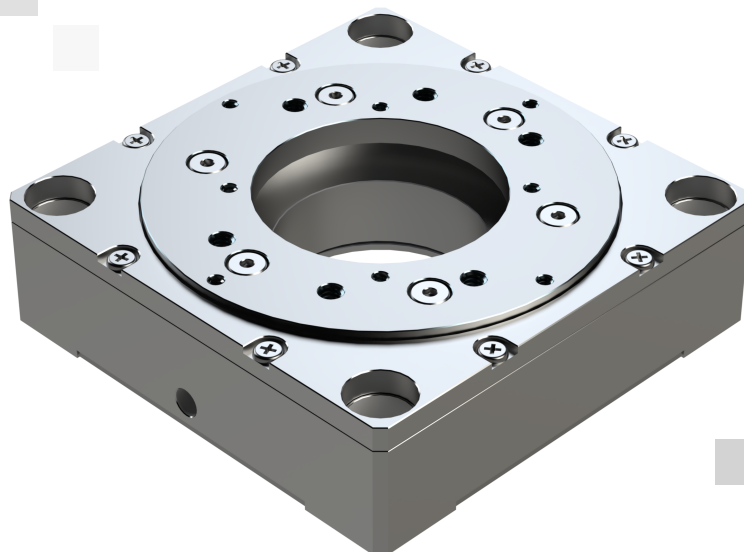


PR-50CR

Series



Piezo Rotation Stage Reference Manual

PR-50CR

Piezo Rotation Stage Reference Manual

Rev 1.0

MICRONIX USA, LLC
Tel: 949-480-0538
Email: info@micronixusa.com
<http://micronixusa.com>

Table of Contents

1. Introduction	3
1.1 Product Description.....	3
1.2 Recommended Controllers.....	3
1.3 Technical Data and Ordering Information	4
2. Preparing to Install the PR-50CR	5
2.1 Installation Preparation.....	5
2.2 Product Handling	5
2.3 Package Contents	5
3. Installing the PR-50CR	6
3.1 PR-50CR Installation.....	6
3.1.1 General Mounting Pattern	6
4. Dimensions	7
4.1 PR-50CR Standard Dimensions.....	8
5. Stacking Configurations	9
5.1 PR-50CR Interface with Other MICRONIX Stages (Examples)	9
5.1.1 PR-50CR + PPS-28PM, Rotation + Translation.....	9
5.1.2 PR-50CR + PPS-50, Rotation + Translation	10
5.1.3 PR-50CR + PPS-60, Rotation + Translation	10
5.1.4 PR-50CR + VT-50L, Rotation + Translation.....	11
5.1.5 PR-50CR + PZS-90, Rotation + Elevation Stage.....	11
5.2 Accessories.....	12
6. Connecting the PR-50CR (MMC-Controller)	13
6.1 Atmospheric Environments.....	13
6.1.1 Open Loop, Atmospheric Wiring Diagram.....	13
6.1.2 Closed Loop (Encoder), Atmospheric Wiring Diagram	14
6.2 Vacuum Environments.....	15
6.2.1 Handling and Preparation	15
6.2.2 Open Loop, Vacuum Wiring Diagram.....	16
6.2.3 Closed Loop (Encoder), Vacuum Wiring Diagram	17
7. Supplementary Information	18
7.1 Maintenance	18
7.2 Units and Conversions.....	18
A. Appendix.....	19
A.1 Piezo Motor Electrical Specification.....	19
A.1.1 2 Phase Piezo Motor Wiring Diagram.....	19
A.1.2 Piezo Motor Specifications	19
A.2 Piezo Motor Wiring Pinouts.....	20
A.2.1 PR-50CR-11000/-51000 – Piezo, Open Loop, Atmospheric Pinout	20
A.2.2 PR-50CR-11200/-51200 – Piezo, Analog, Atmospheric Pinout	20
A.2.3 PR-50CR-11300/-51300 – Piezo, Digital, Atmospheric Pinout	20
A.2.4 PR-50CR-11006/9 or -51006/9 – Piezo, Open Loop, Vacuum Pinout	21
A.2.5 PR-50CR-11206/9 or -51206/9 – Piezo, Analog, High Vacuum Pinout	21
A.2.6 PR-50CR-11306/9 or -51306/9 – Piezo, Digital, High Vacuum Pinout	22

A.3 Standard D-sub Connector Pinout..... 23

A.4 Feedthroughs..... 23

A.5 Using an Analog Encoder 24

 A.5.1 Analog Encoder Overview..... 24

 A.5.2 Operating and Electrical Specifications 24

 A.5.3 Analog Output..... 24

 A.5.4 Index Window 24

 A.5.5 Resolution 24

A.6 Using a Digital Encoder..... 25

 A.6.1 Digital Encoder Overview 25

 A.6.2 Operating and Electrical Specifications 25

 A.6.3 Digital Output 25

 A.6.4 Index Window 25

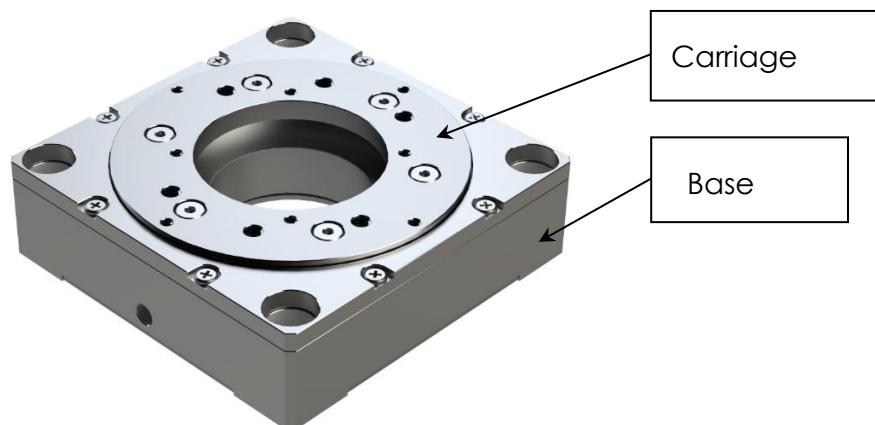
 A.6.5 Resolution 25

1. Introduction

1.1 Product Description

The PR-50CR is a compact piezo rotation stage with unlimited travel and a 25mm aperture in the carriage with a 22mm through hole. A steel cross roller bearing ensures smooth motion and high stability. It utilizes our patented multiphase piezo motor resulting in high speed ($> 15^\circ/\text{s}$) and high blocking torque. Versions capable of operation in vacuum (10^{-9} mbar) are available.

Product Specifications	Open Loop	Analog Encoder	Digital Encoder
Travel	360°, Limitless		
Max Speed	$>5^\circ/\text{s}$ (MMC-100) $>15^\circ/\text{s}$ (MMC-110 & NanoDrive)		
Resolution	$1\ \mu^\circ$	$50\ \mu^\circ$	$10\ \mu^\circ$
Bi-directional Repeatability	NA	$\pm 200\ \mu^\circ$	$\pm 200\ \mu^\circ$
Max Load	3kg		
Environment	Atmospheric, HV, UHV		



1.2 Recommended Controllers

The following controllers are available from MICRONIX USA:

Controller	Piezo Motor	Analog Encoder	Digital Encoder
MMC-100	✓	✓	✓
MMC-110	✓	✓	✓
NanoDrive	✓		✓
MMX-120	✓	✓	✓

CAUTION: Ensure the controller is compatible with the stage's motor and feedback signals and that connector types match before connecting. Improper connections or incompatibility may cause damage to the stage or controller.

