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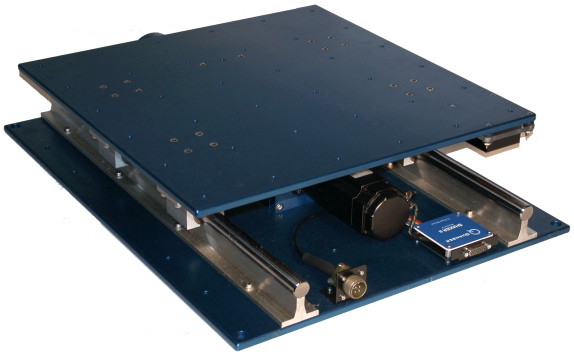
Shake Table II



User Manual

STII

Quanser Inc.
2014

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1 PRESENTATION

The Quanser Shake Table II (STII) shown in Figure 1.1 is an instructional shake table device that was originally developed for the University Consortium on Instructional Shake Tables (UCIST). It can be used to teach structural dynamics, vibration isolation, feedback control, and various other topics for mechanical, aerospace, and civil engineers.

The shake table is rated to drive a 7.5 kg load at 2.5 g. The stage rides on two ground-hardened metal shafts using linear bearings which allows for smooth linear motions with low path deflection. When starting from center the stage is capable of moving $\pm$7.62 cm, or $\pm$3-inches (i.e., total travel of 15.24 cm). The 400 Watt 3-phase brushless DC actuator is connected to a robust ball-screw assembly. The motor has an embedded high-resolution encoder used to measure stage position with a resolution of 3.10 μm. An analog accelerometer is mounted to measure the acceleration of the stage directly.

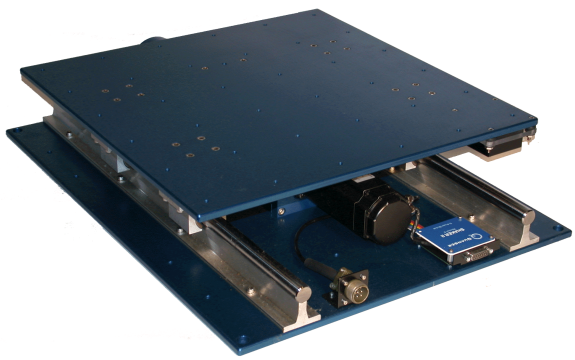


Figure 1.1: Quanser Shake Table II

The main devices used to run the shake table is depicted in Figure 1.2. The entire system is comprised of:

1. Quanser Shake Table II
2. Power amplifier: Quanser UPM-180-25B
3. Data acquisition (DAQ) device, e.g., Quanser Q4 or Q8 board.
4. PC running QUARC® or Quanser Rapid Control Prototyping Toolkit® software

The interaction between the different system components is shown in Figure 1.2. Using QUARC® on the PC/laptop, the user specifies a command signal to the shake table (e.g., sine wave, earthquake). The current needed to move the stage at the desired position is calculated in QUARC® and sent through the analog output channel of the DAQ device to the power amplifier. The amplifier applies the current and drives the motor on the Shake Table II. The table tracking the commanded signal and the resulting displacement and acceleration of the stage are measured by the on-board encoder and the accelerometer sensors. The encoder and accelerometer are connected to the DAQ and their signals can be displayed and processed further in QUARC®. Plotted data can be also be saved for later analysis.

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.

