1 Presentation

The Hexapod, pictured in Figure 1.1, is a six degree of freedom (6 DOF) motion platform that can be used in a wide variety of educational and research areas, e.g. rehabilitation, immersive simulations, and earthquake engineering.

This parallel robotic device is able to supports a maximum load of 100 kg and has a bandwidth of 10 Hz (when unloaded and depending on the travel distance). Each of the joints is connected to a low backlash linear ball-screw actuator and has a stroke between ± 15 cm from the center position. The position of each joint is measured using a high-resolution 10,000 count encoders. The top base plate, i.e. the end-effector, is connected to each motor through the six arms using universal joints. An optional Force-Torque sensor can also be mounted on the end-effector to sense the XYZ forces and the torques about those axes.

The Hexapod has its own built-in power amplifier and data acquisition device.

Figure 1.1: Hexapod

Main Hexapod features:

- High-precision linear ball-screws
- 100W high torque direct drive DC motors
- Encoders to measure position of each motor
- Low friction universal joints
- Brake system
- Safety limit switches
- Built-in amplifier
- Built-in USB data acquisition (DAQ) device
- Optional Force-Torque sensor

Caution

This equipment is designed to be used for educational and research purposes and is not intended for use by the general public. The user is responsible to ensure that the equipment will be used by technically qualified personnel only.

2 System Specifications

2.1 System Parameters

Table 2.1 lists and characterizes the main parameters associated with the Hexapod.

Description	Value
Dimensions (L x W x H)	1.1 x 1.1 x 0.75 m^3
Total mass of Hexapod	100 kg
Arm length	0.375 m
Platform radius	0.25 m
Maximum acceleration	1 g
Maximum payload mass	100 kg
Moving mass (pre-load)	8 kg
Bandwidth	0-10 Hz [1]
Actuator maximum force	403 N
Maximum stroke	0.3 m ($\pm$0.15 m)
Support link length (joint-to-joint)	377.825 mm
Payload platform side length	433 mm
Workspace [2]	X: $\pm$ 7.4 cm Y: $\pm$ 11.0 cm Z: $\pm$ 5.4 cm Roll: $\pm$ 17 deg Pitch: +15 deg & -27 deg Yaw: $\pm$ 27 deg
Maximum speed [2]	X: 0.67 m/s Y: 0.67 m/s Z: 0.67 m/s Roll: 152 deg/s Pitch: 152 deg/s Yaw: 80 deg/s
Lead screw pitch	10 mm

Table 2.1: Hexapod System Parameters

2.2 Operating Envelope

The operating envelope of the Hexapod depends on the payload, joint stroke/motion range and the desired motion bandwidth (frequency). The following table captures the maximum joint stroke ranges for a sine wave command that have been tested based on various sample payload scenarios and input signal frequencies.

Note: The Hexapod has not yet been tested at frequencies above 7.5 Hz for a 100 kg load.

[1] Frequency range is dependent on the displacement and load. See 2.2 for more information. For more details, please contact Quanser.
[2] Assuming other 5 DOF's are held at home position.

Note: The maximum speed limits outlined in Table 2.1 were relaxed to obtain the joint stroke ranges listed here

Max Joint Stroke Range (± mm)	Frequency (Hz)											
Payload (kg)	**0.1**	**0.2**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**	**5**	**7.5**	**10**	**15**
0 kg (no load)	105	105	105	105	75	60	45	37	15	7	4	2
15 kg	105	105	105	105	75	60	45	35	14	7	4	2
100 kg	105	105	105	80	60	45	30	20	8	3	N/A	N/A

Table 2.2: Hexapod Operation Envelope

3 System Hardware

3.1 System Schematic

The interaction between the different system components on the Hexapod is illustrated in Figure 3.1. The DAQ is interfaced to the PC or laptop via USB link. The Hexapod provides a built-in data acquisition device and an integrated amplifier.

On the data acquisition (DAQ) device block, the six motor encoders are connected to the Encoder Input (EI) channels #0 through #5. PWM Output channels 0-5 and Digital Output (DO) lines 6-11 on the DAQ are connected to the power amplifier command inputs, which then drive the DC motors. The digital outputs lines handle the motor direction. Digital Input (DI) channels 0-5 monitor the amplifier drive status (e.g. if any faults occur) and DI #6 reads the emergency stop signal, which is triggered by the Emergency Stop (E-Stop) switch, shown in Figure 3.6. Digital Output (DO) channels #12 and #13 are used to enable the amplifier drives and turn the brake system on/off. The *Other Channels* #14000 to #14005 measure the motor velocity using the encoder velocity hardware. Note that these measurements are independent of the sample rate of the model and are unaffected by sample rate jitter.

