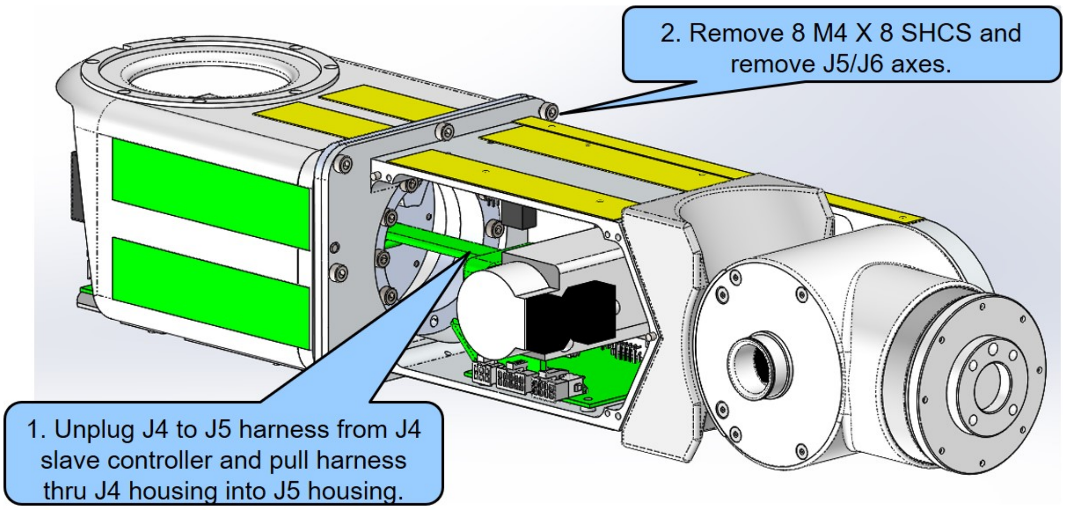
Tools Required:

1. 3.0mm hex driver
2. 2.5mm hex driver
3. 2.0mm hex driver

The motors and harmonic drives in PFDD6 are not items that can be replaced in the field. There are two major subassemblies in the DD6 outer link. These are the J5/J6 assembly and the J4 assembly. These are factory replacement items. In order to replace one of these assemblies in the PFDD6, the user must:

1. Remove the foam covers from the outer link, including J4 and J5.
2. Remove the J5 cover plate from the J5/J6 axes.
3. Unplug the J4 to J5 harness from the J4 slave amplifier, pull harness through J4 into J5 housing.
4. Remove the J5/J6 axes from J4 by removing 8 M4 X 8 SHCS.
5. At this point the J5/J6 assembly may be returned to the factory and a new assembly attached.





To replace the J4 assembly, the M5 screws which attach the J4 housing to the J3 output shaft must be removed, at which point the J4 assembly may be returned to the factory and an replacement may be installed.

Replacing the Robot Main 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. 5.0mm socket driver

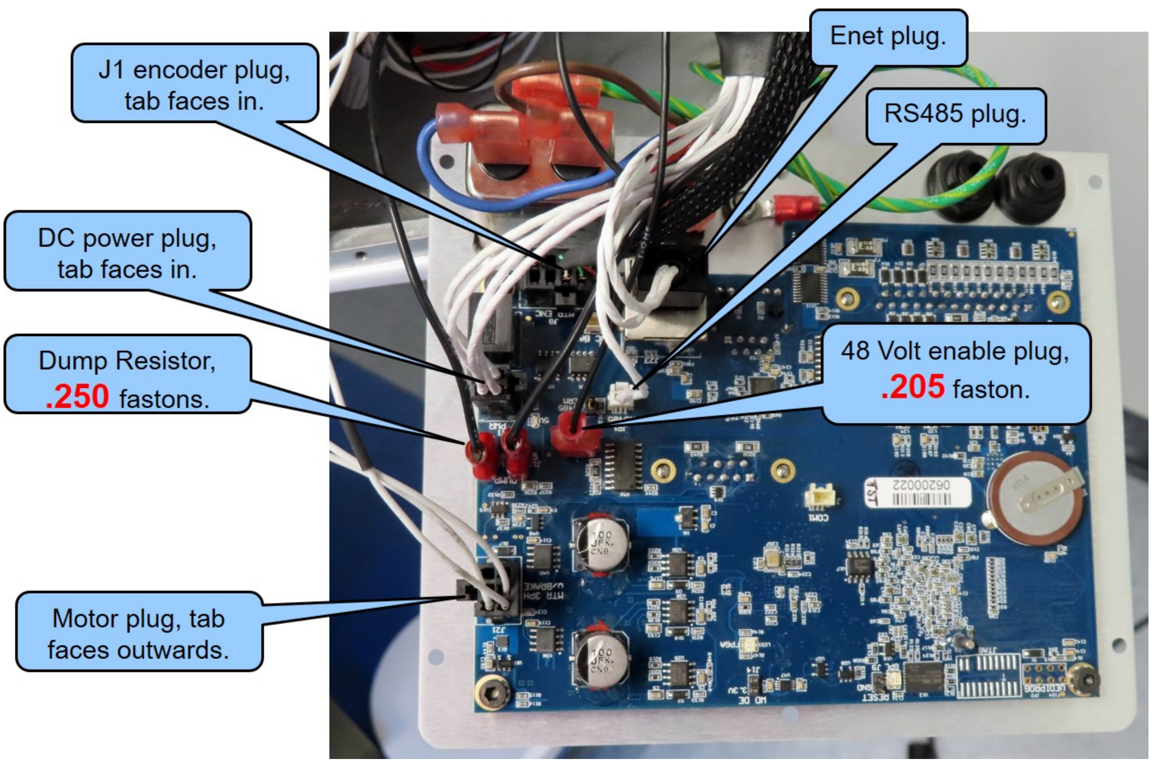
Spare Parts Required for main robot controller

1. PreciseFlex™ PFD0 Controller PN P/N PFD0-EA-00001

Prior to replacing the controller, if the controller will boot up, the user may wish to make copies of both the robot PAC files (config directory), any project files (projects directory), and the "Sys" files (sys directory), to a PC. These files can be copied using ftp://192.168.0.1/flash or the IP address of the controller.

To replace the Robot Controller the user must:

1. Turn off the robot power and remove the AC power cord.
2. Remove the connector panel from the base of the robot by removing M3 X 6 flat head screws.



3. Remove main robot controller, PFD0-EA-00001 by removing 3 M3 X 8 SHCS and the D-Sub standoffs from the connector side of the panel.
4. Replace the controller and connect the wires as shown above.
5. Replace the connector panel.
6. Reload the robot PAC files (config directory), any project files (projects directory), and the “Sys” files (sys directory), from a PC. These files can be copied using ftp://192.168.0.1/flash or the IP address of the controller.

7. Recalibrate the robot.

FTP directory /flash/ at 192.168.0.1

To view this FTP site in File Explorer: press Alt, click **View**, and then click **Open FTP Site in File Explorer**.

Up to higher level directory

```
01/01/1970 12:00AM      Directory .
04/13/2020 02:41PM      Directory ..
01/27/2020 05:19PM      Directory config
04/03/2020 03:35PM      Directory projects
04/03/2020 03:34PM      Directory sys
```

Replacing the Z axis Slave Controller

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

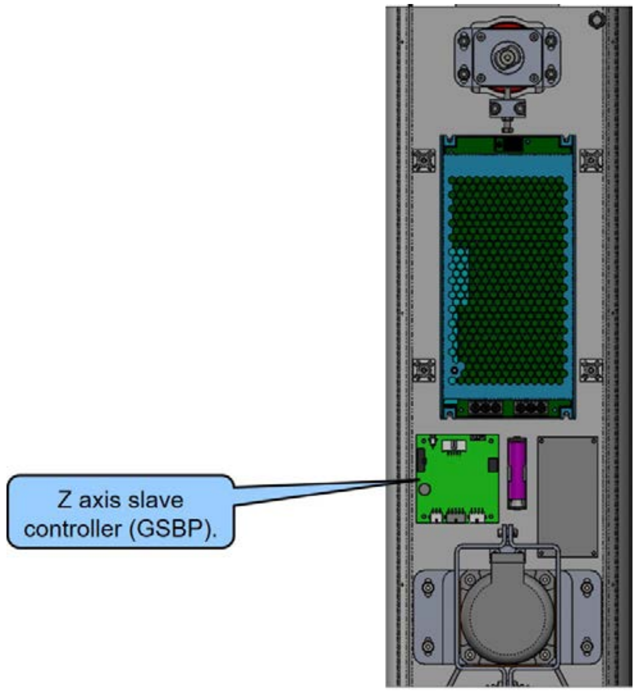
Tools Required:

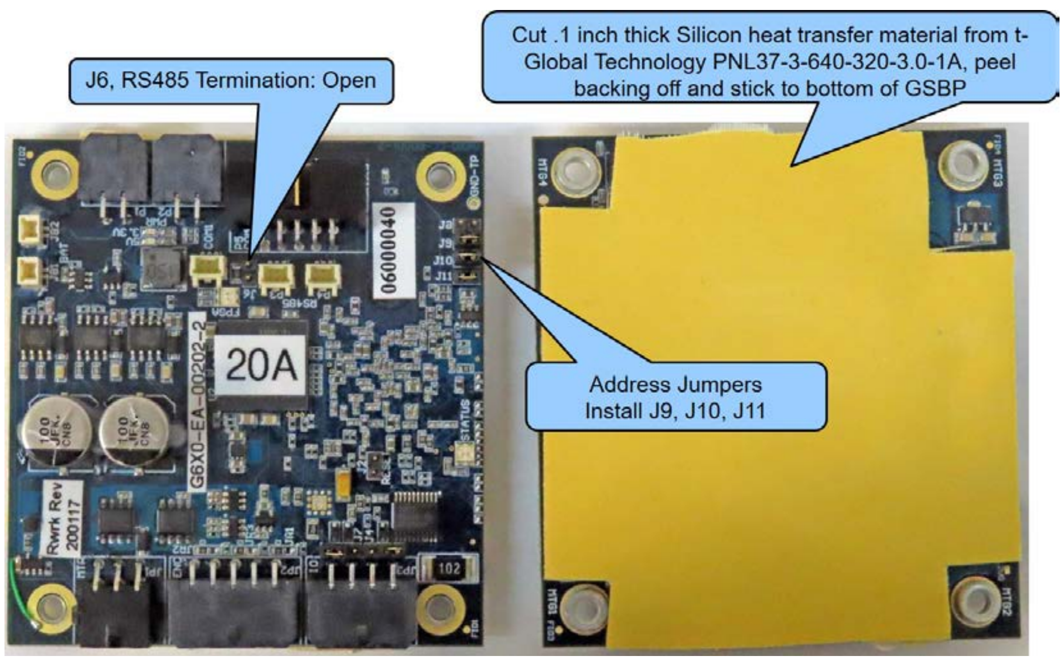
1. 2.0mm hex driver
2. 2.5mm hex driver

Spare Part Required: G6X0-EA-00202 with thermal pad

To replace the Z axis Slave Controller the user must:

1. Turn off the robot power and remove the AC power cord.
2. Remove the curved read cover from the Z column.
3. Remove the Gripper Controller by removing 4 M3 X 10mm SHCS and unplugging the cables.
4. Replace the Slave Controller and re-attach the harness.
5. Set the jumpers correctly for the address and termination.
6. Replace the curved rear cover.
7. Recalibrate the robot.