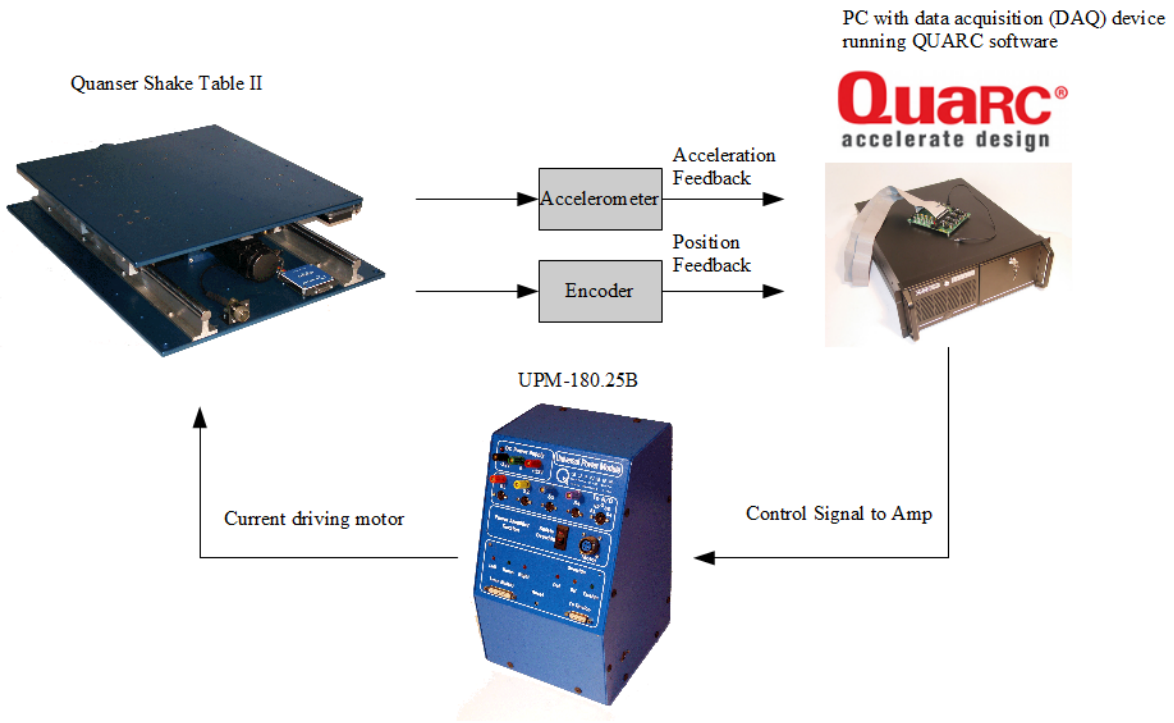


Figure 1.2: Interaction between main Shake Table II components

2 COMPONENTS

The SRV02 components are identified in Section 2. Some of the those components are then described in Section 2.2.

2.1 Nomenclature

The components listed in Table 2.1 are labeled in Figure 2.1.

ID	Component	ID	Component
1	Stage	9	Sensor circuit board
2	Base plate	10	Right limit sensor
3	DC motor	11	Home position sensor
4	Lead screw	12	Left limit sensor
5	Ball nut	13	Motor leads connector
6	Manual adjustment knob	14	Motor encoder and hall sensors connector (i.e. potentiometer)
7	Linear guide	15	Accelerometer
8	Linear bearing block	16	Accelerometer connectors

Table 2.1: Components

2.2 Description

2.2.1 Stage

The top stage on the Shake Table II is shown as ID #1 in Figure 2.1. It is 18 $\times$ 18 inch^2, or 45.7 $\times$ 45.7 cm^2, and 9.7 mm thick. The stage has many screw holes that can be used to mount structures and other objects, e.g., Quanser Active Mass Damper.

2.2.2 Bottom Plate

The bottom support plate, shown in by ID #2 in Figure 2.1, is 24 $\times$ 18 inch^2, or 60.9 $\times$ 45.7 cm^2, and 1.24 mm thick. The steel linear guides and ball-screw are installed onto this plate. There bottom plate has 4 large screw holes at each corner and smaller screw holes along the sides of the plate. These can be used to fasten the shake table onto a ground floor support to prevent the shake table system from moving, or at least reduce the amount of vibration. Although this is not necessary, it is recommended in order to yield more precise results when, for instance, measuring acceleration.

2.2.3 DC Motor

The Shake Table II incorporates a Kollmorgen AKM24 brushless 3-phase DC Motor, shown by ID #3 in Figure 2.1. The motor has a power of 400 W. It is connected to a ball-screw that and drives the ball nut assembly fastened to the bottom of the shake table platform. The brushless commutation is ensured through three hall sensors with a phasing of 120 degrees. Some of the motor specifications are included in Table 3.1. More detailed motor specifications are available in the motor specification sheet [4] under AKM24F.

Caution: Input 15 A peak, 3.75 A continuous.

2.2.4 Lead Screw

The lead screw, shown by ID #4 in Figure 2.1, circulates through a ball nut, component #5 in Figure 2.1, that is attached to the bottom of the shake table stage and is rotated by the motor. The lead screw has a pitch of 0.50 inches. Thus the shake table stage moves 0.50 inches, or 1.24 cm, per single ball-screw revolution.

Caution: Exposed moving parts.

2.2.5 Encoder

The encoder is embedded inside the DC motor and is used to measure the linear position of the stage. It cannot be identified externally. The motor encoder has a resolution of 2048 lines per revolution. In quadrature mode this gives 8192 counts per full rotation motor shaft rotation. The effective resolution, i.e., minimum linear position that can be detected, of the stage displacement is 3.10 μm.

2.2.6 Linear Bearing Block

For smooth motion, the stage is fitted with low friction linear ball bearing blocks, shown by ID #8 in Figure 2.1, that glide on two ground hardened shafts, identified by component #7 in Figure 2.1.