1.3 *Technical Data and Ordering Information*

Detailed specifications and ordering information can be found on the [PR-50CR](#) product page on the MICRONIX USA website.

2. Preparing to Install the PR-50CR

2.1 Installation Preparation

When mounting the stage, it is important to consider the flatness of the mounting surface, as the stage will conform to the shape of that surface. The stage's performance and structural integrity are impacted by the mounting flatness.

The stage specification is tested at a temperature of $20^{\circ}\text{C} \pm 5^{\circ}\text{C}$ unless otherwise specified. Ensure the following conditions are met before operating the stage:

- Mounting surface is clean and free of debris, burrs or dings.
- Recommended mounting surface flatness is less than $25\text{ }\mu\text{m}$ for optimal performance.
- Indoor atmosphere is free of corrosive gases, excessive dust, and condensation.
- Operating temperature range of $5\text{--}40^{\circ}\text{C}$.
- Relative humidity between 20-80%.
- The stage is located away from water, heat, and electrical noise.

2.2 Product Handling

- The PR-50CR rotation stage is a precision mechanical device and should be handled with care. Do not drop or mishandle the stage.
- Use proper cable management to ensure a clean and safe operating environment.
- Properly connect the stage to the controller before powering on the controller. Failure to do so can result in damage to the stage.
- Allow for easy access to the stage in case of servicing.

NOTE: Piezo stages use friction-based motion with ceramic components that are sensitive to oils. Wear powder-free nitrile gloves when handling the stage to avoid contamination.

NOTE: It is possible to gently move the carriage manually without damaging the stage.

WARNING: Keep hands clear of all moving parts while the stage is in motion to avoid personal injury.

2.3 Package Contents

The package contains all necessary components for the PR-50CR stage setup. If the product is damaged or there are missing components, contact MICRONIX USA immediately. Do not discard product packaging in case of return shipment.

Package Contents:

- PR-50CR Piezo Rotation Stage
- Reference Manual
- Any other previously agreed upon components such as a controller

3. Installing the PR-50CR

3.1 PR-50CR Installation

NOTE: It is possible to gently move the carriage manually without damaging the stage.

Additional mounting hardware may be required for custom applications.

To secure the PR-50CR to the mounting surface, use four M3 socket head cap screws at a 0.5 Nm recommended torque.

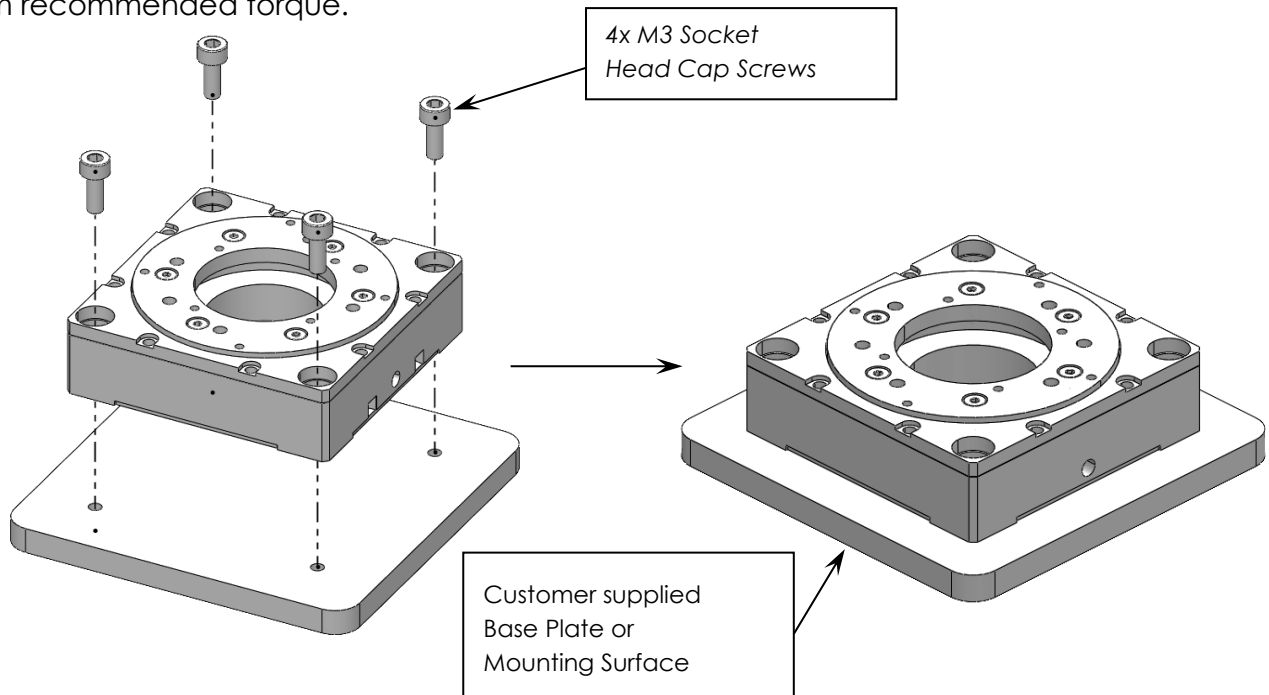
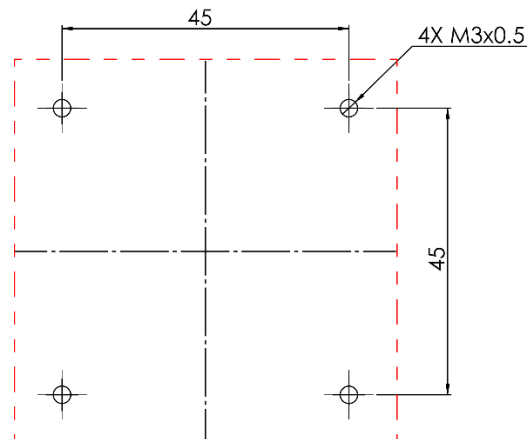


Figure 3-A. PR-50CR General Mounting Installation

3.1.1 General Mounting Pattern

Mounting Surface Hole Pattern (mm)