Z axis slave controller (GSBP).


J6, RS485 Termination: Open
Cut .1 inch thick Silicon heat transfer material from t-Global Technology PNL37-3-640-320-3.0-1A, peel backing off and stick to bottom of GSBP
Address Jumpers
Install J9, J10, J11
20A
06000040

Replacing the J3 axis Slave Controller

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

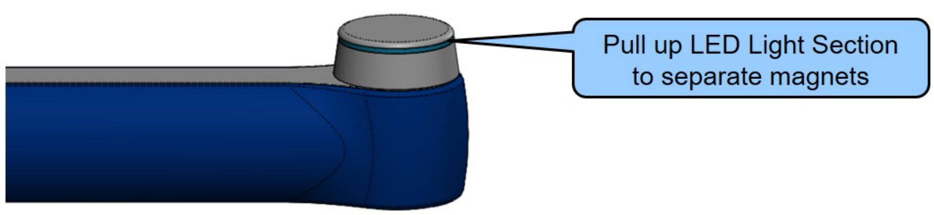
Tools Required:

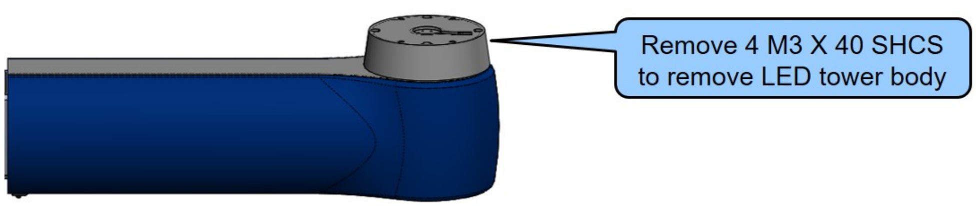
1. 2.5mm hex driver

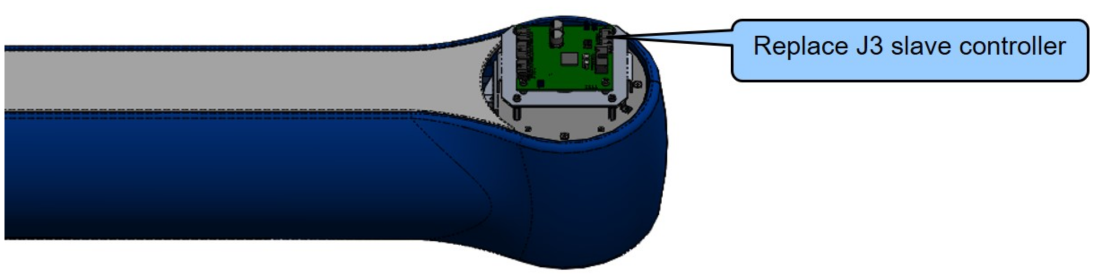
Spare Part Required: G6X0-EA-00202

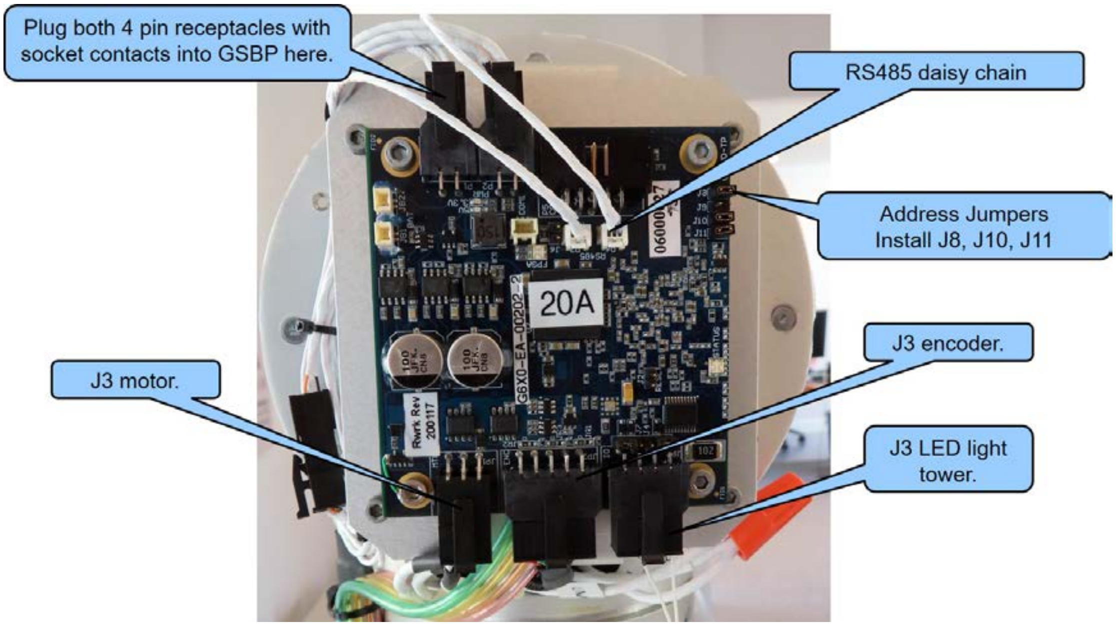
To replace the J3 axis Slave Controller the user must:

1. Turn off the robot power and remove the AC power cord.
2. Remove the LED light tower cover by pulling up on the light section to release magnets.
3. Remove the LED light tower body by removing 4 M3 X 40 SHCS. Unplug LED pigtail.
4. Replace the Slave Controller and re-attach the harness.
5. Set the jumpers correctly for the address and termination.
6. Replace the LED light tower parts.
7. It is not necessary to recalibrate the robot if only this controller is replaced.









Replacing the J4 or Gripper Slave Controller in PFDD4

> **DANGER:** Before replacing any Controller, the AC power should be removed.

Tools Required:

1. 2.5mm hex driver

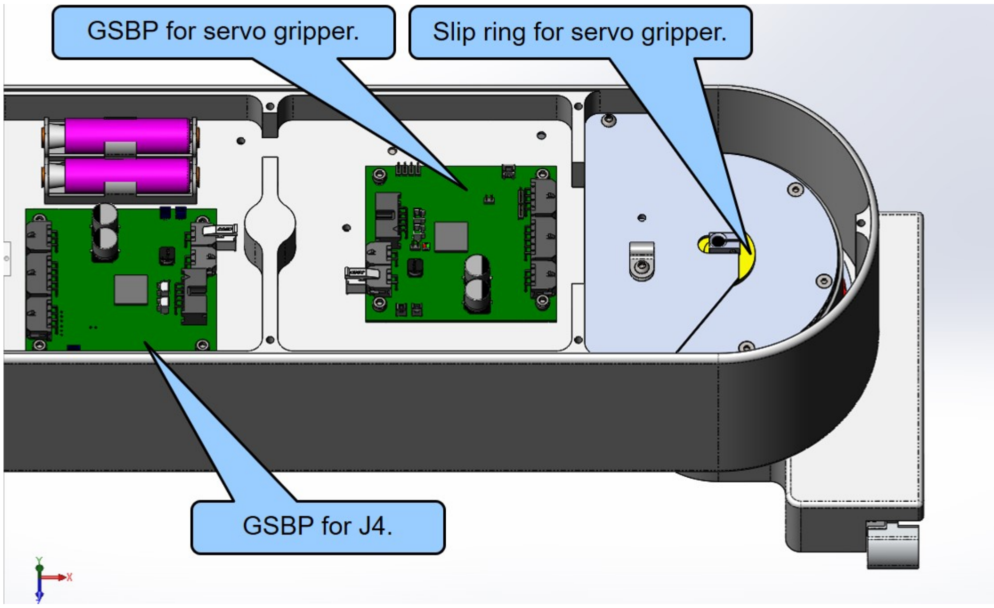
Spare Part Required:

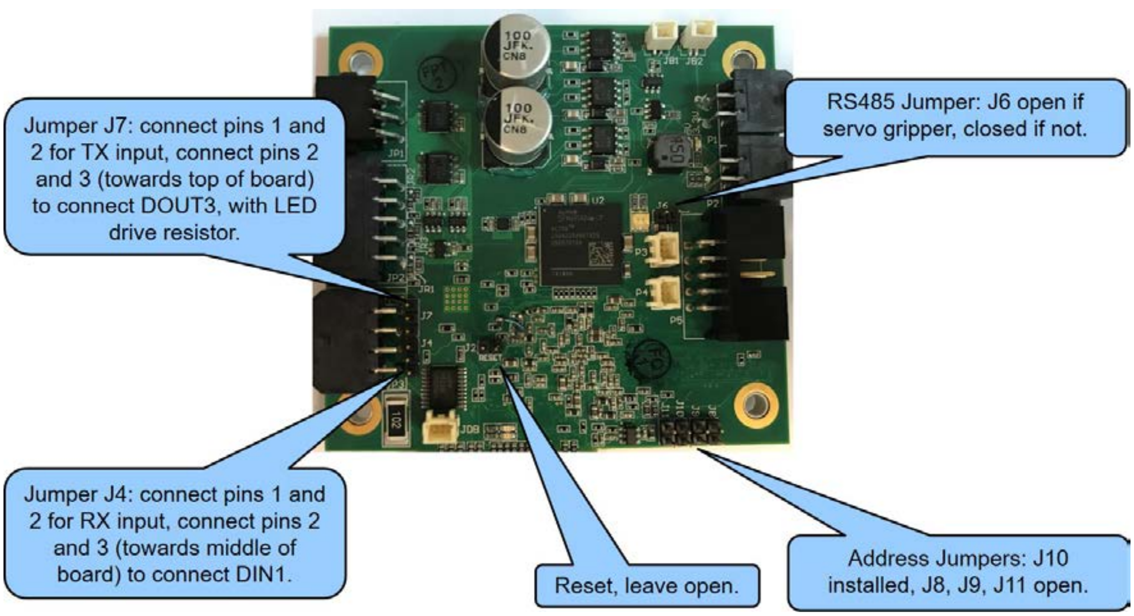
1. G6X0-EA-00202 for J4 axis (20A, differential encoder)
2. G6X0-EA-00101 for Gripper (10A, single ended encoder)