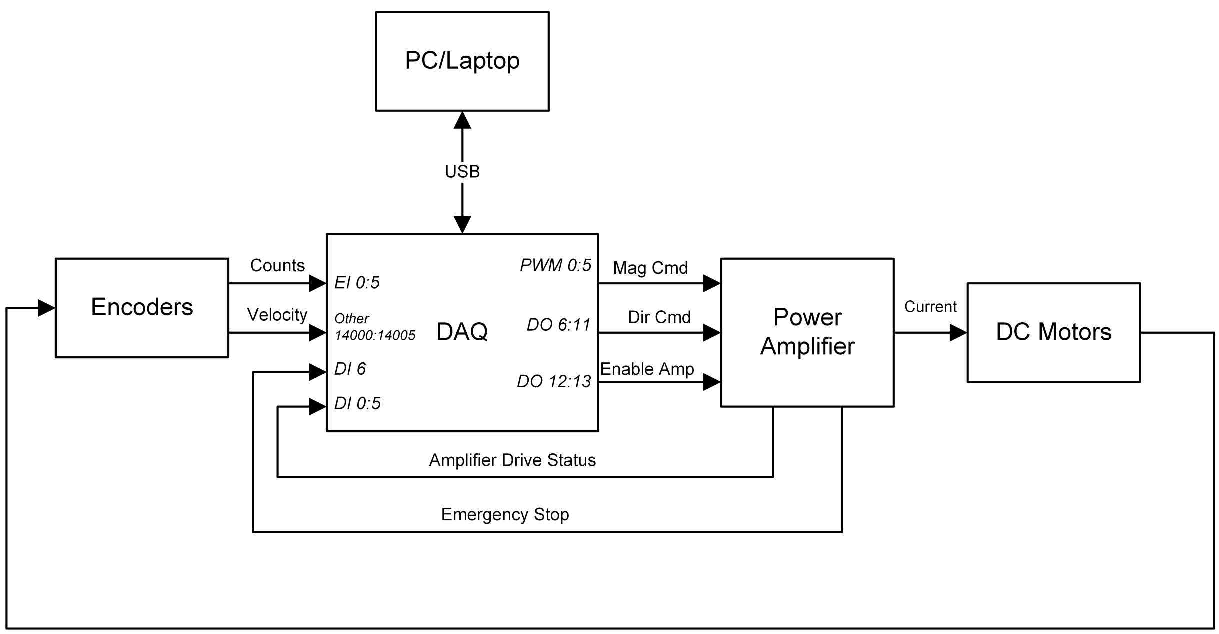


Figure 3.1: Interaction between Hexapod components.

The schematic given in Figure 3.2 illustrates the main Hexapod components and how they interact with a data acquisition (DAQ) device.