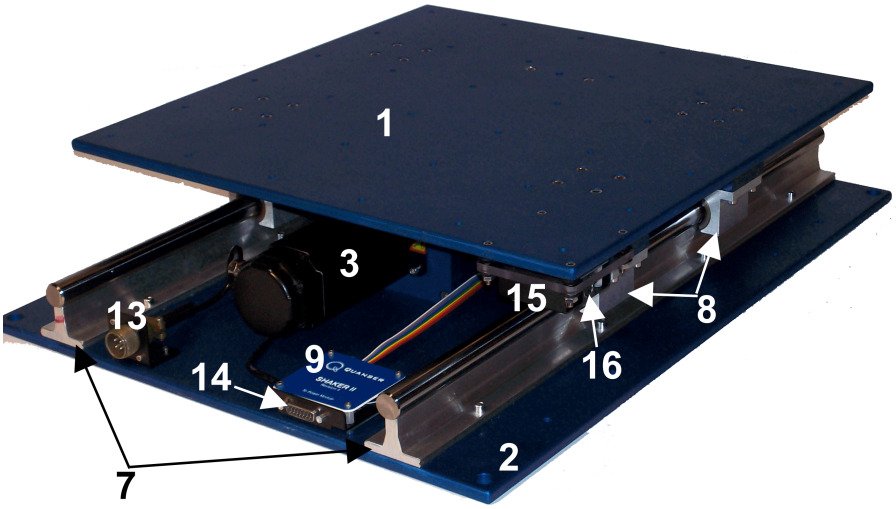
2.2.7 Limit Switches

These *Right*, *Home*, and *Left*, proximity sensors are shown in Figure 2.1 with ID #10, 11, and 12, respectively. The *Left* or *Right* limit switches get triggered when the top stage moves close to the left or right mechanical range. Similarly, the *Home* sensor is set to high when the top stage is at the mid-stroke or center position. These sensors are used to deactivate the power amplifier for safety as well as for calibrating the stage to its center position.

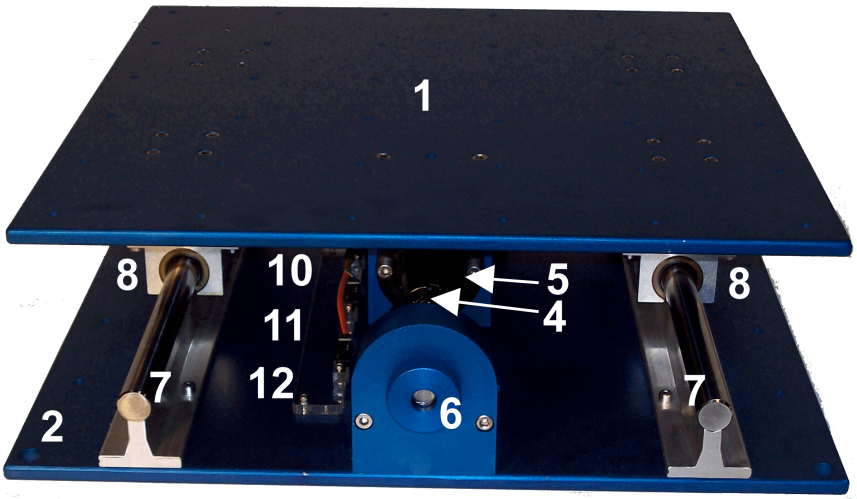
2.2.8 Accelerometer

A dual-axis ADXL210E accelerometer is mounted underneath the stage of the Shake Table II to measure the acceleration of the stage in both the x and y directions. It is shown with ID #15 label in Figure 2.1. The sensor has a range of $\pm$10 g and its noise, in the operating range of the shake table, is approximately $\pm$5.0 mV, i.e., $\pm$5.0 mg. The analog sensor is calibrated such that 1 V equals 1 g, or 9.81 m/s^2. See the ADXL210E accelerometer specification sheet [1] for more details.

Caution: The accelerometer readings can be misleading and lead to unexpected results. Please use caution when using them as they are generally used as indicators.



(a) Top View



(b) Top Corner View

Figure 2.1: Shake Table II Components

3 SPECIFICATIONS

Table 3.1 lists and characterizes the main parameters associated with the Shake Table II.

Symbol	Description	Value
R_m	Motor armature resistance	2.94 Ω
L_m	Motor armature inductance	6.16 mH
k_t	Motor current-torque constant	0.36 N-m/A
k_m	Motor back-emf constant	0.224 V/(rad/s)
P_b	Ball screw pitch	0.0127 m/rev [0.5 in/rev]
$M_{l,max}$	Maximum total load mass	15.0 kg [33.0 lb]
M_s	Mass of Shake Table II system	27.2 kg [60.0 lb]
	Dimension of top stage	0.46 $\times$ 0.46 m^2 [18 $\times$ 18 in^2]
	Dimension of bottom stage.	0.61 $\times$ 0.46 m^2 [24 $\times$ 18 in^2]
	Height from bottom to top stage.	12.4 cm [4.875 in]
x_{max}	Maximum stroke position from midway point.	76.2 mm [3.0 in]
v_{max}	Maximum velocity of stage.	664.9 mm/s [26.18 in/s]
F_{max}	Maximum force of stage.	708.7 N [159.3 lb]
a_{max}	Maximum acceleration of stage for 0 kg load.	24.5 m/s^2
g_{max}	Maximum *rated* acceleration of stage for 0 kg load.	2.50 g
K_ENC	Encoder sensitivity gain	3.1006 μm/count 1.22×10^{-4} in/count
K_ACC	Accelerometer sensitivity gain	-1 g/V
	Dynamic load capacity of ball nut.	12000 N [2697.6 lb]
	Life expectancy of ball nut at full load.	6.35×10^8 m [2.50×10^{10} in]
	Life expectancy of linear bearing.	6.35×10^6 m [2.5×10^8 in]
	Load carrying capacity of linear bearings.	131.5 kg [290 lb]