To replace the J4 axis Slave Controller in the PFDD4 the user must:

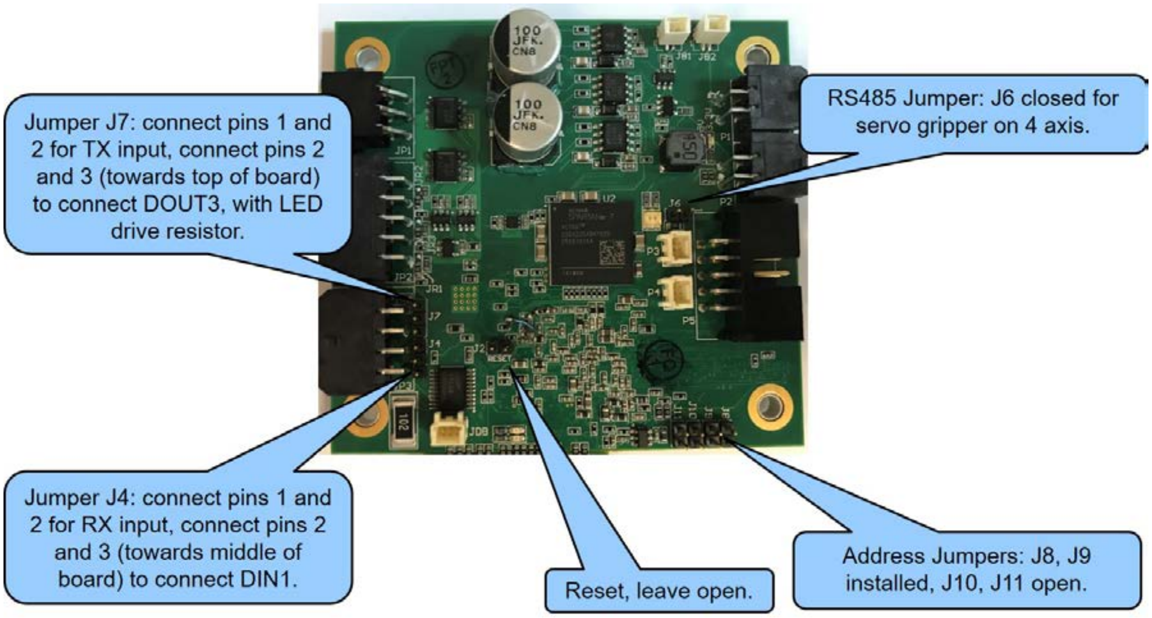
1. Turn off the robot power and remove the AC power cord.
2. Remove the foam side cover from the outer link. It is attached with Velcro.
3. Remove the foam top cover from the outer link. It is attached with Velcro.
4. Remove the sheet metal cover from the outer link.
5. Replace the slave controller (GSBP).

6. Set the jumpers correctly for the address and termination.
7. Recalibrate the robot.
8. Replace the covers.





GSBP for J4 Axis, PFDD4



GSBP for 23N Servo Gripper, PFDD4

Replacing the Gripper and Slip Ring in PFDD4

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

Tools Required:

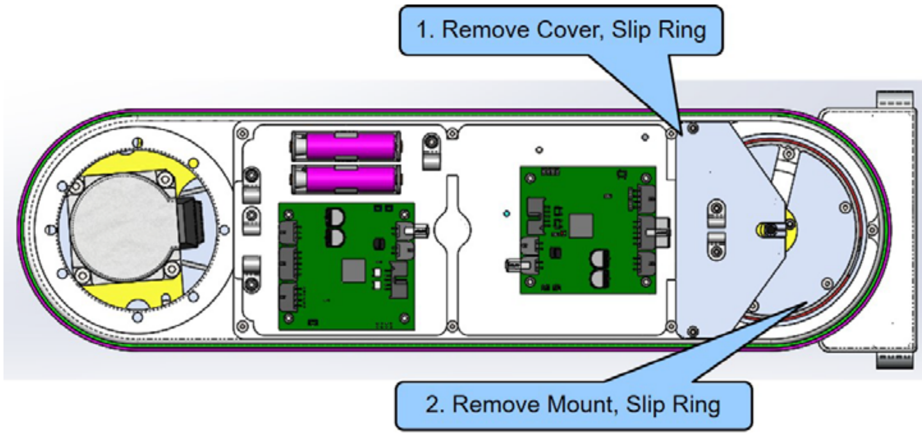
1. 1.5mm hex driver
2. 2.0mm hex driver
3. 2.5mm hex driver

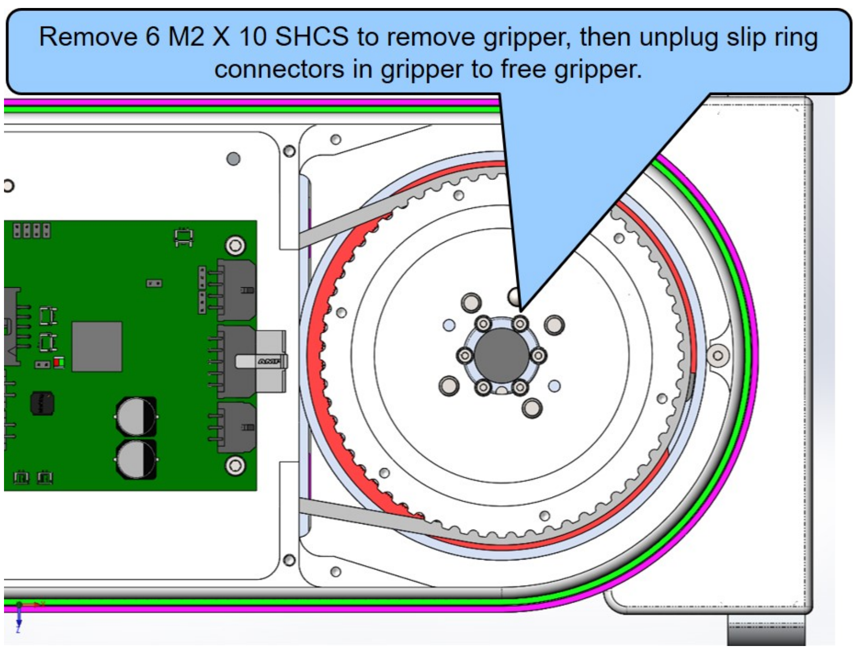
Spare Part Required:

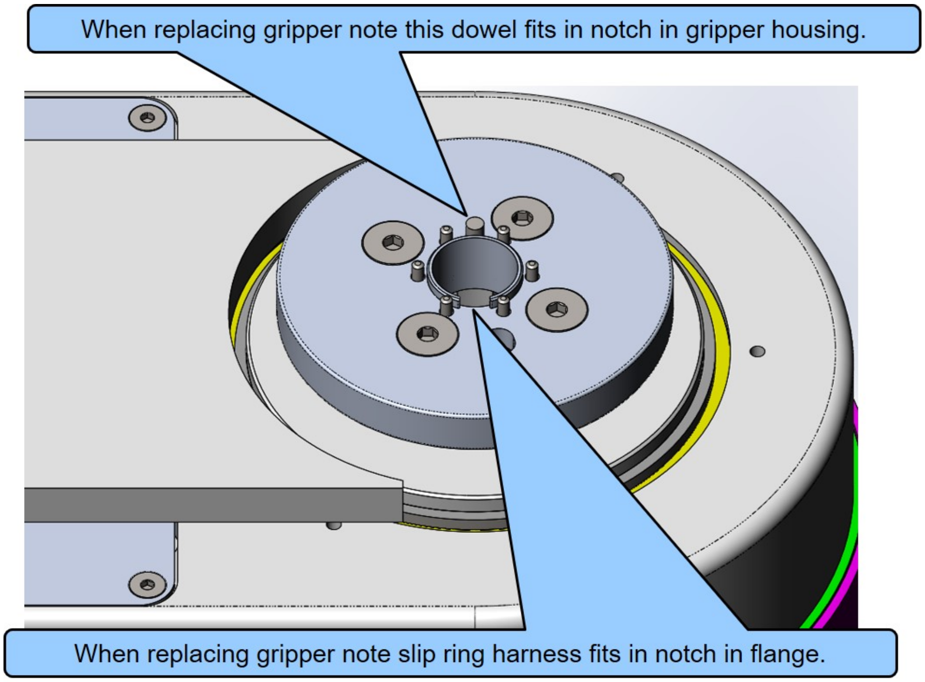
1. 23N Servo Gripper with Spring Return PF0S-MA-00001
2. Slip Ring for 23N Servo Gripper with Spring Return PF04-MA.00010

To replace the 23N Servo Gripper or Slip Ring in the PFDD4 the user must:

1. Turn off the robot power and remove the AC power cord.
2. Remove the foam side cover from the outer link. It is attached with Velcro.
3. Remove the foam top cover from the outer link. It is attached with Velcro.
4. Remove the sheet metal cover from the outer link.
5. Remove cover, slip ring and mount, slip ring.
6. Remove 6 M2 X 10 SHCS to release gripper, then unplug slip ring connectors in gripper.
7. At this point you may replace the gripper or the slip ring.
8. Reassemble parts, be careful not to pinch the slip ring cable, it fits in notch in flange.
9. The robot does not need to be recalibrated after changing the slip ring or gripper.