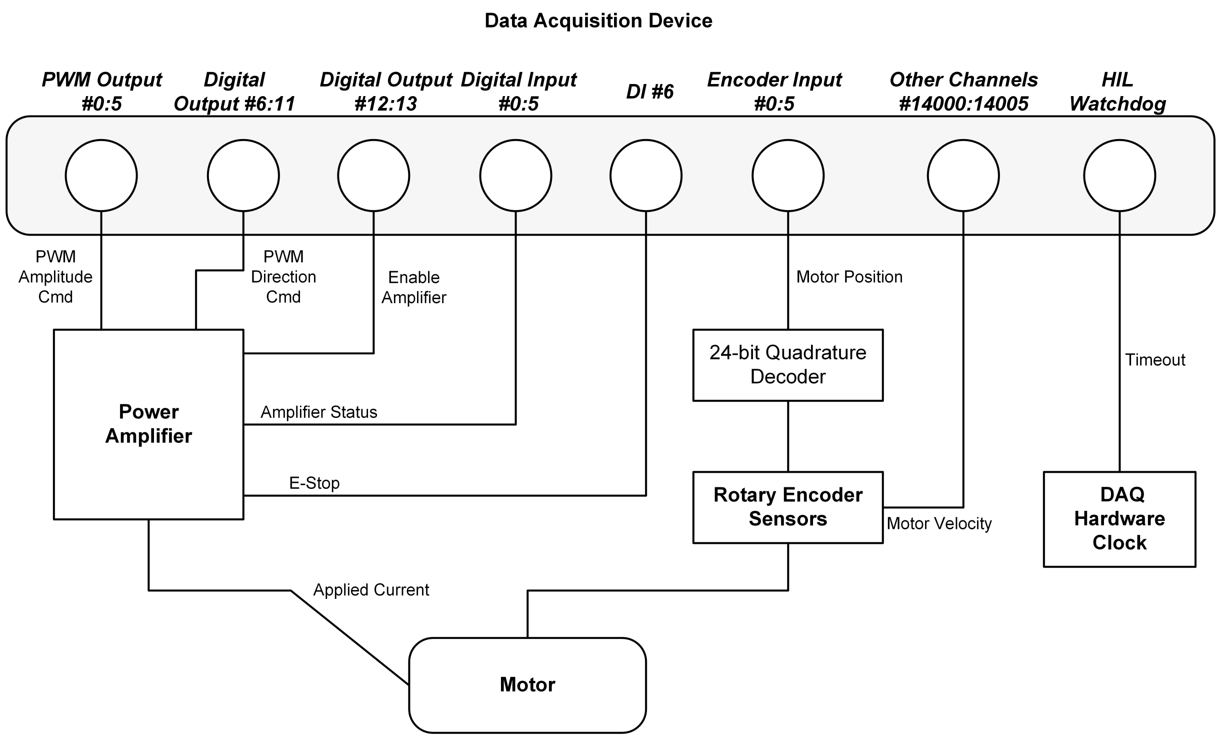


Figure 3.2: DAQ interface to components

3.2 Hardware Components

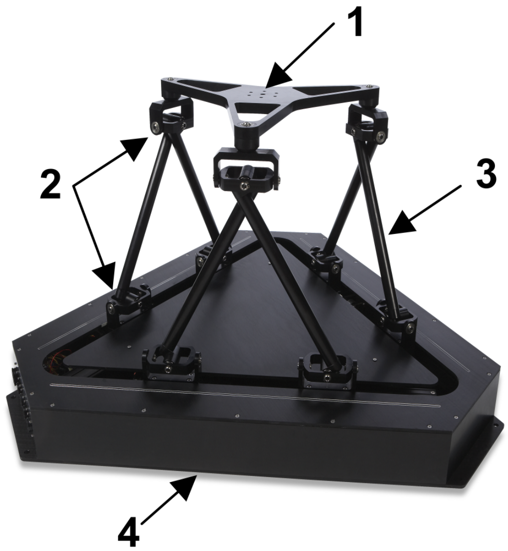
The main Hexapod components are listed in Table 3.1 and shown in Figure 3.3, Figure 3.4, and Figure 3.5.

ESD Warning

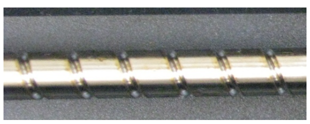
The internal components are sensitive to electrostatic discharge. Before handling the Hexapod, make sure you touch something metal to ground yourself.

ID	Component	ID	Component
1	Top stage (mounting plate)	10	USB DAQ connector
2	Universal joint	11	E-Stop connector
3	Base to motor arm	12	Ball-screw
4	Base platform	13	DC motor
5	Power connector	14	Limit safety switch (not shown)
6	Power switch	15	Emergency stop switch (E-Stop)
7	Main Supply Fuse (not shown)	16	Force-torque sensor (optional)
8	10 A supply fuse	17	Amplifier drive
9	3 A supply fuse	18	Rotary optical encoder

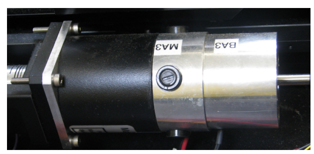
Table 3.1: Hexapod Components



(a) Hexapod components



(b) Ball-screw (ID #12)



(c) DC motor (ID #13)