Table 3.1: Specifications

4 SYSTEM SETUP

The following is a listing of the hardware components used in this experiment:

1. **Power Amplifier**: Quanser UPM-180-25B.
   See the UPM User Manual [2] for amplifier specifications.
2. **Data Acquisition Device**: Quanser Q4 and Q8 HIL devices with the *Q8 Extended Terminal Board*.
3. **Shake table hardware**: Shake Table II
4. **PC with control software**: PC with the Quanser QUARC® or Quanser Rapid Control Prototyping Toolkit® software.

See the corresponding documentation for more information on these components. The cables supplied with the Shake Table II are described in Section Section 4.2 and the procedure to connect the above components is given in Section 4.3.

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 Getting Starting

Before going through the necessary connections outlined in Section 4.3:

1. Make sure you have a PC that is set up with the necessary Quanser QUARC® or Quanser Rapid Control Prototyping Toolkit® software. If these have not been set up (in case you are configuring your own PC), go to the *QUARC Quick Installation Guide* or *RCP Installation Guide* for instructions.
2. Ensure the Quanser Q4 or Q8 data acquisition (DAQ) device is installed in your PC and connected to the Q8 Extended Terminal Board. See the *Q8 Extended Terminal Board User Manual* [3] for instructions on how to connect the Q4/Q8 DAQ in your PC to the terminal board.

   Note: If a PC was included with the shipment, both the QUARC or RCP software and the Q4/Q8 DAQ board have already been installed in the PC.
3. Go to Section 4.3 for instructions on how to connect the Shake Table II to the UPM-180-25B power amplifier and the Q8 Extended Terminal Board (DAQ). Ensure all equipment is powered off before making any of these connections. This includes turning off your PC and the UPM-180-25B.

4.2 Cable Nomenclature

The cables used to connect the Quanser UPM-180-25B to a Quanser DAQ and experiment are shown in Table 4.1. Depending on your configuration, not all these cables are necessary.

Cable	Type	Description
 (a) From MultiQ	DB25 to DB25	This cable connects the Quanser Q4/Q8 data acquisition device to the UPM-180-25B power amplifier. It carries the motor encoder signals, limit sensor signals, calibrate signal, and the analog sensor signals from the S1, S2, S3, and S4 connectors on the amplifier. It also carries the control/command signal (to be amplified and sent to the motor) as well as the calibrate and enable digital signals.
 (b) Motor Cable	4-pin-Amphenol to 4-pin-Amphenol	The 3-phase motor cable connects the output of the UPM-180-25B amplifier to the motor on the Shake Table II system.
 (c) E-Stop	E-Stop	The E-Stop must be connected to the UPM-180-25B for proper operation. The E-Stop button locks in the disabled position when pressed. To release the E-Stop, twist the red button clockwise.
 (d) To Device Cable	DB15 to DB15	This cable connects the *To Device* connector on the UPM-180-25B amplifier to the Shake Table II circuit board. It carries the three limit switch signals, the motor Hall effect signals, and the motor encoder signals. It also supplies the DC power required by the sensors.
 (e) Analog Cable	6-pin-mini-DIN to 6-pin-mini-DIN	This cable connects an external analog sensor to the UPM-180-25B *S1*, *S2*, *S3*, or *S4* connectors. The cable also supplies $\pm$ 12 VDC from the amplifier to power the connected sensors.

Table 4.1: Cables used to connect the UPM-180-25B to a Quanser DAQ and experiment

4.3 Connections

This section describes the connections used to connect the Quanser Q8 Extended Terminal Board to the UPM-180-25B power amplifier and the Quanser Shake Table II system. The connections are summarized in Table 4.2, and pictured in Figure 4.1. Connection details are given below.

Cable	From	To	Signal
1	Q8 Terminal Board: *Table X* connector	UPM-180-25B *From MultiQ* connector	Drives the amplifier to move the stage and receives the accelerometer, stage encoder, calibration, and limit detector signals.
2	UPM-180-25B: *To Device* connector	Shake Table II: circuit board	Limit switch signals, motor Hall effect signals, and motor encoder signals, as well as power for these sensors. **Tighten the screw locks on the DB15 connectors at both ends of the cable.**
3	UPM-180-25B: *Motor* connector	Shake Table II: motor connector	UPM-180-25B output to the motor. The UPM-180-25B adjusts the output duty cycle to maintain the commanded output current.
4	E-Stop button	UPM-180-25B *E-Stop* connector	Emergency stop. **Must be connected in order to enable the amplifier and drive the table.**
5	Shake Table II: accelerometer connector	UPM-180-25B *S1* connector	Accelerometer signal, and power for the accelerometer.