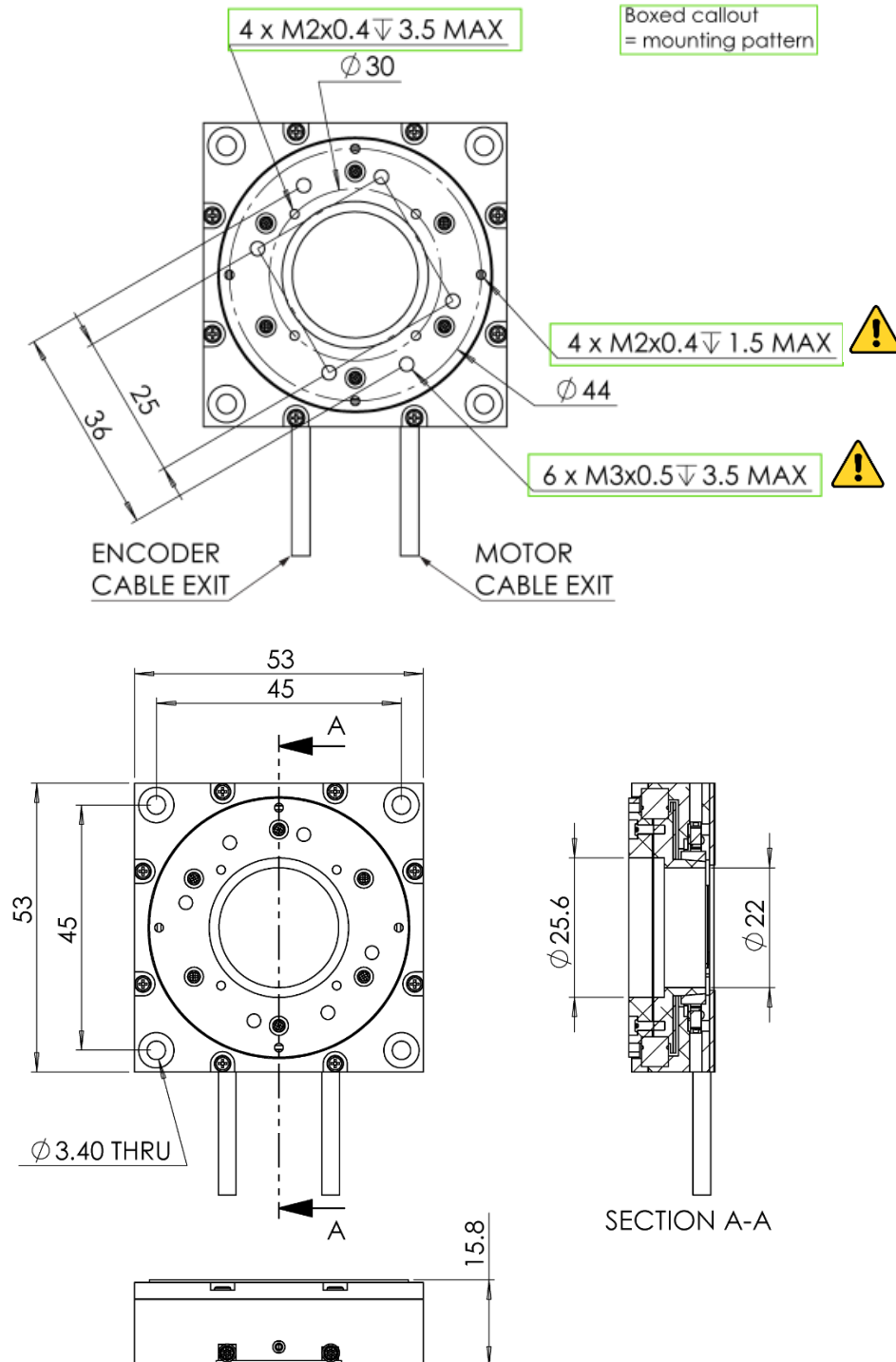
3.2 Mounting to the PR-50CR

The payload mounts to the PR-50CR via the circular carriage on the top of the stage. The recommended specifications for mounting to the PR-50CR are found below:

- Use 4 x M2X0.4 - 6H screws or 4 x M3X0.5 - 6H with a max depth of 1.5 mm or 3.5 mm according to the diagram in section 4.1. Longer screws may damage the stage.
- For best performance, torque all 4 screws to 0.16 Nm.
- For best performance, the payload surface mating surface should have a flatness of 12.7 μm or better.

4. Dimensions

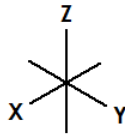
4.1 PR-50CR Standard Dimensions



CAUTION: Do not use screws longer than specified to avoid internal damage.

5. Stacking Configurations

- Additional configurations are available upon request.
- Images are positioned according to:



5.1 PR-50CR Interface with Other MICRONIX Stages (Examples)

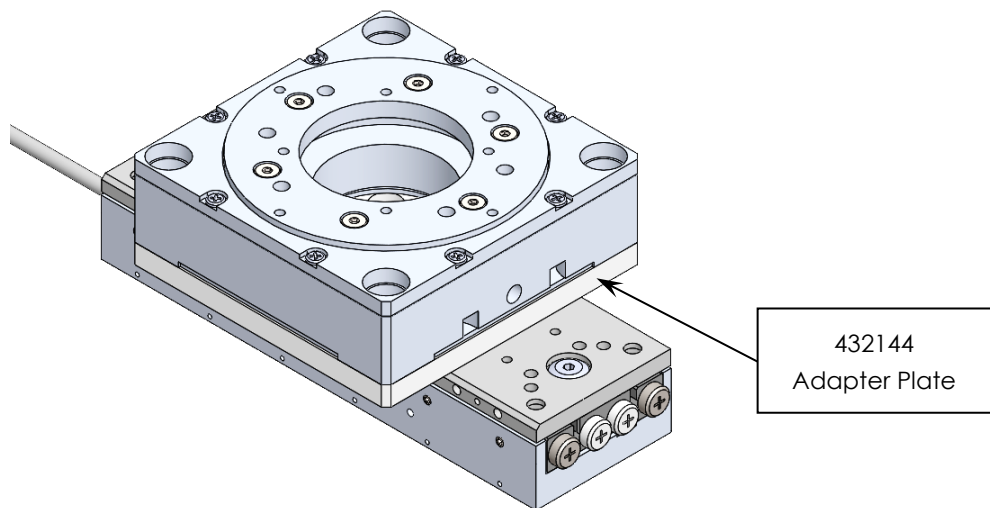
The PR-50CR can be mounted onto a range of MICRONIX stages, enabling flexible multi-axis configurations. Examples of common stage pairings and required adapter plates are shown below.

If an adapter is required and not listed, contact MICRONIX USA for assistance.

5.1.1 PR-50CR + PPS-28PM, Rotation + Translation

Provides 360° motion from 51mm up to 102 mm of XY travel when used with adapter plate 432144.

See the [PPS-28](#) user manual for XY stage mounting configurations and details.

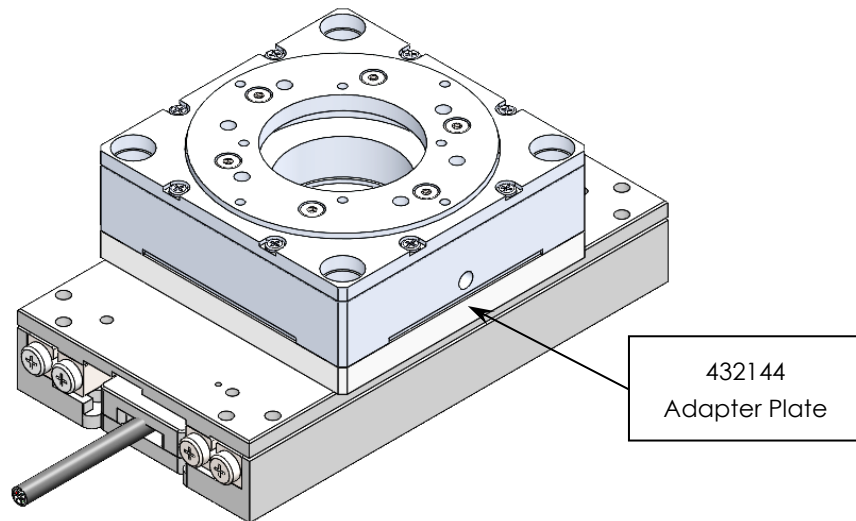


PR-50CR & PPS-28

5.1.2 PR-50CR + PPS-50, Rotation + Translation

Provides 360° motion with up to 100 mm of XY travel when used with adapter plate 432144.