Replacing the Gripper Spring or Cable

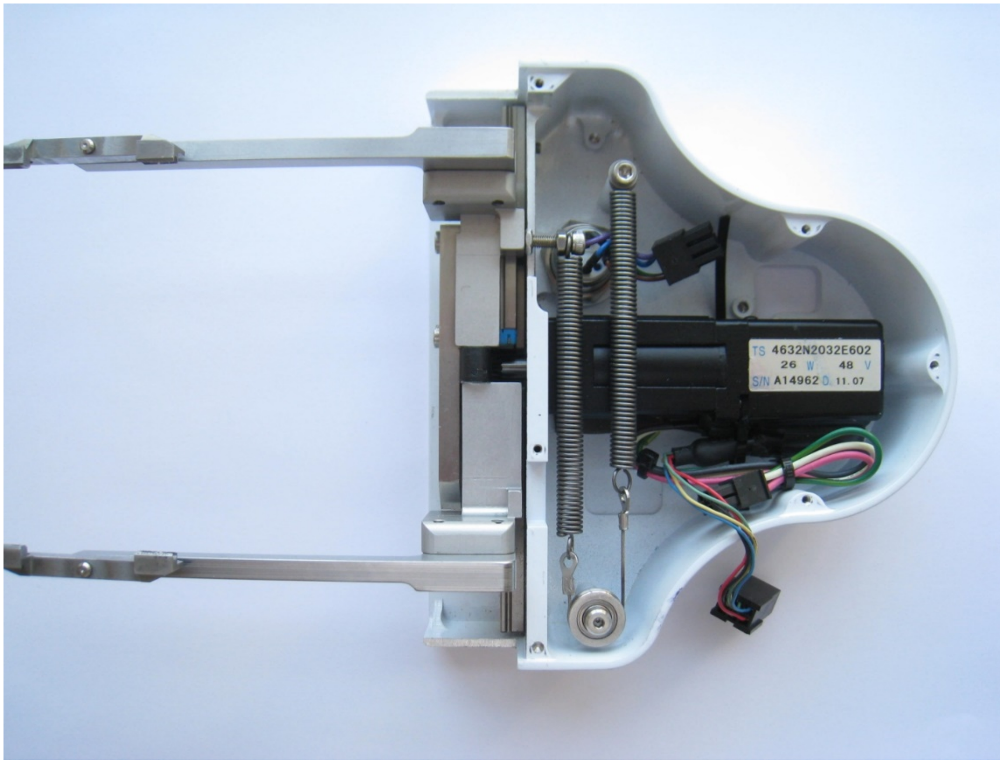
Tools Required:

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

Spare Parts Required: Spring and Cable Assembly PN XX

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:

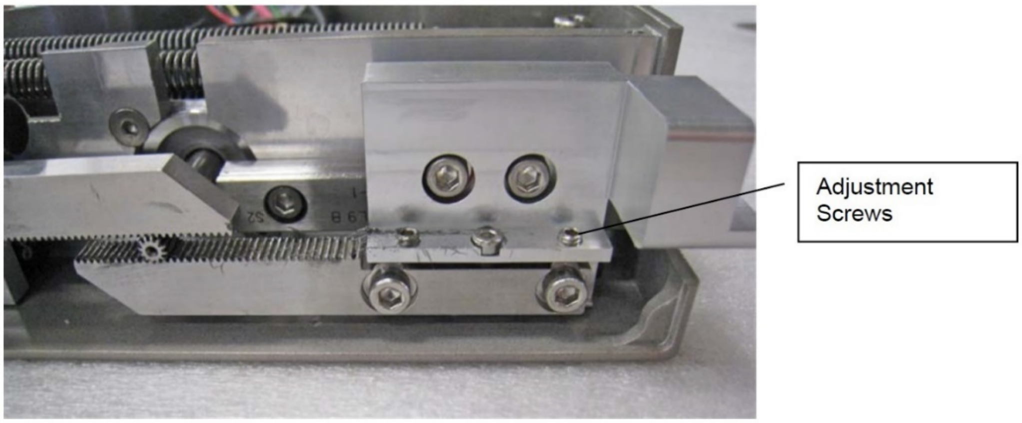
1. 1.3mm “stubby” hex L wrench
2. 1.5mm “stubby” hex L wrench

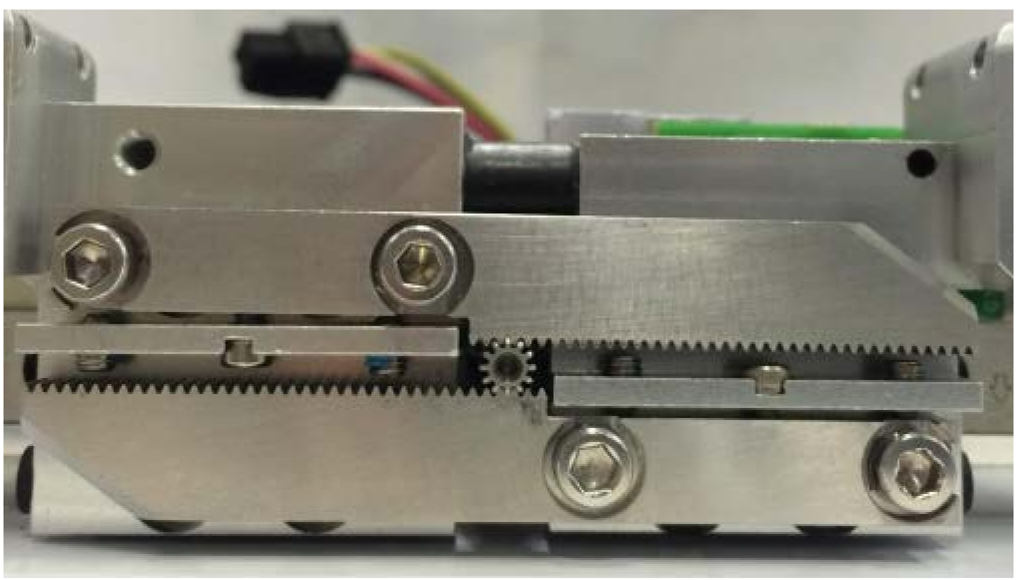
Spare Parts Required: none

To adjust the gripper backlash the user must:

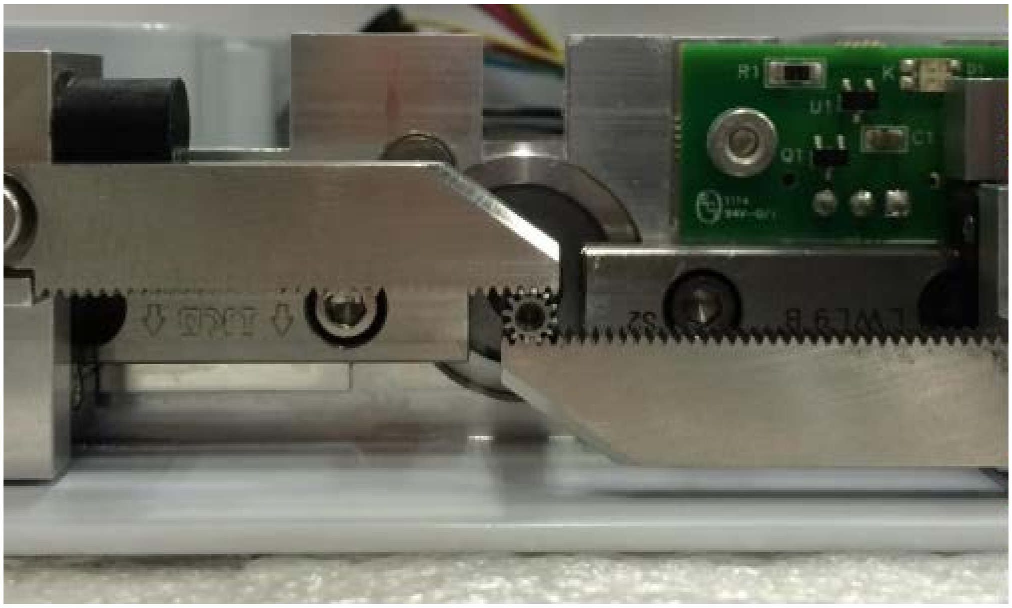
1. Remove the Gripper Cover by removing 6 M2 X 6mm FHCS.
2. For grippers with spring return, disconnect one end of the spring to remove spring tension.
3. Move the racks back and forth to determine which rack has backlash and where it is located on the rack.
4. Loosen the 2 M3 X 8 SHCS clamping the rack 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

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 J3 Clock Spring Harness to the J4 Motor

Tools Required:

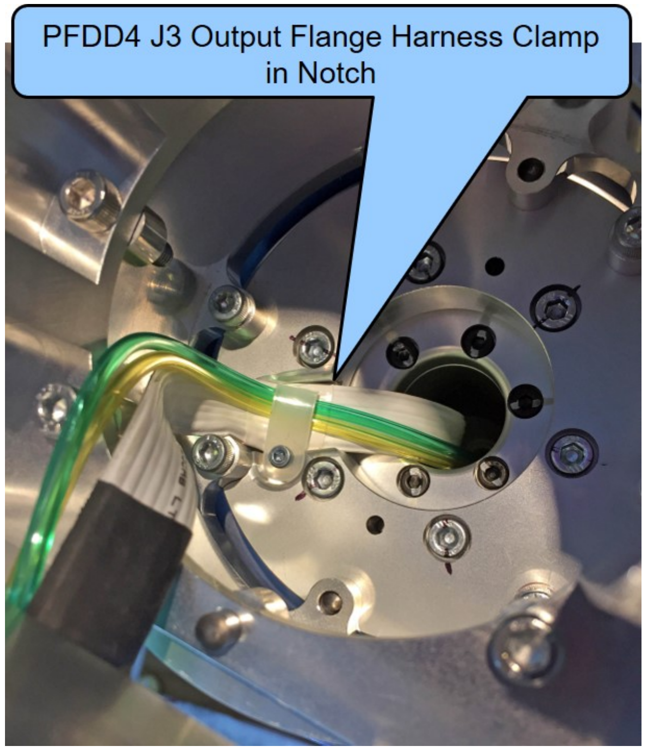
1. 2.0mm hex driver
2. 2.5mm hex driver

Spare Parts Required: J3 Clock Spring Harness PN PFD0H-MA-00021

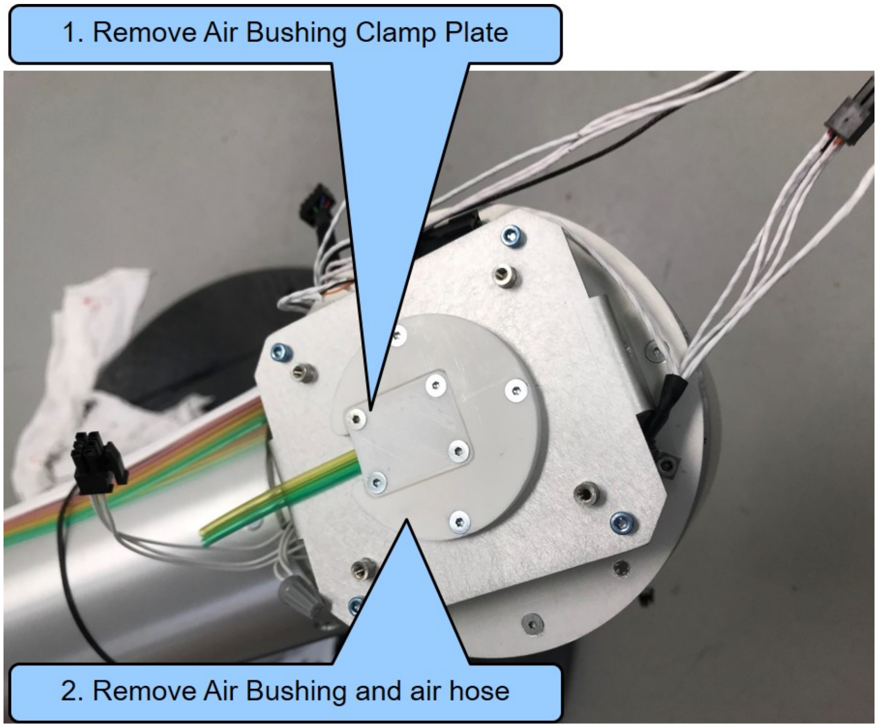
To replace the harness the user must:

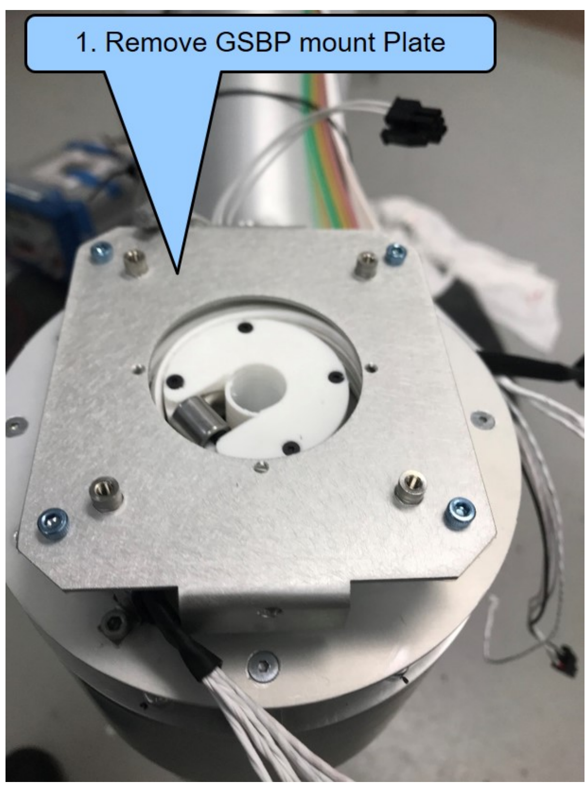
1. Remove the LED light tower and J3 Slave Controller per instructions for these assemblies.

2. For the PFDD4, remove the foam side covers, the foam bottom cover, the sheet metal bottom cover, the foam top cover and the sheet metal top cover to expose the harness.
3. For the PFDD4, unplug the end of the clockspring harness from the J4 slave controller in the outer link, then remove the outer link from the J3 spacer by removing 6 M5 X 12 SHCS.
4. For the PFDD4 remove the harness clamp from the J3 output flange to release the outer link end of the harness.



5. For the PFDD6, simply remove the J4 foam end cover, and unplug the J4 end of the clockspring harness from the J4 slave amp (GSBP).
6. Remove the air hose clamp plate and thru hole bushing, and pull air hose up thru J3.


1. Remove Air Bushing Clamp Plate
2. Remove Air Bushing and air hose


1. Remove GSBP mount Plate

1. To remove harness, do these operations in reverse. Make sure you are completely clockwise against the hard stop looking from the top. Route so there is a total of four wraps
2. Clamp with Cable Clamp, Clip, J3 (PFD0-MC-M0132), neoprene strip, M3-10 FHCS and Loctite 222.
3. Install Lid, Bushing, J3 so it constrains the harness folded over going down elbow. Fasten with M2-6 FHCS Alloy and Loctite 222.

7. Remove the clockspring harness as shown above, then install new harness as shown above. *For the PFDD4 it is important to make the sure the harness is clamped in the notch in the J3 output flange as show, or the J4 motor will interfere with the harness.*
8. Replace parts.
9. For the PFDD4, it will be necessary to recalibrate the robot, as the J4 encoder was disconnected from the battery backup when the outer link was removed.
10. For the PFDD6, it is not necessary to recalibrate the robot as the J3 encoder is a single turn absolute encoder and the J3 slave amp does not require an external battery.

Replacing the J4 to Gripper Controller Harness in the PFDD4

Tools Required:

1. 2.0mm hex driver
2. 2.5mm hex driver

Spare Parts Required: Harness PN PFD0H-MA-00017

To replace the harness the user must:

1. Remove the foam side covers, the foam top cover, and the sheet metal top cover from the outer link.
2. Replace the harness between the J4 slave controller and the gripper controller.
3. Replace the covers. It is not necessary to recalibrate the robot.

Replacing the J4 slave controller in the PFDD6

Tools Required:

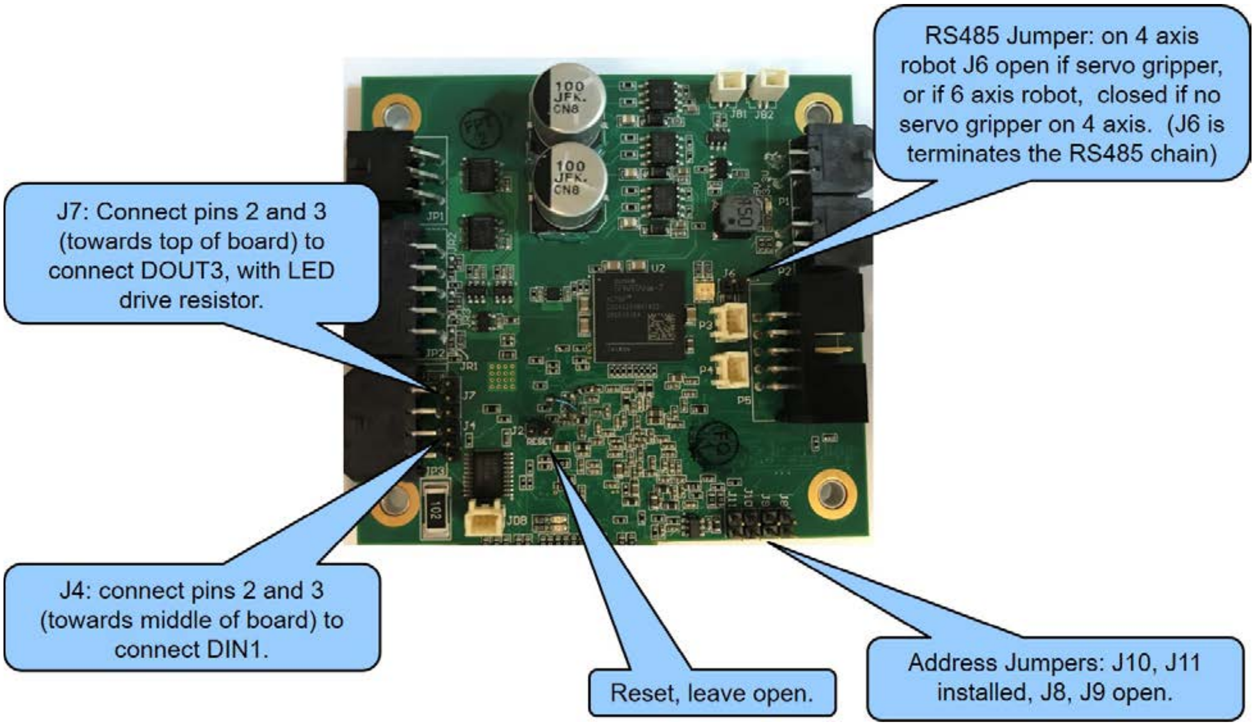
1. 2.0mm hex driver
2. 2.5mm hex driver
3. 5.0mm hex socket driver

Spare Parts Required:

1. Slave controller PN G6X0-EA-00202 for J4 axis (20A, differential encoder)

To replace these items the user must:

1. Remove the foam end cover from J4, and the bottom cover from J4.
2. Remove the J4 controller mount plate from the bottom of J4.
3. Unplug the J3 to J4 harness and the J4 to J5 harness and the motor connectors.
4. Replace the J4 slave controller (GSBP).
5. Replace the parts.
6. Recalibrate the robot.