Table 4.2: Connecting the UPM-180-25B to a Quanser DAQ and Shake Table II

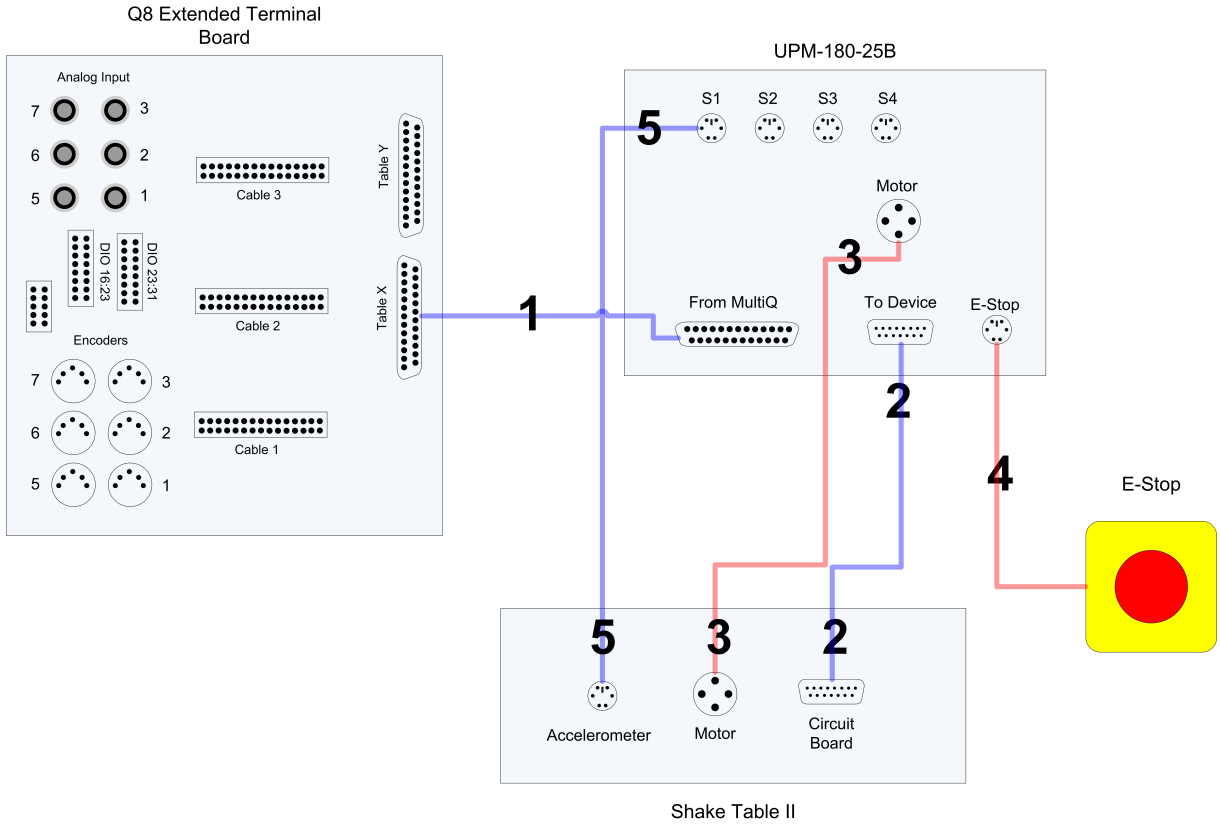


Figure 4.1: Connecting the UPM-180-25B to a Quanser DAQ and Shake Table II

Follow these steps to connect the UPM-180-25B power amplifier to the Quanser Q8 Extended Terminal Board and the Quanser Shake Table II system:

1. Connect the DB25 to DB25 cable from the *Table X* connector on the Q8 Extended Terminal Board to the *From MultiQ* connector on the UPM-180-25B, ensuring that the screw locks are fastened at both ends. See connection #1 shown in Figure 4.1. See connection #1 shown in Figure 4.1. This carries the command signal that controls the output to the motor as well as the three limit switch signals, the motor Hall effect signals, and the motor encoder signals.

2. Connect the DB15 to DB15 cable from the *From Device* connector on the UPM-180-25B to the *To Power Module* connector on the Shake Table II, ensuring that the screw locks are fastened at both ends. See connection #2 shown in Figure 4.1. This cable carries the three limit switch signals, the motor Hall effect signals, and the motor encoder signals.

   Caution: The screw locks on the DB15 connectors must be fastened at both ends of the cable. Failure to fasten the screw locks could result in the cable coming loose, which could cause damage to the equipment and/or injury to nearby personnel.

3. Connect the 4-pin-Amphenol to 4-pin-Amphenol motor cable from the *To Load* connector on the UPM-180-25B to the Shake Table II motor connector. See connection #3 shown in Figure 4.1. This cable connects the output of the UPM-180-25B to the Shake Table II motor.