See the [PPS-50](#) user manual for XY stage mounting configurations and details.

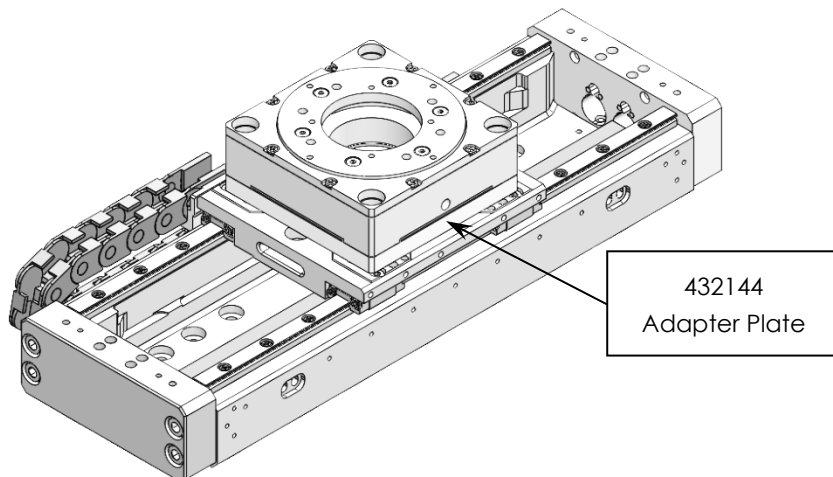


PR-50CR & PPS-50

5.1.3 PR-50CR + PPS-60, Rotation + Translation

Provides 360° motion with up to 300 mm of XY travel used with adapter plate 432144.

See the [PPS-60](#) user manual for XY stage mounting configurations and details.

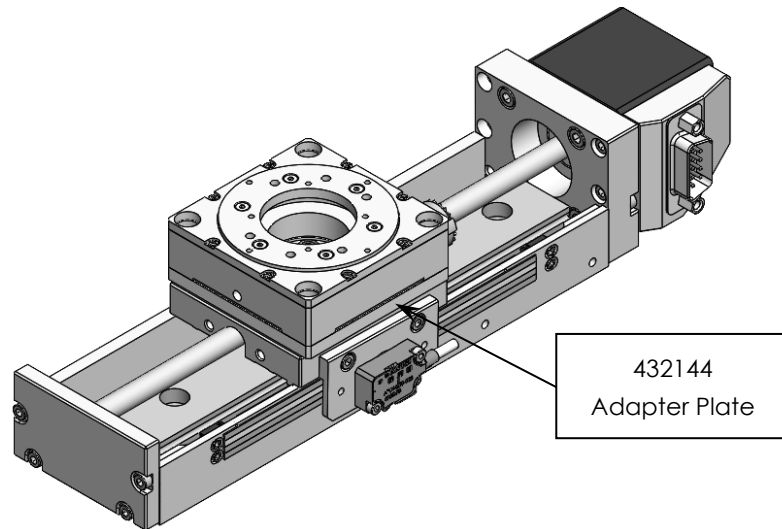


PR-50CR & PPS-60

5.1.4 PR-50CR + VT-50L, Rotation + Translation

Provides 360° motion with up to 300 mm of XY travel when used with adapter plate 432144.

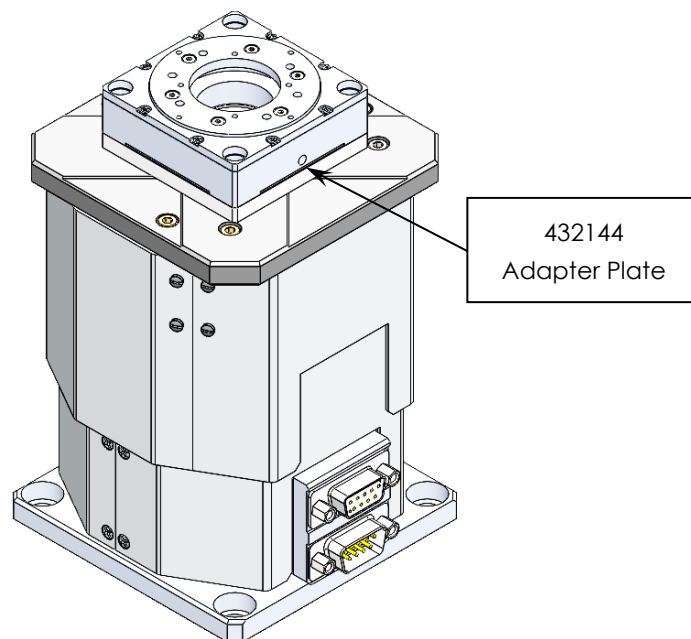
See the [VT-50L](#) User Manual for XY stage mounting configurations and details



PR-50CR & VT-50L

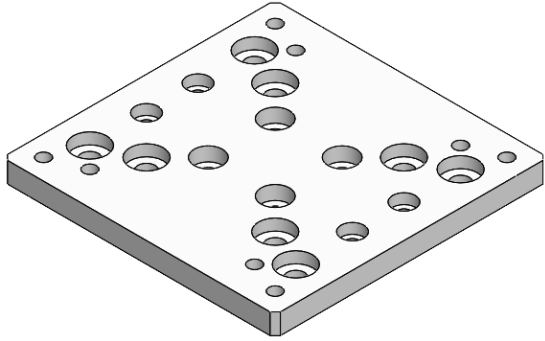
5.1.5 PR-50CR + PZS-90, Rotation + Elevation Stage

Provides 360° motion with up to 35 mm of vertical elevation when used with a [PZS-90](#) stage and adapter plate 432144.



PR-50CR & PZS-90

5.2 Accessories

432144 PR-50CR Adapter Plate

Used to adapt the PR-50CR rotary stage to linear/elevation stages for θ -X mounting configurations.

6. Connecting the PR-50CR (MMC-Controller)

6.1 Atmospheric Environments

For controller information refer to the appropriate MMC controller manual.

6.1.1 Open Loop, Atmospheric Wiring Diagram

Connecting the PR-50CR in an open loop configuration only requires that the D-sub 9 Pin Motor Cable be connected to a compatible controller. Connect the stage as shown below. For details regarding the pinout see Appendix Section A.2.1.