Replacing the J4 to J5 Controller Harness, the J5 to J6 Controller Harness, OR the J5 OR J6 slave controller in the PFDD6

Tools Required:

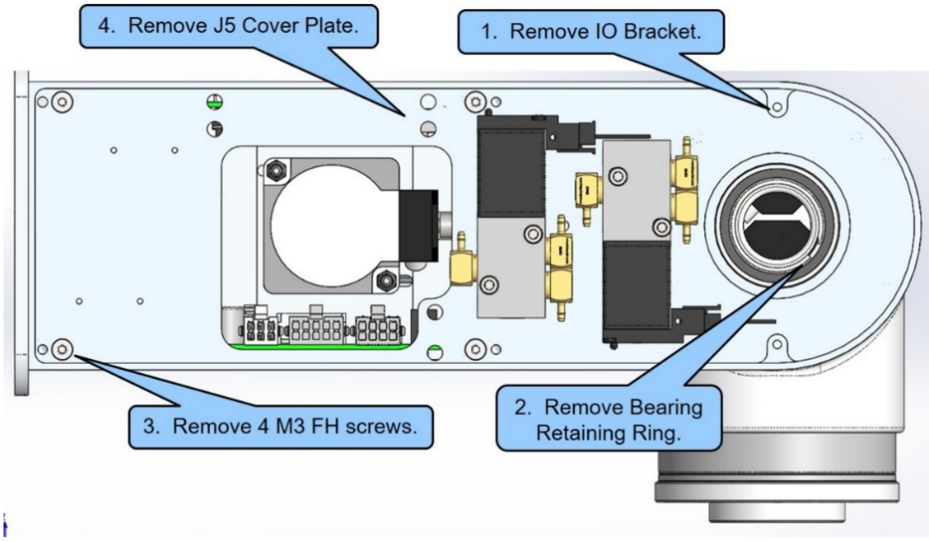
1. 2.0mm hex driver
2. 2.5mm ball end hex driver

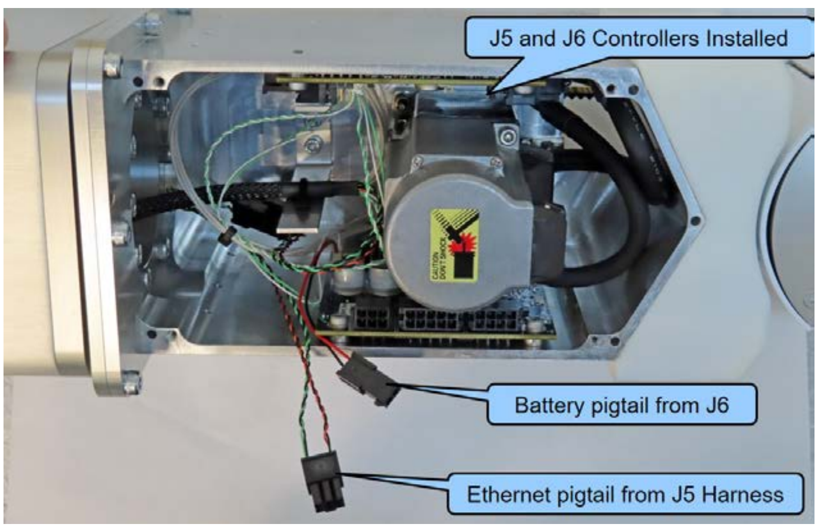
Spare Parts Required:

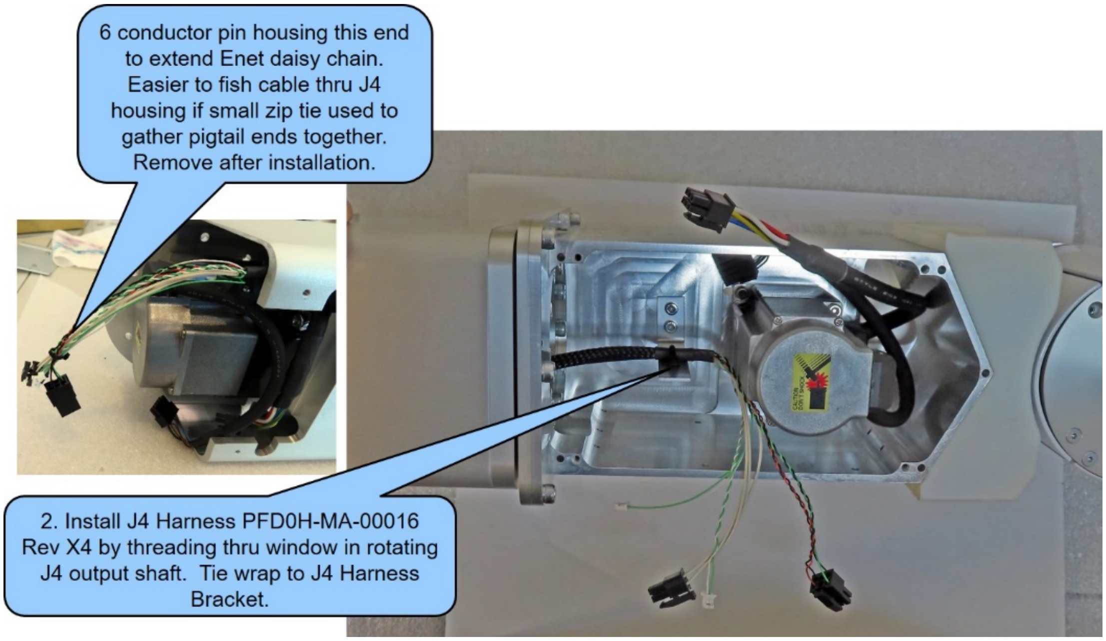
1. Harness PN PFD0H-MA-00016
2. Slave controller PN G6X0-EA-00202 for J4 axis (20A, differential encoder)

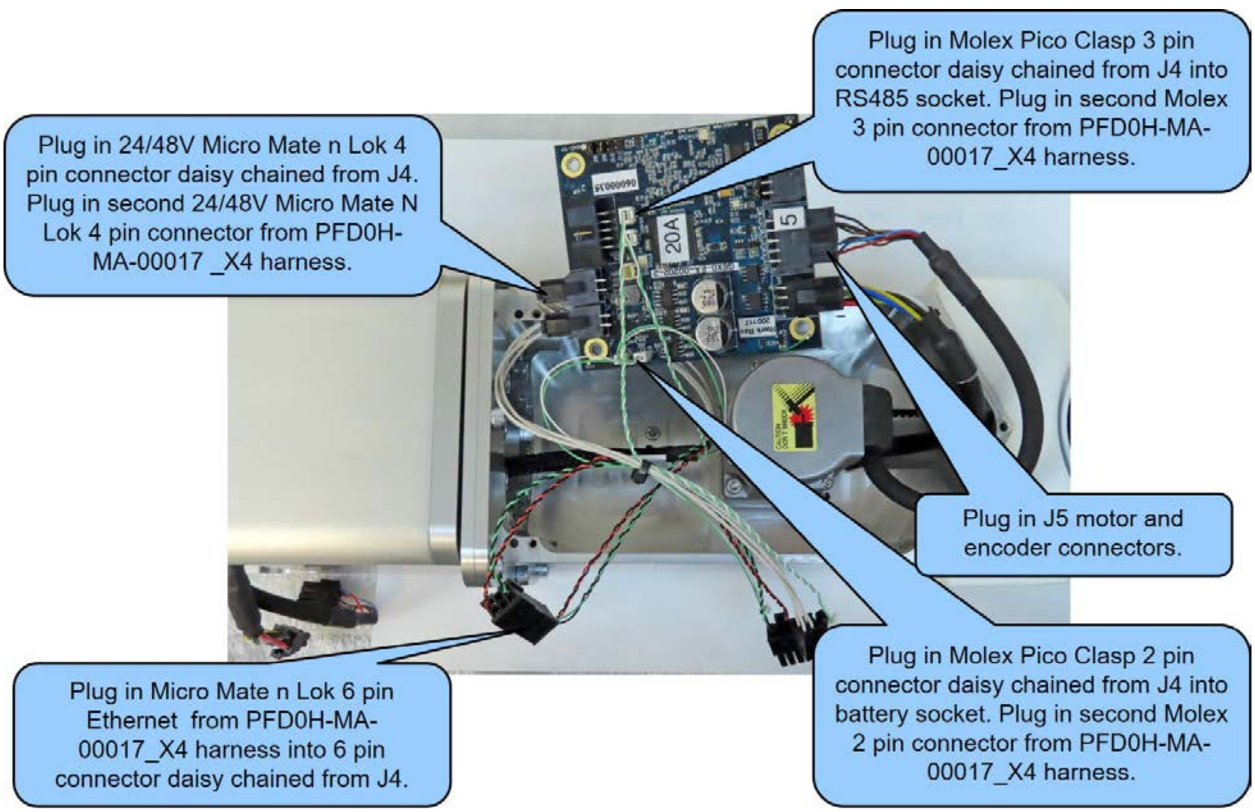
To replace these items the user must:

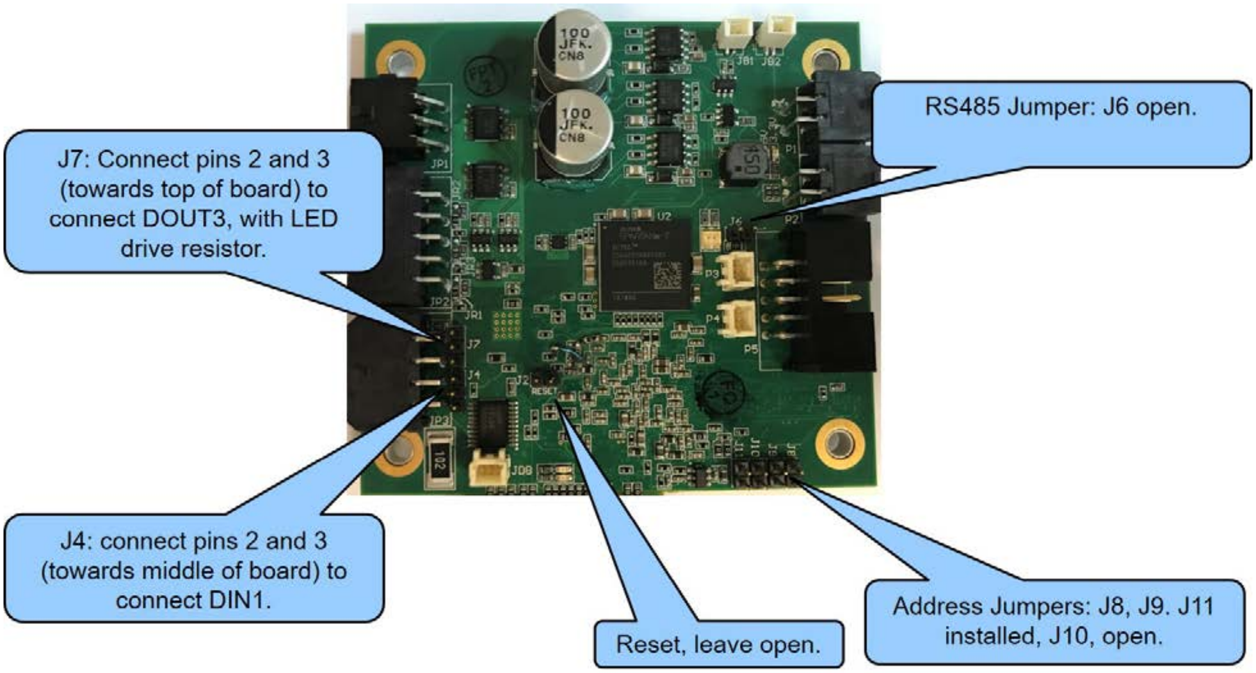
1. Remove the foam side cover from J5, the foam end cover from J4 and the J5 cover plate.