4. Connect the Emergency Stop (E-Stop) button to the *E-Stop* connector on the UPM-180-25B. See connection #4 shown in Figure 4.1.

5. Connect the 6-pin-mini-DIN to 6-pin-mini-DIN cable from the *S1* connector on the UPM-180-25B to the accelerometer connector on the side of the Shake Table II. This connection is labeled #5 in Figure 4.1.

5 X-Y SHAKE TABLE II CONFIGURATION

Two Shake Table II devices can be mounted perpendicular together, as shown in Figure 5.1, to have displacements in both the x and y directions.

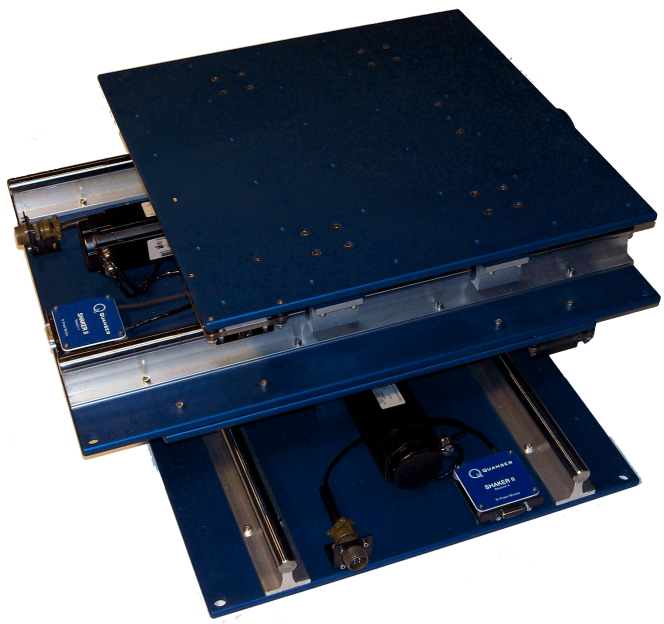


Figure 5.1: Shake Table II systems in X-Y configuration

The following hardware components are required for the X-Y Shake Table II system:

1. **Power Amplifier**: 2x Quanser UPM-180-25B (for each shake table)
2. **Data Acquisition Device**: 1x Quanser Q8 data acquisition device with 1x *Q8 Extended Terminal Board*.
3. **Shake table hardware**: 2x Quanser Shake Table II devices

Follow these steps to setup the X-Y Shake Table II system:

1. See Section 4.3 for instructions on how to set up a single-axis Shake Table II system and make sure each Shake Table II has been tested properly.
2. Go through Section 5.1 for some instructions on mounting the y-axis table onto the x-axis table.
3. Connect the two Quanser UPM-180-25B devices to the Q8 Extended Terminal Board and the two Shake Table II devices, as detailed in Section 5.2.

5.1 Mounting the Shake Tables

The bottom table drives the x-axis motions and the y-axis displacements are generated by shake table mounted on top. The axes are illustrated in Figure 5.2.

Follow these steps to mount the top y-axis table onto the bottom x-axis shake table:

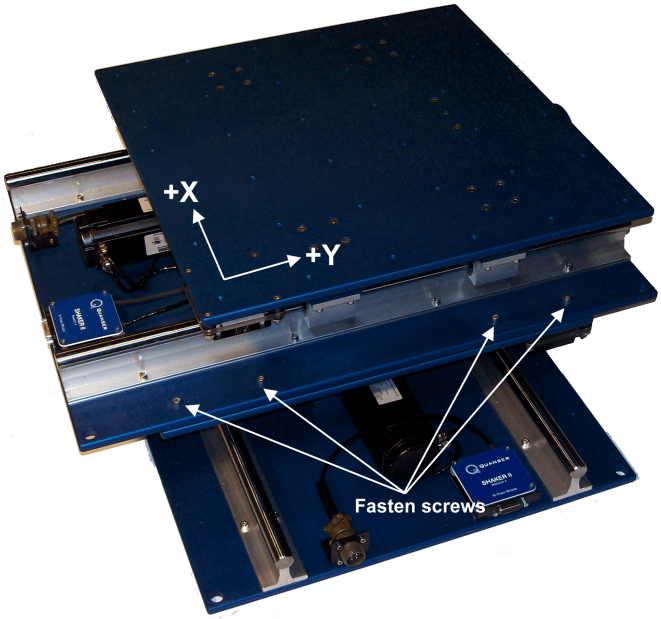


Figure 5.2: Axes on the Shake Table II systems in X-Y configuration

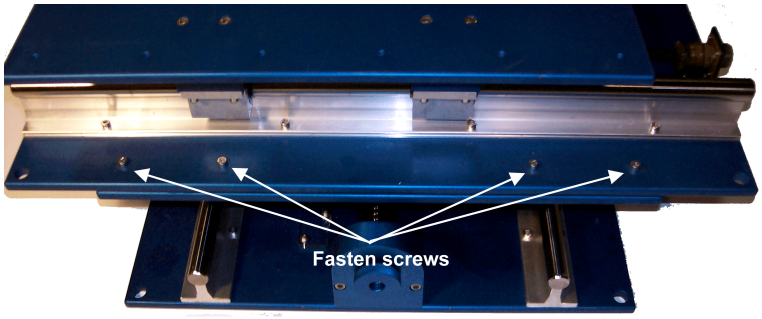


Figure 5.3: Side view of screw holes on the Shake Table II systems in X-Y configuration