Cable Descriptions:

A. Motor Cable (Male D-sub 9 Pin, 1.5m PVC Black Cable)

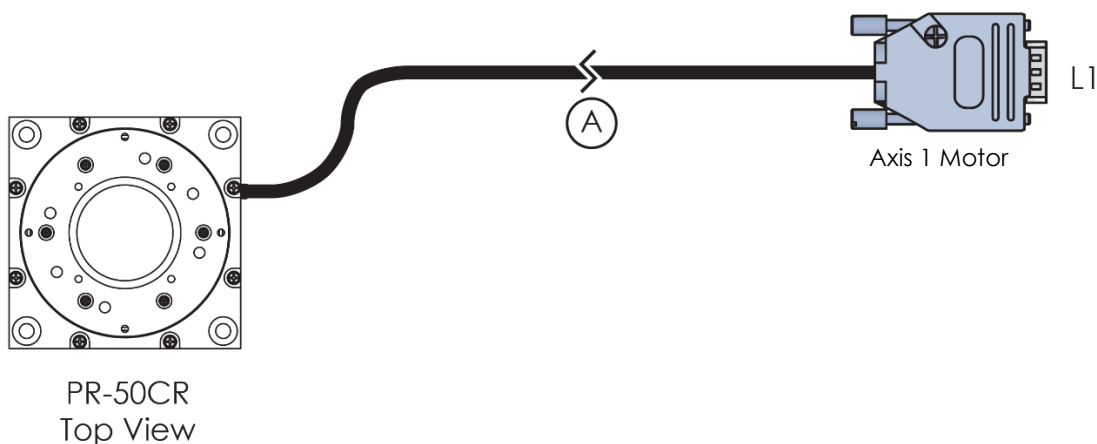


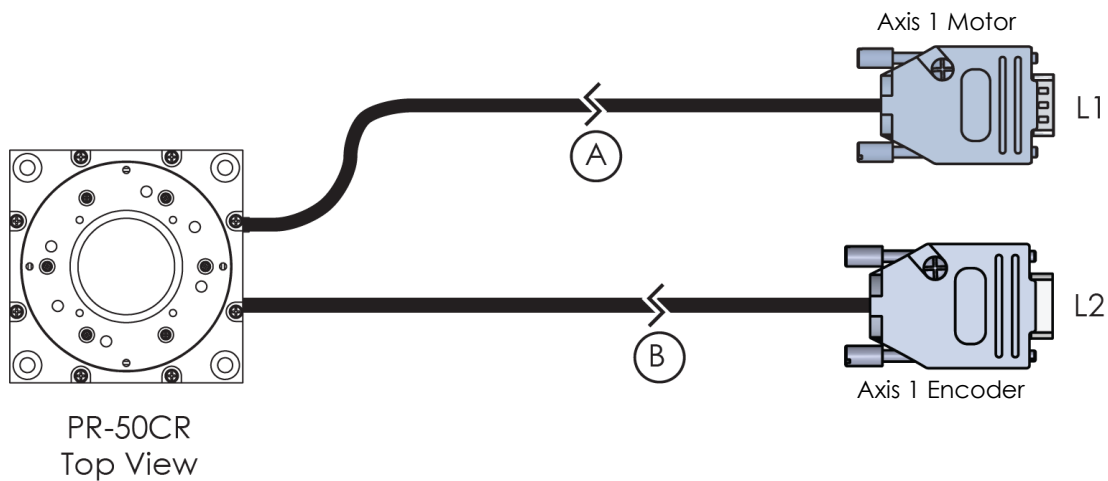
Figure 6-A. PR-50CR, Piezo Motor, Open Loop, Atmospheric Wiring Diagram

6.1.2 Closed Loop (Encoder), Atmospheric Wiring Diagram

See Appendix Sections A.2.2 and A.2.3 for analog and digital pinouts respectively.

Cable Descriptions:

- A. Motor Cable (Male D-sub 9 Pin, 1.5m PVC Black Cable)
- B. Encoder Cable (Female D-sub 9 Pin Module, 1.5m PVC Black Cable)



**For digital encoders, the interpolator is internal to connector*

Figure 6-B. PR-50CR, Piezo Motor, Closed Loop, Atmospheric Wiring Diagram

6.2 Vacuum Environments

6.2.1 Handling and Preparation

When handling stages configured for vacuum use, take the necessary precautions, such as wearing powder-free nitrile gloves, clean room garments, etc. to avoid any contaminants. Maximum bake-out temperature is 100°C. As standard, the stage is supplied with non-vacuum-compatible connectors. MICRONIX USA optionally offers this stage supplied with vacuum-rated connectors installed, see chart below.

Connector Description	Connector Material	Contacts	Backshell
High Vacuum Glass- filled Diallyl Phthalate D-Subminiature	DAP	T2 Female Crimps, Gold Pins (Accuglass P/N: 111652)	Nickel-plated Zinc Backshell Strain Relief
Ultra-High Vacuum D-Subminiature	PEEK	T1 Female Crimps, Gold Pins (Accuglass P/N: 100180)	PEEK UHV Strain Relief

Environment	Open Loop	Closed Loop
High Vacuum (10^{-6} mbar)	9 Pin Female DAP	15 Pin Female DAP
Ultra-High Vacuum (10^{-9} mbar)	9 Pin Female PEEK	15 Pin Female PEEK

Connecting the PR-50CR in a vacuum chamber requires the use of a feedthrough connector at the vacuum chamber wall. For final application, the customer is responsible for providing their own feedthrough connection.

The vacuum compatible PR-50CR will be supplied with wiring for a straight through feedthrough, not a cross over gender changer. MICRONIX USA supplies test connectors that simulate the vacuum feedthrough, to allow for functionality testing prior to installation in a vacuum chamber. See the Appendix Section A.4 for feedthrough pins.

6.2.2 Open Loop, Vacuum Wiring Diagram

See the Appendix Section A.2.4 for pinout information.

Cable Descriptions:

- A. Vacuum Motor Cable (Female D-sub 9 Pin PEEK or DAP, 1.5m Silver Braided Cable)
- B. Atmospheric Motor Cable (Female D-sub 9 Pin to Male D-sub 9 Pin, 1.5m PVC Black Cable)