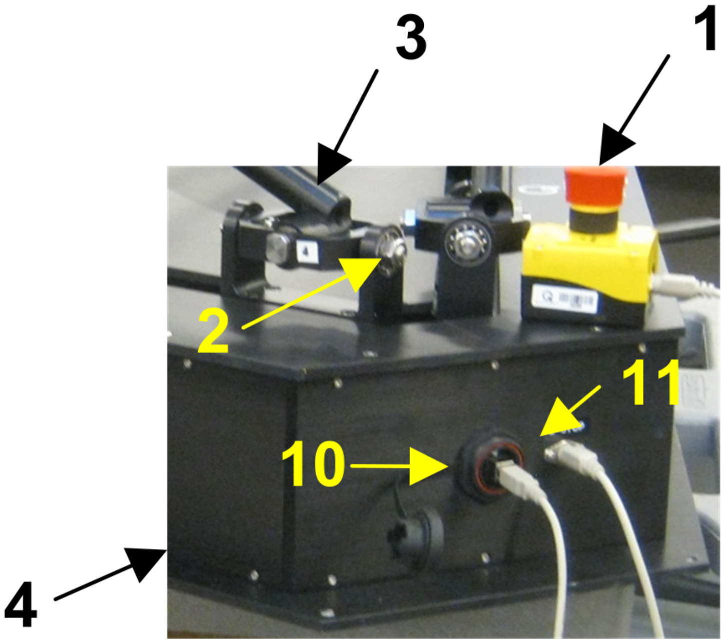
(d) Universal joint (ID #2)

Figure 3.3: Hexapod components

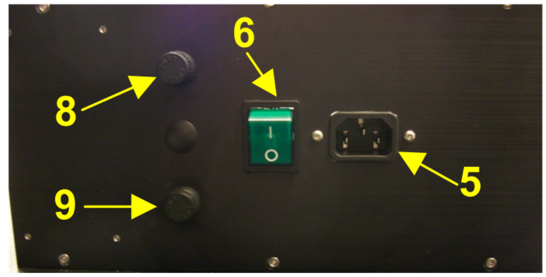
3.2.1 DC Motor

The Hexapod incorporates a Magmotor Brushed DC motor S23-200 series (winding *H*). Some of the motor specifications are given in Table 3.2. For more details, refer to the supplied motor specification sheet.

⚠ **Caution** **Motor input current from amplifiers is limited to 4.7 A peak, 3.9 A continuous.**



(a) USB connector panel



(b) Power connector panel

Figure 3.4: Hexapod power and USB connection panels

Symbol	Description	Value
$\tau_{max,p}$	Peak stall torque	5.65 N-m [800 oz-in]
$\tau_{max,c}$	Continuous stall torque	0.530 N-m [75 oz-in]
R_m	Resistance	1.35 Ω
L_m	Inductance	0.87 mH
k_t	Current-torque constant	0.136 N-m/A [19.3 oz-in/A]
k_m	Motor back-emf constant	0.136 V/(rad/s) [14.3 V/k_{rpm}]
J_m	Rotor inertia	7.062×10^{-5} kg-m^2 [0.010 oz-in-s^2]
$I_{max,p}$	Peak current	48 A
$I_{max,c}$	Continuous current	4.7 A

Table 3.2: Hexapod DC motor parameters

3.2.2 Encoder

The encoders used to measure the angular position of the DC motor and linear link position of the Hexapod are US Digital model E6-2500-250-I-D-H-D-B. They are differential optical shaft encoders and output 10,000 counts per revolution in quadrature mode (2,500 lines per revolution).