1. There is a total of 8 screw holes that will be used to fasten the two shake tables together. Figure 5.2 shows the 4x screw holes on one side.
2. Place the 8 rubber stops on the 8 screw holes on the designated bottom shake table. The rubber stops prevents the top stage of the x-axis Shake Table II from being scratched and they also helps minimize vibrations between the two tables.
3. As pictured in Figure 5.2, position the y-axis shake table onto the stage of the bottom Shake Table II (i.e., the one with the rubber stops).
4. Insert the 8 screws into the 8 screw holes depicted in Figure 5.2 and Figure 5.3. The rubber stops may have shifted around when the top table was mounted. It is recommended to have two people for this task. One person lifts the top system while the other can align the screw with the screw hole and the rubber stop. Don't tighten the screws fully until they are all positioned properly.
5. Tighten the 8 screws to fasten the top y-axis table to the bottom x-axis table.

5.2 Connecting the X-Y Shake Table Configuration

This section describes the connections used to connect the Quanser Q8 Extended Terminal Board to the 2x UPM-180-25B power amplifiers and the 3x Shake Table II systems for X-Y motion. The connections are summarized in Table 5.1, and pictured in Figure 5.4.

Cable	From	To	Signal
1	Q8 Terminal Board: **Table X** connector	UPM-180-25B X-Axis *From MultiQ* connector	Drives the amplifier to move the stage and receives the accelerometer, stage encoder, calibration, and limit detector signals.
2	UPM-180-25B X-Axis: *To Device* connector	Shake Table II X-Axis: circuit board	Limit switch signals, motor Hall effect signals, and motor encoder signals, as well as power for these sensors. **Tighten the screw locks on the DB15 connectors at both ends of the cable.**
3	UPM-180-25B X-Axis: *Motor* connector	Shake Table II X-Axis: motor connector	UPM-180-25B output to the motor. The UPM-180-25B adjusts the output duty cycle to maintain the commanded output current.
4	E-Stop button	UPM-180-25B X-Axis *E-Stop* connector	Emergency stop. **Must be connected in order to enable the amplifier and drive the table.**
5	Shake Table II X-Axis: accelerometer connector	UPM-180-25B X-Axis *S1* connector	Accelerometer signal, and power for the accelerometer.
6	Q8 Terminal Board: **Table Y** connector	UPM-180-25B Y-Axis *From MultiQ* connector	Drives the amplifier to move the stage and receives the accelerometer, stage encoder, calibration, and limit detector signals.
7	UPM-180-25B Y-Axis: *To Device* connector	Shake Table II Y-Axis: circuit board	Limit switch signals, motor Hall effect signals, and motor encoder signals, as well as power for these sensors. **Tighten the screw locks on the DB15 connectors at both ends of the cable.**
8	UPM-180-25B Y-Axis: *Motor* connector	Shake Table II Y-Axis: motor connector	UPM-180-25B output to the motor. The UPM-180-25B adjusts the output duty cycle to maintain the commanded output current.
9	E-Stop button	UPM-180-25B Y-Axis *E-Stop* connector	Emergency stop. **Must be connected in order to enable the amplifier and drive the table.**
10	Shake Table II Y-Axis: accelerometer connector	UPM-180-25B X-Axis *S1* connector	Accelerometer signal, and power for the accelerometer.