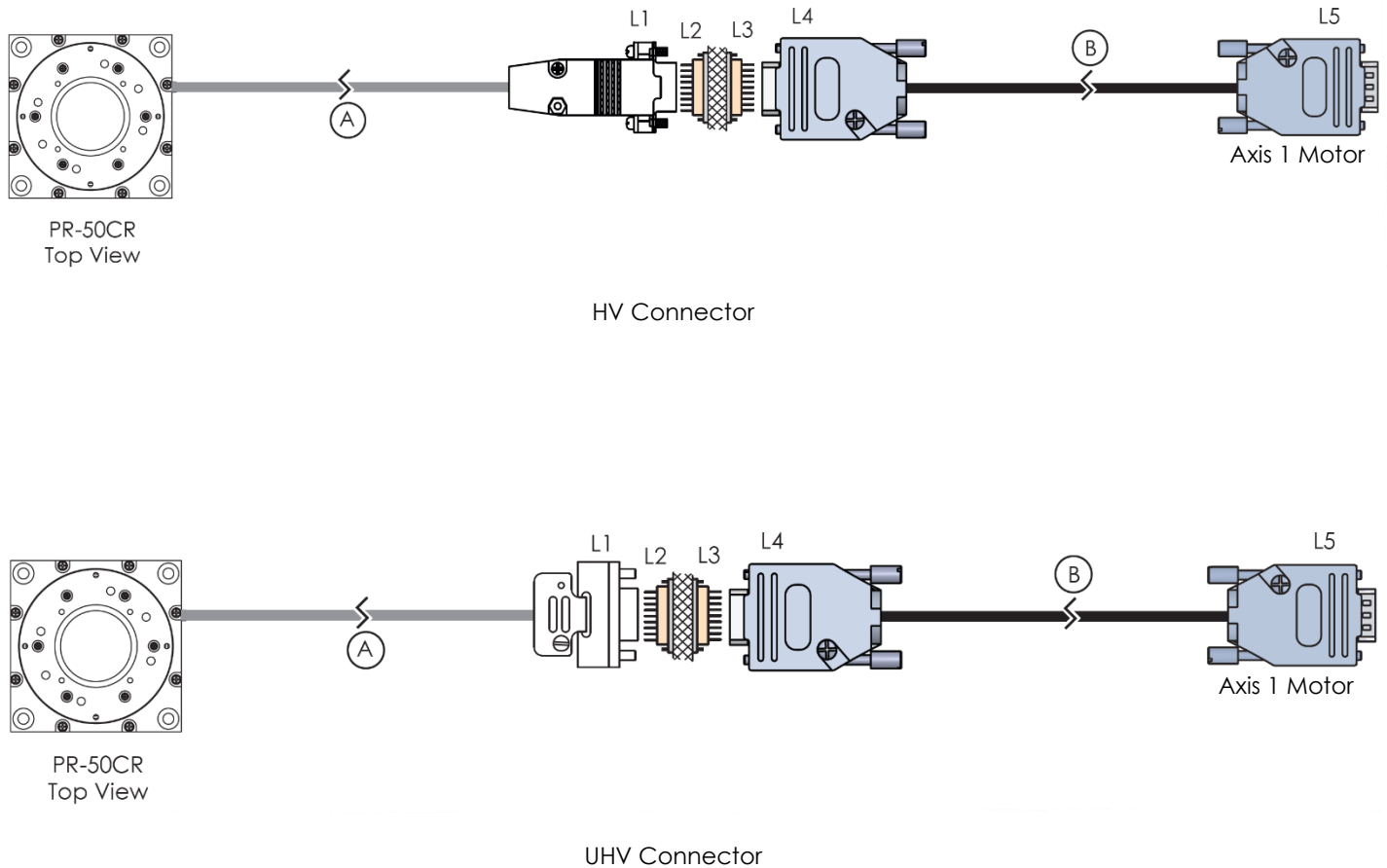


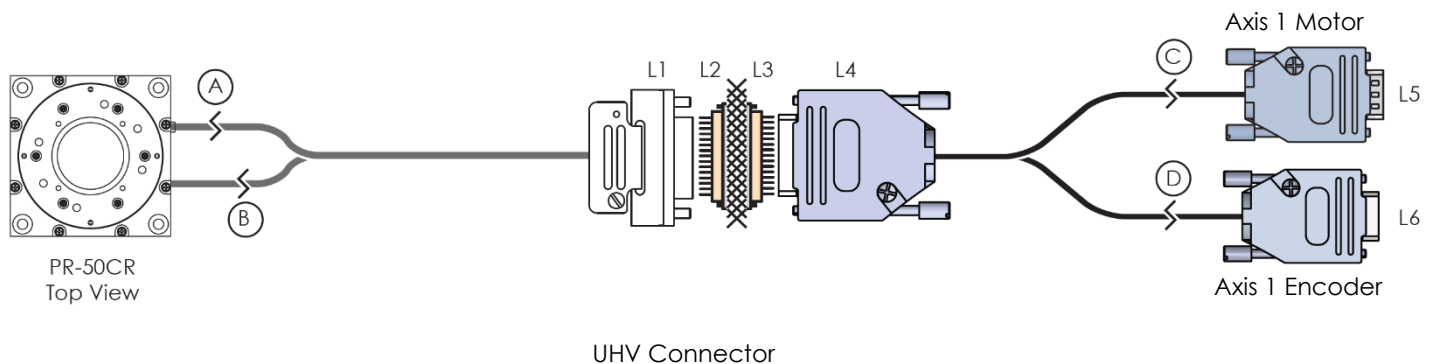
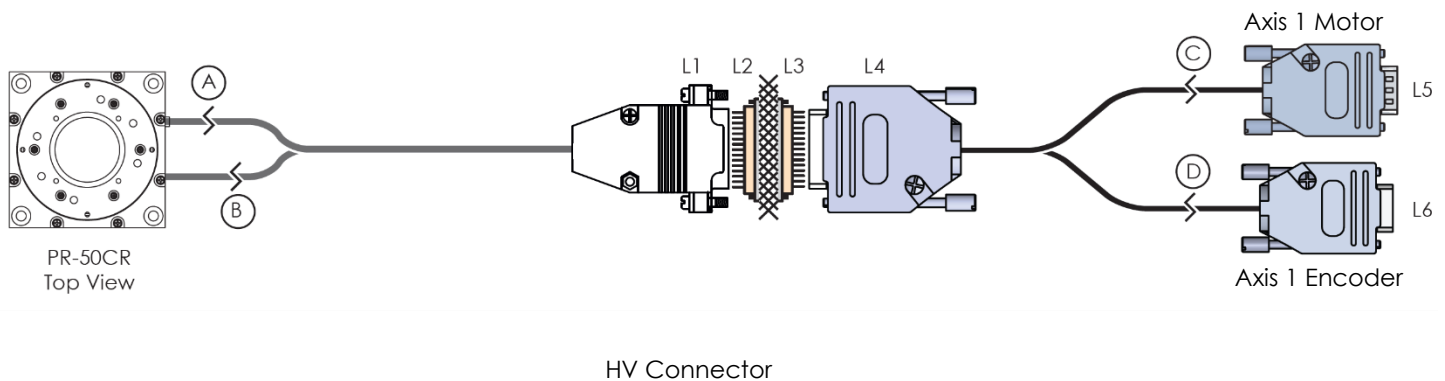
Figure 6-C. PR-50CR, Piezo Motor, Open Loop, Vacuum Wiring Diagram

6.2.3 Closed Loop (Encoder), Vacuum Wiring Diagram

See the Appendix Section A.2.5 and A.2.6 for analog and digital pinouts respectively.

Cable Descriptions:

- A. Vacuum Encoder Cable (Female D-sub 15 Pin PEEK Connector, 1.5m Silver Braided Cable)
- B. Vacuum Motor Cable (Female D-sub 15 Pin PEEK Connector, 1.5m Silver Braided Cable)
- C. Atmospheric Motor Breakout Cable (Female D-sub 15 Pin to Male D-sub 9 Pin, 1.5m PVC Black Cable)
- D. Atmospheric Encoder Breakout Cable (Female D-sub 15 Pin to Female D-sub 9 Pin, 1.5m PVC Black Cable)



**For digital encoders, the interpolator is internal to connector*

Figure 6-D. PR-50CR, Piezo Motor, Closed Loop, Vacuum Wiring Diagram

7. Supplementary Information

7.1 Maintenance

The PR-50CR rotation stage utilizes a maintenance-free design. Do not modify the stage or perform any maintenance unless specifically instructed to do so by MICRONIX USA personnel. If the stage is not performing up to the original specifications, please contact MICRONIX USA.