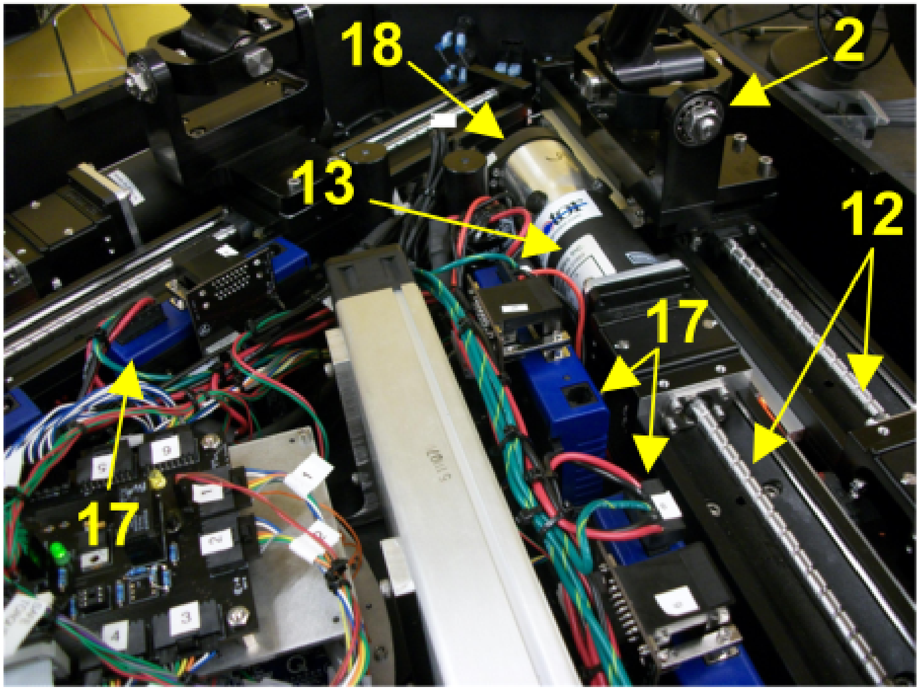


Figure 3.5: Hexapod amplifiers and linear actuators

Description	Value
Encoder line count	2,500 lines/rev
Encoder line count in quadrature	10,000 lines/rev
Linear position resolution	1 μm
Angular position resolution	0.036 deg

Table 3.3: Hexapod encoder system parameters

3.2.3 Data Acquisition (DAQ) Device

The Hexapod includes a USB data acquisition device with eight 24-bit encoder channels with quadrature decoding, eight analog output channels, eight analog input channels. The channel to hardware interface is shown in Figure 3.2. The DAQ is very similar to the Quanser Q8-USB board. See the Q8-USB User Manual for more information.

3.2.4 Power Amplifier

The Hexapod uses a Copley Junus Amplifier controller (JSP-180-20). This is a high-bandwidth PWM current-controlled power amplifier. Specifications are listed in Table 3.4. For additional information, see the supplied product sheet from the manufacturer.

Note that the product sheet lists the maximum peak current of 20A and the maximum continuous current of 10A. The current limits givens in Table 3.4 are the limits that were configured through software to match the DC motors.

Description	Value
Amplifier type	Linear
Amplifier gain	0.5 A/V
Peak current limit	4.7 A
Continuous current limit	3.9 A
Peak Power	3.41 kW
Maximum continuous voltage	85 V
Supply AC voltage	110-240 V

Table 3.4: Hexapod amplifier parameters

The amplifiers are set up to fault on over-current or over-temperature. Furthermore, if a limit switch is triggered (limit switches are described in 3.2.6) the motor commands are inhibited. The amplifier itself is not disabled (and the brake is not engaged), but any motor commands towards the limit switch's direction is not accepted and prevents the joint from moving any further towards the limit of the linear guide. The amplifier drive accepts commands to move the joint away from the limit.

3.2.5 Ball Screw Actuator

Each of the six universal joints that are connected to the base platform of the Hexapod are driven using Misumi LX3010C-B1-T3056.4-400 linear actuator. Specifications are listed in Table 3.5. They have a total travel of 30 cm, or $\pm$15 cm from the mid-stroke position. Lead screw pitch is 10 mm.

Description	Value
Total travel	30 cm ($\pm$ 15 cm)
Lead screw pitch	10 mm
Positioning accuracy	0.06 mm
Positioning repeatability	$\pm$0.005 mm
Backlash	0.02 mm
Supply AC voltage	110-240 V

Table 3.5: Hexapod linear ball-screw parameters

Caution

Exposed moving parts.

3.2.6 Limit Switches

Inductive limit switches are installed on each end of the base linear actuators. When any of the limit switches are triggered (i.e. the joint went pass it), the motor commands are inhibited towards the limits direction.

3.2.7 Emergency Stop Switch

The Emergency Stop, i.e. E-Stop, switch shown in Figure 3.6 must be connected to the Hexapod for proper operation. When red button is pressed DOWN, the amplifiers are disengaged and the motor cannot be driven. The amplifiers can only be enabled if the E-Stop is connected to the Hexapod system and the red button is in the upright, released position. To release the E-Stop, twist the red button clockwise until the button goes to the upright position.

The *Calibration* button must be pressed down and held during the calibration procedure of the system.

Figure 3.6: Emergency stop switch (ID #15)

3.2.8 Force-Torque Sensor

A force-torque sensor such as the one shown in Figure 3.7 can be mounted to the top stage (e.g. using an custom made adapter) in order to take force and torque measurements. This component is *optional* and is not part of the standard offering.

Figure 3.7: Force-Torque sensor (ID #16, optional)]

3.3 Top Plate and Base Dimensions

The base dimensions to mount the Hexapod is illustrated in Figure 3.8.