Table 5.1: Connections for the X-Y Shake Table II system

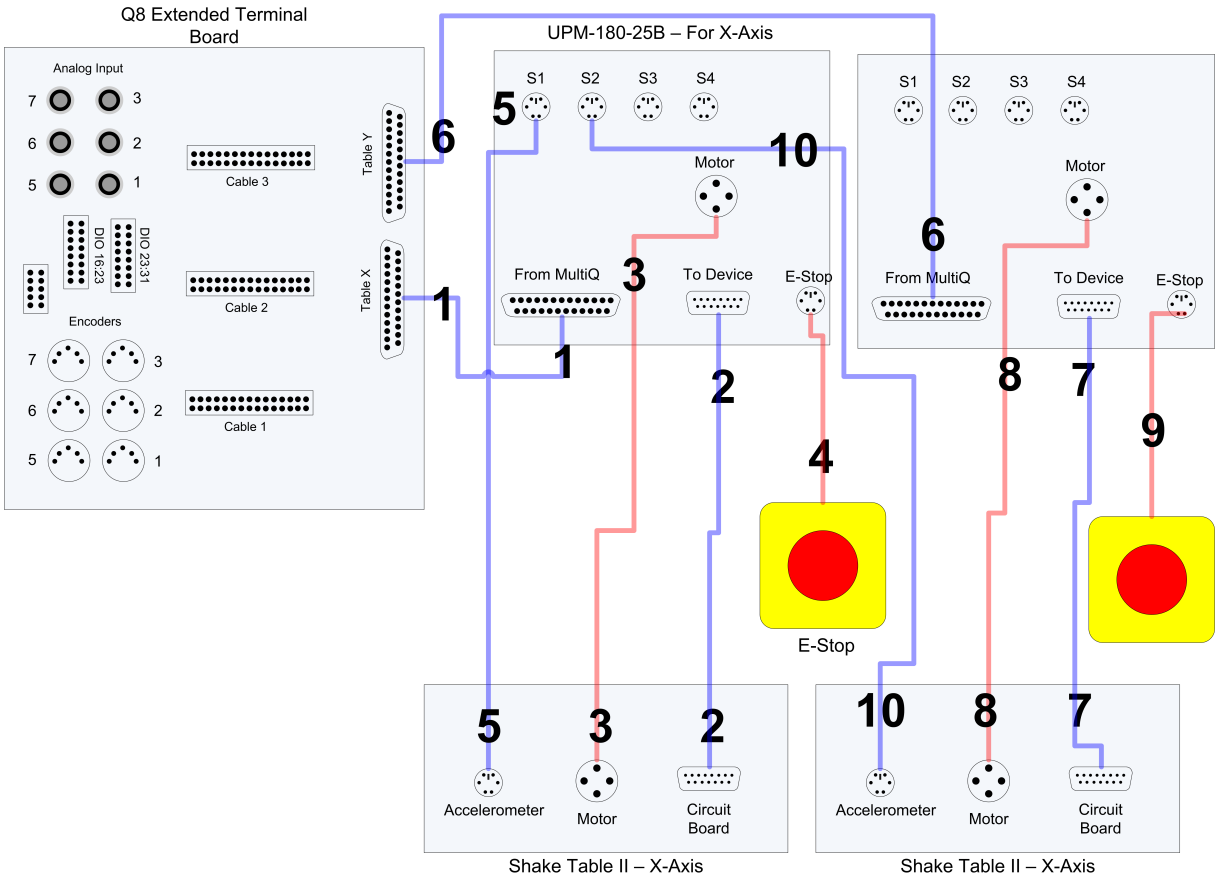


Figure 5.4: Connecting the X-Y Shake Table II system

6 TROUBLESHOOTING

Stage is not moving when running controllers.

If the table does not move when the calibration, sine, sweep, or earthquake controllers are ran then go through the following checklist:

- **Is the red power LED in the top-left corner on the UPM-180-25B power amplifier lit?** If not, turn the switch to the OFF position and ensure the AC cord is securely connected. If after switching the UPM ON the LED is still not lit, the fuse may be blown. Replace the fuse and try re-powering the UPM.
- **Are the LEFT and RIGHT LED's flashing?** The UPM has not been initialized. See the *Shake Table II Laboratory Guide* for the procedure to initialize the amplifier.
- **Is the OK LED on the amplifier ON when running the controller?** If not, ensure that the E-Stop switch is connected to the amplifier and it is in the *upper, released* position.
- **Is the red LED on the *Q8 Extended Terminal Board* lit?** If it is NOT lit, then the fuse on the terminal board may be blown or there may be a lack of power being supplied to the terminal board. See the Q8 Extended Terminal Board User Manual [3] for fuse replacement and rating information.
- **Is the red LED on the *Q8 Extended Terminal Board* dim?** If the LED on the Q8 Extended Terminal Board is dim, then the fuse on the actual Q4/Q8 data acquisition device that is inside the computer may be blown. To replace the fuse on the Q4/Q8 board, please follow the instruction given the Q8 Extended Terminal Board User Manual [3].

Encoder is not measuring.

- Review the Connection #1 and #2 in Section 4.3.
- Verify that the data acquisition device is functional. The LED on the *Q8 Extended Terminal Board* should be lit bright red. Otherwise, follow the fuse replacement procedure.

Accelerometer is not measuring.

- Review the Connections #1 and #5 in Section 4.3. Make sure the analog cable is firmly connected to the accelerometer connector and the S1 connector on the amplifier.
- Ensure the power amplifier is powered on and operational.
- Verify that the data acquisition device is functional. The LED on the *Q8 Extended Terminal Board* should be lit bright red. Otherwise, follow the fuse replacement procedure.

7 TECHNICAL SUPPORT

To obtain support from Quanser, go to http://www.quanser.com/ and click on the **Technical Support** link. There is an online FAQ with commonly found issues. If your issue is not addressed, then go to technical support request page and fill out the required information.

REFERENCES

[1] Analog Devices. Adxl210e. 2002.

[2] Quanser Inc. *Universal Power Module (UPM) User Guide*, 2006.

[3] Quanser Inc. *Q8 Extended Terminal Board User Manual*, 2014.

[4] Danaher Motion. *AKM Series Motors*, 2005.