7.2 Units and Conversions

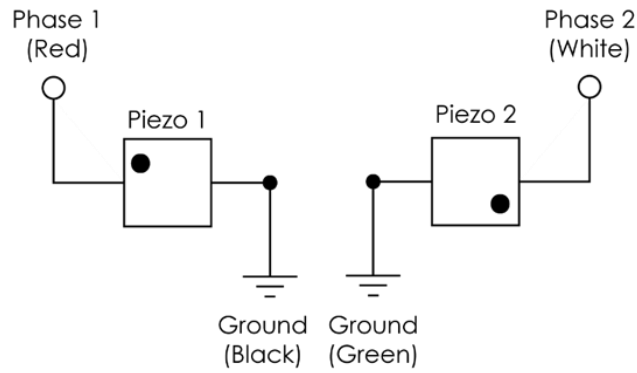
All measurements in this document are in the metric system of units.

Metric Unit	English Unit
1 millimeter	0.0394 inches
1 micron	0.0000394 inches
1 Newton	0.2248 lbs.
1 Newton-meter	8.85 in-lbs

A. Appendix

A.1 Piezo Motor Electrical Specification

A.1.1 2 Phase Piezo Motor Wiring Diagram



A.1.2 Piezo Motor Specifications

Voltage	60V maximum
Capacitance	150nF $\pm$ 15%

A.2 Piezo Motor Wiring Pinouts

A.2.1 PR-50CR-11000/-51000 – Piezo, Open Loop, Atmospheric Pinout

See Figure 6-A.

Motor	Pinout for PR-50CR-11000/-51000		Cable A D-sub 9M
	Description	Color	L1
	Motor 1, Phase 1	Red	1
	Motor 1, Phase 2	White (Green TP)	2
	Motor 2*, Phase 1	White (Grey TP)	3
	Motor 2*, Phase 2	White (Blue TP)	4
	Motor 1, Ground	Black/Green	5
	Motor 2*, Ground	Grey/Blue	5
	Shield	-	Casing

* Greyed out rows are for High Force Piezo option

A.2.2 PR-50CR-11200/-51200 – Piezo, Analog, Atmospheric Pinout

See Figure 6-B.

Motor	Pinout for PR-50CR-11200/-51200		Cable A D-sub 9 M
	Description	Color	L1
	Motor 1, Phase 1	Red	1
	Motor 1, Phase 2	White (Green TP)	2
	Motor 2*, Phase 1	White (Grey TP)	3
	Motor 2*, Phase 2	White (Blue TP)	4
	Motor 1, Ground	Black/Green	5
	Motor 2*, Ground	Grey/Blue	5
	Shield	-	Casing

* Greyed out rows are for High Force Piezo option

		Cable B D-sub 9F	
Encoder	Description	Color	L2
	Cos +	Brown	1
	Sin +	Blue	2
	Index+	Violet	3
	GND	Grey	4
	+5V	White (Grey TP)	5
	Cos -	White (Brown TP)	6
	Sin -	White (Blue TP)	7
	Index -	White (Violet TP)	8
	Shield	-	Casing

A.2.3 PR-50CR-11300/-51300 – Piezo, Digital, Atmospheric Pinout

See Figure 6-B.

Motor	Pinout for PR-50CR-11300/-51300		Cable A D-sub 9M
	Description	Color	L1
	Motor 1, Phase 1	Red	1
	Motor 1, Phase 2	White (Green TP)	2
	Motor 2*, Phase 1	White (Grey TP)	3
	Motor 2*, Phase 2	White (Blue TP)	4
	Motor 1, Ground	Black/Green	5
	Motor 2*, Ground	Grey/Blue	5
	Shield	-	Casing

* Greyed out rows are for High Force Piezo option

Cable B
D-sub 9F

Encoder	Description	Color	L2
	A +	Brown	1
	B +	Blue	2
	Index+	Violet	3
	GND	Grey	4
	+5V	White (Grey TP)	5
	A -	White (Brown TP)	6
	B -	White (Blue TP)	7
	Index-	White (Violet TP)	8
	Shield	-	Casing

A.2.4 PR-50CR-11006/9 or -51006/9 – Piezo, Open Loop, Vacuum Pinout

See Figure 6-C.

	Pinout for PR-50CR-11006 or -51006	Cable A D-sub 9F			Feedthrough D-sub 9M			Cable B D-sub 9F D-sub 9M	
		L1	L2	L3	Color	L4	L5		
Motor	Motor 1, Phase 1	Red	5	5	1	Red	1	1	
	Motor 1, Phase 2	White (Green TP)	4	4	2	White (Green TP)	2	2	
	Motor 2*, Phase 1	White (Grey TP)	3	3	3	White (Grey TP)	3	3	
	Motor 2*, Phase 2	White (Blue TP)	2	2	4	White (Blue TP)	4	4	
	Motor 1, Ground	Black/Green	1	1	5	Black/Green	5	5	
	Motor 2*, Ground	Grey/Blue	1	1	5	Grey/Blue	5	5	
	Shield	-	6	6	9	-	9	Casing	

* Greyed out rows are for High Force Piezo option

A.2.5 PR-50CR-11206/9 or -51206/9 – Piezo, Analog, High Vacuum Pinout

See Figure 6-D.

	Pinout for PR-50CR-11206 or -51206	Cable A&B D-sub 15F			Feedthrough D-sub 15M			Cable C D-sub 9M		Cable D D-sub 9F
		L1	L2	L3	Color	L4	L5	L6		
MOTOR A & C	Motor 1, Phase 1	Red	1	1	8	Red	8	1	-	-
	Motor 1, Phase 2	White (Green TP)	2	2	7	White (Green TP)	7	2	-	-
	Motor 2*, Phase 1	Black/Green	9	9	15	Black/Green	15	5	-	-
	Motor 2*, Phase 2	White (Grey TP)	3	3	6	White (Grey TP)	6	3	-	-
	Motor 1, Ground	White (Blue TP)	11	11	13	White (Blue TP)	13	4	-	-
	Motor 2*, Ground	Grey/Blue	9	9	15	Grey/Blue	15	5	-	-
	Shield	-	10	10	14	-	14	Casing	-	-
Encoder B & D	Encoder GND	Grey	8	8	1	Grey	1	-	-	4
	A+	Brown	7	7	2	Brown	2	-	-	1
	+5V	White (Grey TP)	6	6	3	White (Grey TP)	3	-	-	5
	A-	White (Brown TP)	5	5	4	White (Brown TP)	4	-	-	6
	B+	Blue	4	4	5	Blue	5	-	-	2
	B-	White (Blue TP)	12	12	12	White (Blue TP)	12	-	-	7
	Index-	White (Violet TP)	13	13	11	White (Violet TP)	11	-	-	8
	Index+	Violet	14	14	10	Violet	10	-	-	3
	Encoder Shield	-	15	15	9	-	9	-	-	Casing

* Greyed out rows are for High Force Piezo option

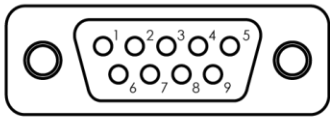
A.2.6 PR-50CR-11306/9 or -51306/9 – Piezo, Digital, High Vacuum Pinout

See Figure 6-D.