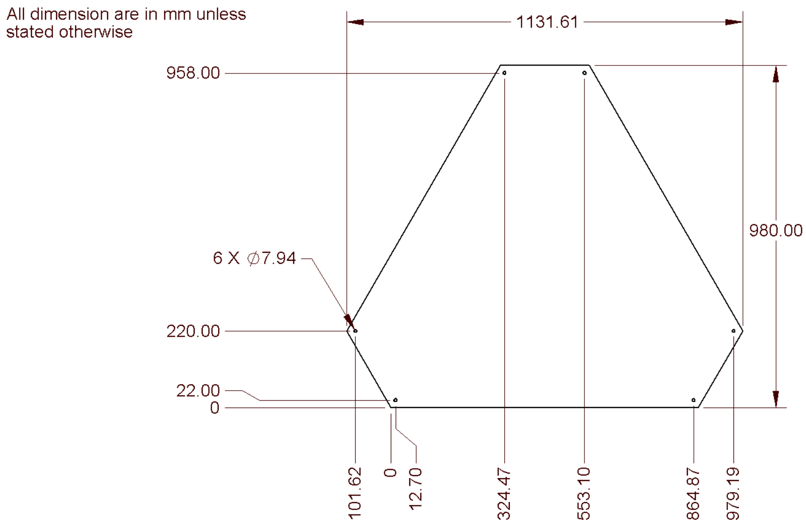


Figure 3.8: Dimensions of Hexapod base plate

The top plate of the Hexapod be used to mount custom structures. The dimensions of the top plate are shown in Figure 3.9. Use the screw holes to securely mount the structure on the system.

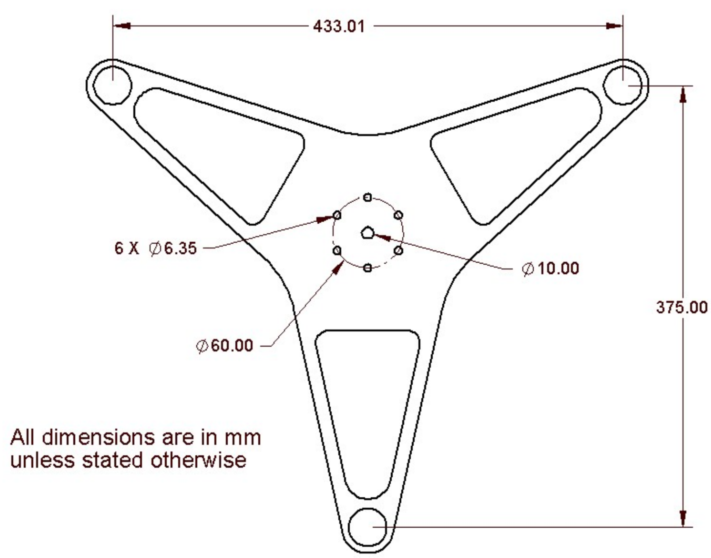


Figure 3.9: Dimensions of Hexapod top plate

4 System Setup

Caution

If the equipment is used in a manner not specified by the manufacturer, the protection provided by the equipment may be impaired.

4.1 Installation Requirements

In order to install and test the Hexapod:

1. PC/laptop with MATLAB®, SIMULINK®, and QUARC® software installed. **Important:** Make sure the PC/laptop has a permanent MATLAB®/SIMULINK® license with all the required toolboxes for the QUARC® software. Please read the *System Requirements* document supplied with QUARC® software and available at https://www.quanser.com/products/quarc-real-time-control-software/ for all the necessary information.
2. Standard wall outlet with voltage supply of 100-240 VAC.
3. It is recommended to mount and fasten the Hexapod to a stable platform or floor (e.g. screwed into concrete floor). Especially when conducting experiments with heavy loads. The base plate and screw hole dimensions is given in Figure 3.8.
4. Following the connection procedure given in 4.2.
5. Run the testing procedure given in Hexapod Laboratory Guide.

Caution

The Hexapod should be mounted on a stable platform or floor prior to operation.

4.2 Connections

This section describes how to connect the Hexapod system for operation. The connection procedure is given below, summarized in Table 4.1 and illustrated in Figure 4.1.

To setup the Hexapod follow these steps:

1. Connect the Emergency Stop (E-Stop) switch to the 6-pin mini-DIN **E-Stop** connector on the Quanser Hexapod.

   Note: The Hexapod cannot be operated without the E-Stop being connected.