4. Remove J5 Cover Plate.
1. Remove IO Bracket.
3. Remove 4 M3 FH screws.
2. Remove Bearing Retaining Ring.

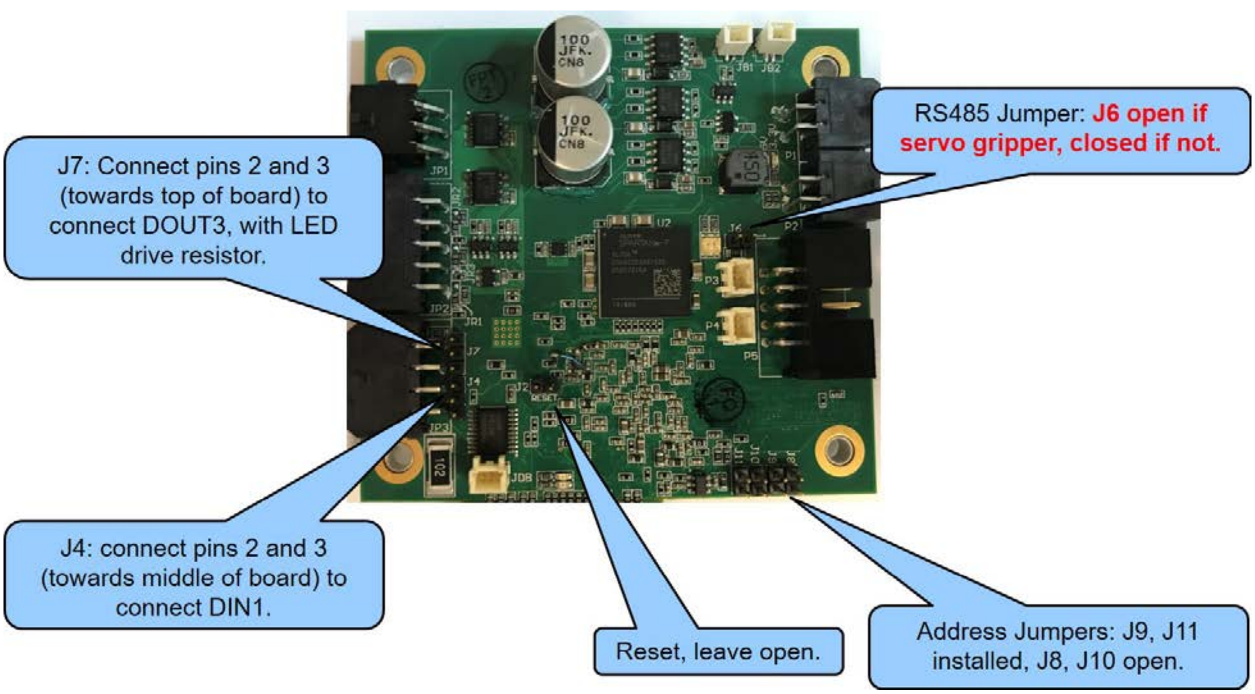

J5 and J6 Controllers Installed
Battery pigtail from J6
Ethernet pigtail from J5 Harness


6 conductor pin housing this end to extend Enet daisy chain. Easier to fish cable thru J4 housing if small zip tie used to gather pigtail ends together. Remove after installation.
2. Install J4 Harness PFD0H-MA-00016 Rev X4 by threading thru window in rotating J4 output shaft. Tie wrap to J4 Harness Bracket.


Plug in Molex Pico Clasp 3 pin connector daisy chained from J4 into RS485 socket. Plug in second Molex 3 pin connector from PFD0H-MA-00017_X4 harness.
Plug in 24/48V Micro Mate n Lok 4 pin connector daisy chained from J4. Plug in second 24/48V Micro Mate N Lok 4 pin connector from PFD0H-MA-00017 _X4 harness.
Plug in J5 motor and encoder connectors.
Plug in Micro Mate n Lok 6 pin Ethernet from PFD0H-MA-00017_X4 harness into 6 pin connector daisy chained from J4.
Plug in Molex Pico Clasp 2 pin connector daisy chained from J4 into battery socket. Plug in second Molex 2 pin connector from PFD0H-MA-00017_X4 harness.



J5 Slave Controller (GSBP) Jumpers



J6 Slave Controller (GSBP) Jumpers

2. Cut the tie wrap holding the J4 to J5 harness to the harness bracket in the J5 housing.
3. Remove the J5 slave controller (GSBP) from the J5 side wall and unplug theJ4 harness connectors.
4. Unplug the harness from the J4 slave controller.
5. Pull the J4 to J5 harness through the J4 housing.
6. Fish the new harness through the housing from the J5 side. There is a cutout in the rotating wall of the J4 output housing that the harness must be fished through. This is easier if a small tie wrap is placed around the J4 end of the harness for this operation, then removed.
7. Plug the new harness into the J5 slave controller, then re-attach the J5 slave controller to the J5 side wall.
8. The J5 and J6 slave controllers can be replaced with this same procedure.
9. Replace the J5 side cover and other parts. Be sure the encoder battery harness is plugged in to the encoder battery pigtail coming J6 controller battery daisy chain connector.
10. Recalibrate the robot.

Replacing the J6 Motor Pigtail Harness

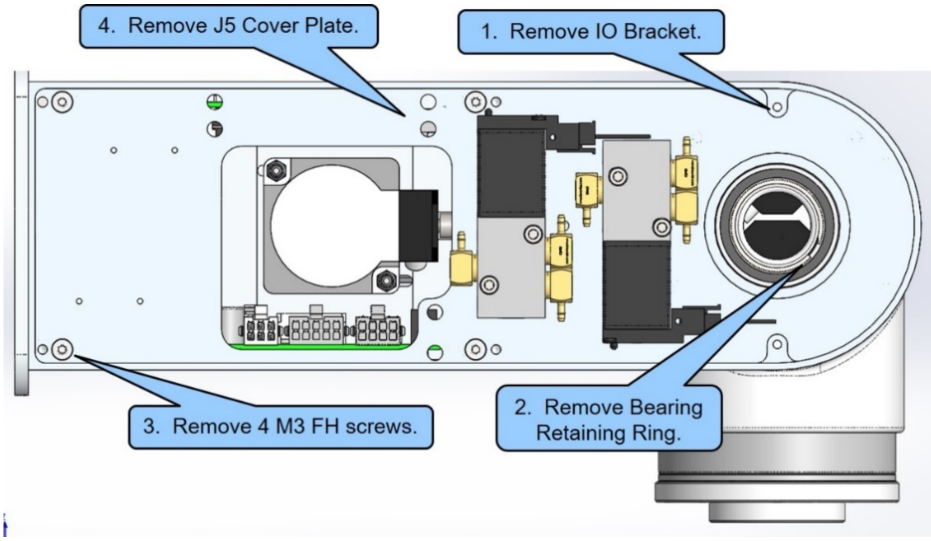
Tools Required:

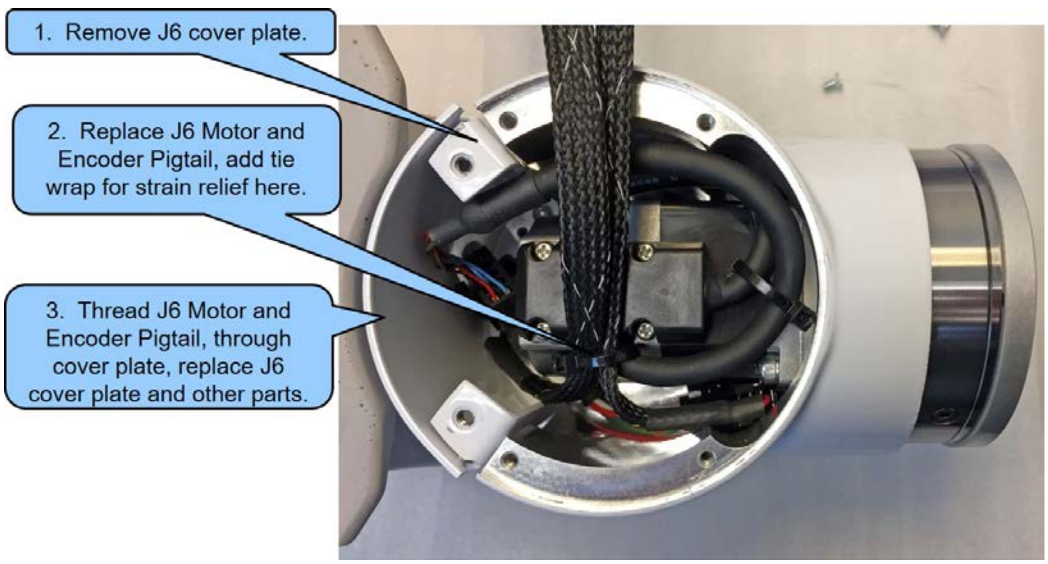
1. 2.0mm hex driver
2. 2.5mm hex driver

Spare Parts Required: Harness PN PFD0H-MA-00010

To replace these items the user must:

1. Remove the foam side cover from J5, the IO harness bracket, and the J5 cover plate, threading the J6 motor pigtail harness thru the 25mm bearing.
2. Remove the J6 cover plate, replace the harness, tie wrap per below, replace parts.
3. Recalibrate the robot.