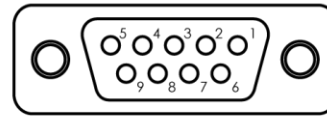
	Pinout for PR-50CR-11306 or -51306	Cable A&B	Feedthrough			D-sub 15F	Cable C	Cable D	
		D-sub 15F	D-sub 15M		D-sub 9M		D-sub 9F		
MOTOR A & C	Description	Color	L1	L2	L3	Color	L4	L5	L6
	Motor 1, Phase 1	Red	1	1	8	Red	8	1	-
	Motor 1, Phase 2	White (Green TP)	2	2	7	White (Green TP)	7	2	-
	Motor 2*, Phase 1	Black/Green	9	9	15	Black/Green	15	5	-
	Motor 2*, Phase 2	White (Grey TP)	3	3	6	White (Grey TP)	6	3	-
	Motor 1, Ground	White (Blue TP)	11	11	13	White (Blue TP)	13	4	-
	Motor 2*, Ground	Grey/Blue	9	9	15	Grey/Blue	15	5	-
	Shield	-	10	10	14	-	14	Casing	-
Encoder B & D	Encoder GND	Grey	8	8	1	Grey	1	-	4
	A+	Brown	7	7	2	Brown	2	-	1
	+5V	White (Grey TP)	6	6	3	White (Grey TP)	3	-	5
	A-	White (Brown TP)	5	5	4	White (Brown TP)	4	-	6
	B+	Blue	4	4	5	Blue	5	-	2
	B-	White (Blue TP)	12	12	12	White (Blue TP)	12	-	7
	Index-	White (Violet TP)	13	13	11	White (Violet TP)	11	-	8
	Index+	Violet	14	14	10	Violet	10	-	3
Encoder Shield	-	15	15	9	-	9	-	Casing	

* Greyed out rows are for High Force Piezo option

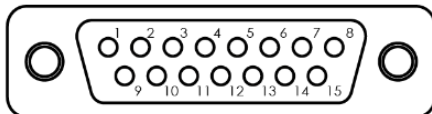
A.3 Standard D-sub Connector Pinout



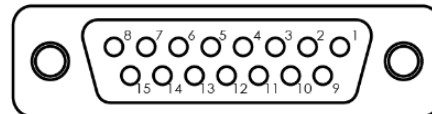
Male Dsub9 Connector (Dsub9M) - Front View



Female Dsub9 Connector (Dsub9F) - Front View



Male Dsub15 Connector (Dsub-15M) - Front View

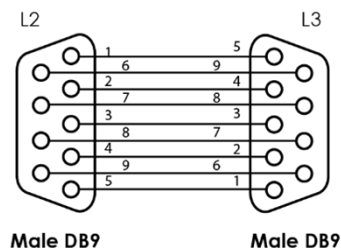


Female Dsub15 Connector (Dsub-15F) - Front View

A.4 Feedthroughs

Recommended feedthrough pinout based on off the shelf feedthroughs.

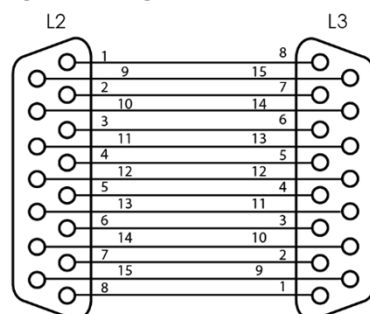
Straight Through 9-Pin Feed-through



Male DB9

Male DB9

Straight Through 15-Pin Feed-through



Male DB15

Male DB15

A.5 Using an Analog Encoder

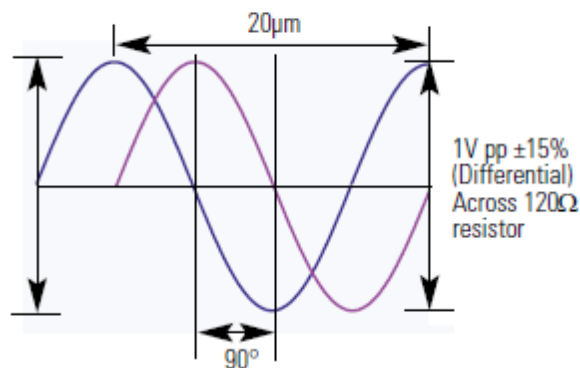
A.5.1 Analog Encoder Overview

A PR-50CR with analog encoder will need to be paired with an appropriate controller that supports 1 V_{pp} sine/cosine encoders such as the MMC-100 and MMC-110. The PR-50CR with an analog encoder will be supplied with a D-sub 9 pin connector that incorporates these encoder signals.

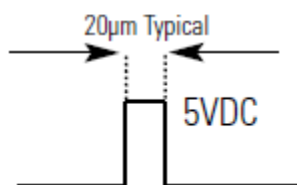
A.5.2 Operating and Electrical Specifications

Power Supply	5VDC $\pm 5\%$ @ 330mA (60mA for sensor)
--------------	--

A.5.3 Analog Output



A.5.4 Index Window



A.5.5 Resolution

All closed loop stages are supplied with a rotary encoder scale with a 3,600-line grating. The interpolation is done in the MICRONIX controller to the resolution specified at the time of order. With an analog encoder, the achievable resolution is $50\mu^\circ$.

A.6 Using a Digital Encoder

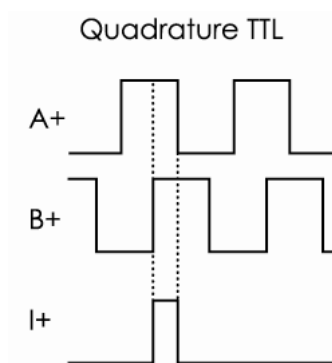
A.6.1 Digital Encoder Overview

The PR-50CR with the digital encoder must be paired with an appropriate controller. The PR-50CR with a digital encoder will be supplied with a 9-pin connector that incorporates these encoder signals.

A.6.2 Operating and Electrical Specifications

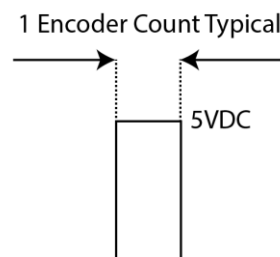
Power Supply	5VDC $\pm 10\%$ @ < 35mA (No outputs terminated) @ < 85mA (A, B, I, and both limits terminated); 50mA at the sensor
--------------	--

A.6.3 Digital Output



NOTE: The index pulse may be aligned with A- or B- at some interpolation values

A.6.4 Index Window



A.6.5 Resolution

All closed loop stages are supplied with a rotary encoder scale with a 3,600-line grating. The digital encoder module interpolates to a higher resolution as specified in the order. With a digital encoder an MMC controller has an achievable resolution of $10\mu^\circ$.