2. Connect USB 2.0 cable from back cover of Hexapod to an enabled USB 2.0 port on your desktop PC or laptop.
3. Connect the **Power** connector on the Hexapod to the wall outlet using the supplied power cable.
4. Turn ON the power switch.
5. The Hexapod driver should install automatically. If not, then you may not have installed all the required software to support the device including either QUARC®.

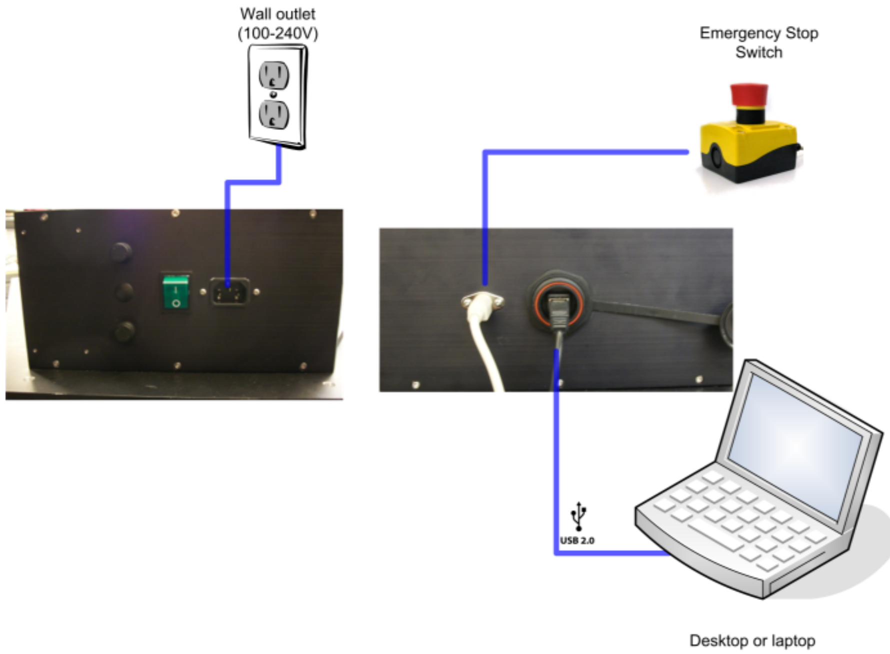


Figure 4.1: Connections between Hexapod and an external DAQ

Cable #	From	To	Signal
1	**E-Stop** switch	Hexapod **E-Stop** connector	Connects the emergency safety switch to the Hexapod.
2	PC: USB 2.0 port	Hexapod **USB** connector	Connects PC to embedded data acquisition (DAQ) device.
3	Hexapod **Power** connector	Wall outlet	Supplies power to the Hexapod.

Table 4.1: Hexapod wiring summary

4.3 Maintenance

Make sure the Hexapod system is ran in clean and dust-free environment at an ambient temperature of $50°$C or below. The linear actuators for each leg of the Hexapod were specifically chosen to provide quality motion and operate maintenance free. They are designed to operate without requiring extra lubrication for 1000 km, or 3.3×10^6 full strokes (i.e. each stroke being the maximum travel of 30 cm).

Please see the *Maintenance* section in the specification sheet for the Misumi LX3010C-B1-T3056.4-400 linear actuator supplied for routine inspection and lubrication recommendations.

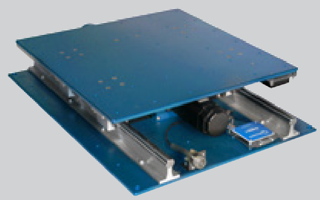
Caution

If lubrication needs to be applied, make sure the Hexapod power is disconnected.

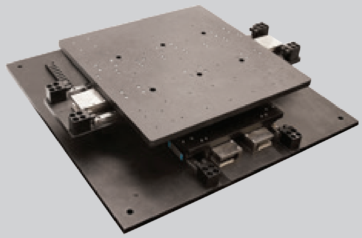
Systems for structural dynamics and analysis teaching and research

Shake Table I-40

Shake Table II

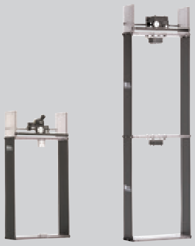


XY Shake Table III



Hexapod

One- or Two-floor Active Mass Damper



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