4. Remove J5 Cover Plate.
1. Remove IO Bracket.
3. Remove 4 M3 FH screws.
2. Remove Bearing Retaining Ring.


1. Remove J6 cover plate.
2. Replace J6 Motor and Encoder Pigtail, add tie wrap for strain relief here.
3. Thread J6 Motor and Encoder Pigtail, through cover plate, replace J6 cover plate and other parts.

Appendix A: Product Specifications

PFDD4 Specifications

General Specification	Range
Range of Motion & Resolution	
J1 (Base Rotation) Axis	+/- 168 degrees
J2 Axis (Z column)	500mm, 1000mm, 1420mm
J3 Axis	+12 to +348 degrees
J4 Axis	+/ 240 degrees
23N 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	+/- 0.020 mm overall in X, Y & Z directions at 18-22C
Performance and Payload	
Maximum acceleration	5000mm/sec^2 with 8kg payload
Maximum speed	600 mm/sec Cartesian, 140 degrees/sec J1, 360 degrees/sec J3
Controller	*AVAILABLE PRECISEFLEX™ CONTROLLERS*: PreciseFlex™ PFD0, PreciseFlex™ GSBP Slave Amp
Interfaces	
General Communications	RS-232 channel, 100Mb Ethernet
Digital I/O Channels	12 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	Four methods available: DIO MotionBlocks (PLC), embedded Guidance Programming Language (standalone), PC controlled over Ethernet using TCP/IP, Guidance Motion: Graphical Programming Interface
Required Power	The PFDD robots power supplies have an input range of 100 to 240 VAC, +/- 10%, 50/60 Hz. 700 watts peak maximum, 150-200 watts rms typical
Weight	43 kg for 500mm travel version, 53 kg for 1000mm version, 63 kg for 1420mm version

PFDD6 Specifications

General Specification	Range
Range of Motion & Resolution	
J1 (Base Rotation) Axis	+/- 168 degrees
J2 Axis (Z column)	500mm, 1000mm, 1420mm
J3 Axis	+12 to +348 degrees
J4 Axis	+100, -220 degrees
J5 Axis	+/- 110 degrees
J6 Axis	+/- 295 degrees
23N 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	+/- 0.020 mm overall in X, Y & Z directions at 18-22C
Performance and Payload	
Maximum acceleration	5000mm/sec^2 with 6kg payload
Maximum speed	600 mm/sec Cartesian, 140 degrees/sec J1, 360 degrees/sec J3
Controller	*AVAILABLE PRECISEFLEX™ CONTROLLERS*: PreciseFlex™ PFD0, PreciseFlex™ GSBP Slave Amp
Interfaces	
General Communications	RS-232 channel, 100Mb Ethernet
Digital I/O Channels	12 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	Four methods available: DIO MotionBlocks (PLC), embedded Guidance Programming Language (standalone), PC controlled over Ethernet using TCP/IP, Guidance Motion: Graphical Programming Interface
Required Power	The PFDD robots power supplies have an input range of 100 to 240 VAC, +/- 10%, 50/60 Hz, 700 watts peak maximum, 150-200 watts rms typical
Weight	45 kg for 500mm travel version, 55 kg for 1000mm version, 65 kg for 1420mm version

Appendix B: Environmental Specifications

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

General Specification	Range & Features
Indoor use only	
Ambient temperature	4ºC to 40ºC
Storage and shipment temperature	-25ºC to +55ºC
Humidity range	10 to 90%, non-condensing
Altitude	Up to 3000m
Voltage	100-240VAC +/- 10%, 50/60Hz
Mains cord rating, min	16AWG, 3 conductor, 10 Amps min
Pollution Degree	2
Approved Cleaning Agents	IPA, 70% Ethanol/30% water, H2O2 Vapor up to 1000ppm
IP Rating with Tape Seal Option	52
IP Rating without Tape Seal Option	11
IK Impact Rating	IK08: 5 joule

Appendix C: Spare Parts List

Reference: the serial number format is:

FD0-yymm-XY-zzzzz
Yy – year
Mm – month
X – controller rev
Y – robot rev
Zzzzz – unique number

Description	Part Number	
Absolute Encoder Battery	G1S0-EC-X0007	
J2 Stage 1 Belt	PFD0-MC-X0006	
J2 Stage 2 Belt 500mm	PFD0-MC-X0003-500	
J2 Stage 2 Belt 1000mm	PFD0-MC-X0003-1000	
J2 Stage 2 Belt 1420mm	PFD0-MC-X0003-1420	
J2 400W Motor	PFD0-MA-00028	
J4 Stage 1 Belt	PFD0-MC-X0050	
J4 Stage 2 Belt	PFD0-MC-X0051	
Main Controller with Complex Kinematics License	PFD0-EA-00001	
Slave Controller GSBP 20A with motor connector pigtail and thermal pad for Z	G6X0-EA-01202	
Slave Controller GSBP 20A no thermal pad	G6X0-EA-00202	
Slave Controller GSBP 10A single ended for 23N grip	G6X0-EA-00101	
J4 400W Motor for PFDD4 with pulley	PFD0-MA-00029	
Assy, J4, HD PFD0	Contact Applications	
Assy, J5 & J6, HD, PFD0	Contact Applications	
PF400 23N Servo Gripper with Spring, without fingers	PF0S-MA-00001	
J3 Clockspring Harness	PFD0-MA-00021	
J4 to Gripper Harness in PFDD4	PFD0-MA-00017	
J4 to J5 Harness in PFDD6	PFD0-MA-00016	
J5 to J6 Harness in PFDD6	PFD0-MA-00017	
J6 Motor and Encoder Pigtail	PFD0-MA-00010	
24 VDC Supply	PS10-EP-24150	
48 VDC Motor Supply	PS10-EP-481000	
Slip Ring Harness Assembly, 23N Spring Gripper	PF04-MA-00010	18Wire
Solenoid Valve	PF05-MC-X0001	
Energy Dump Resistor Assembly	PFD0-MA-00024	
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
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.
Replace slip ring in DD4 if present	For units with 23N electric replace the slip ring every third inspection test, or 20,000 hours of operation.

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. If it appears a belt tension is not correct, 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	4.1	12	130	50	70	123	145
Z S2	4.7	14	500	400	500	78	87
Z S2	4.7	14	1000	400	500	39	44
Z S2	4.7	14	1420	400	500	27	31
J4 S1	2.8	15	176	60	80	107	124
J4 S2	4.1	25	173	100	120	90	99

Appendix F: Unpacking the Robot

Release latches on crate. Once released, the top and three sides can be lifted vertically off to expose the robot and accessory box.
No screws need to be removed.

Handle Parts and Accessories Box Here

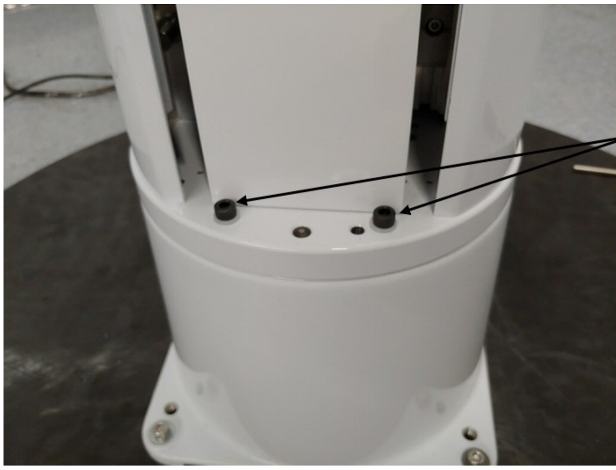
Handle Parts and Accessories should include:

- One Ethernet Cable
- One Power Cable
- One Calibration Pin Bag
- One Estop Jumper
- Two M6-50 SCHS for Top Handle
- Two M10-20 fine SHCS for Lower Handle
- Two Handles for Moving Robot

Attach handle to base assembly using two M10-20 Fine Pitch SHCS (McMaster 96144A262)

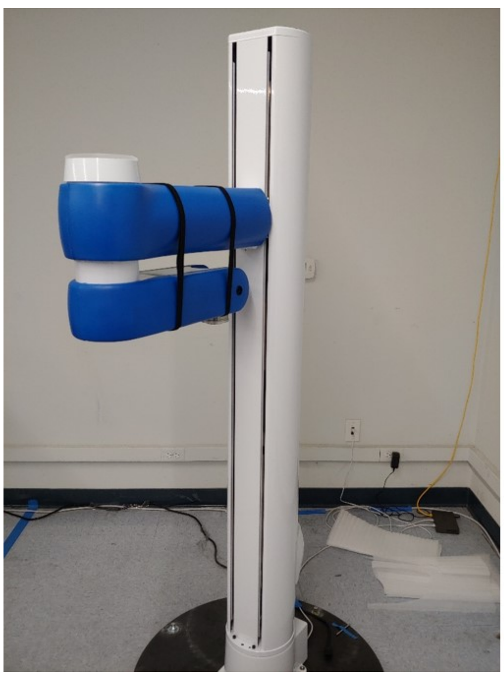
Remove bag prior to transporting robot to it's mounting location

1. Remove two screws from endcap
2. Attach handle using two M6-50 SHCS from Handles and Accessories box.



These bolts restrain rotation of base with arm straight out.
Use two M6-50 SHCS (McMaster 91290A205) and two M6 Nylon Washers (McMaster 95610A570). Torque to hand tight.

Make sure these bolts are removed prior to operating robot after robot is bolted in place. These should be installed before any lifting of the robot occurs.



1. With two people, lower robot onto mounting surface and tilt up slightly to remove the lower base handle.
2. Tip robot fully upright and mount secure while supporting robot. Robot must not be unsupported until securely bolting to mounting surface.
3. Remove handles from top and replace top endcap screws.
4. Remove lower anti rotation bolts and nylon washers.
5. Remove Velcro arm restrains.
6. Install Estop Jumper D-Sub