QUANSER

INNOVATE. EDUCATE.

# USER MANUAL

## Ball and Beam Experiment

Set Up and Configuration

CAPTIVATE. MOTIVATE. GRADUATE.

Quanser Inc.
119 Spy Court
Markham, Ontario
L3R 5H6
Canada
info@quanser.com
Phone: 1-905-940-3575
Fax: 1-905-940-3576

Printed in Markham, Ontario.

For more information on the solutions Quanser Inc. offers, please visit the web site at:
http://www.quanser.com



**Waste Electrical and Electronic Equipment (WEEE)**

This symbol indicates that waste products must be disposed of separately from municipal household waste, according to Directive 2002/96/EC of the European Parliament and the Council on waste electrical and electronic equipment (WEEE). All products at the end of their life cycle must be sent to a WEEE collection and recycling center. Proper WEEE disposal reduces the environmental impact and the risk to human health due to potentially hazardous substances used in such equipment. Your cooperation in proper WEEE disposal will contribute to the effective usage of natural resources. For information about the available collection and recycling scheme in a particular country, go to ni.com/citizenship/weee.

**电子信息产品污染控制管理办法 （中国 RoHS）**

**中国客户** National Instruments 符合中国电子信息产品中限制使用某些有害物质命令 （RoHS）。
关于National Instruments 中国 RoHS合规性信息，请登录 ni.com/environment/rohs_china
(For information about China RoHS compliance, go to ni.com/environment/rohs_china)

**CE Compliance** CE

This product meets the essential requirements of applicable European Directives as follows:

- 2006/95/EC; Low-Voltage Directive (safety)
- 2004/108/EC; Electromagnetic Compatibility Directive (EMC)

# 1 Presentation

## 1.1 Description

The Quanser Ball and Beam module, pictured in Figure 1.1, consists a track on which the metal ball is free to roll. The track is fitted with a linear transducer to measure the position of the ball, i.e. it outputs a voltage signal proportional to the position of the ball. One side of the beam is attached to a lever arm that can be coupled to the load gear of the Quanser Rotary Servo unit. By controlling the position of the servo, the beam angle can be adjusted to balance the ball to a desired position.

Figure 1.1: Quanser Ball and Beam system

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 Components

The Ball and Beam components are identified in 2.1. Some of the those components are then described in 2.2.

## 2.1 Component Nomenclature

The components of the Ball and Beam module are listed in Table 2.1 and labeled in Figure 2.1.

| ID | Component | ID | Component |
|---|---|---|---|
| 1 | Rotary Servo | 7 | Support arm |
| 2 | Lever arm | 8 | Support base |
| 3 | Coupling screw | 9 | Analog ball position sensor connector |
| 4 | Steel ball | 10 | Support arm screws |
| 5 | Ball and Beam Potentiometer sensor | 11 | Calibration base |
| 6 | Ball and Beam Steel rod | | |

Table 2.1: Listing of Ball and Beam Components

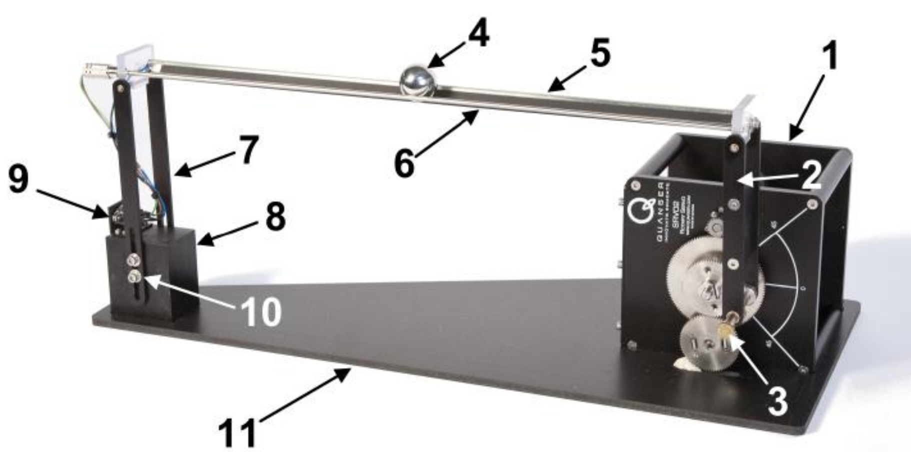



Figure 2.1: Components on Ball and Beam system

## 2.2 Component Description

### 2.2.1 Ball Position Sensor

The track of the Ball and Beam linear transducer module on which the metal ball is free to roll consists of a steel rod in parallel with a nickel-chromium wire-wound resistor forming the track. The resistive wire is the black strip that is stuck on the plastic which is fastened onto the metal frame. The position of the ball is obtained by measuring the voltage at the steel rod. When the ball rolls along the track, it acts as a wiper similar to a potentiometer resulting in the position of the ball.

Caution

**Regular cleaning of the beam is recommended to ensure proper operation of the ball and beam experiment. Clean both the beam and the steel ball using rubbing alcohol.**

# 3 Specifications

Table 3.1 lists and characterizes the main parameters associated with the Ball and Beam. See Figure 3.1 for an illustration of the Ball and Beam dimensions and the variables $\alpha$, $\theta$, and $x$ that are associated with the system. Some of the parameters listed in Table 3.1 are used in the mathematical model.

| Symbol | Description | Value |
|---|---|---|
| | Mass of ball beam module | 0.65 kg |
| | Calibration base length | 50 cm |
| | Calibration base depth | 22.5 cm |
| L | Beam length | 42.55 cm |
| | Lever arm length | 12.0 cm |
| $r_{arm}$ | Distance between servo output gear shaft and coupled joint | 2.54 cm |
| | Support arm length | 16.0 cm |
| $r_b$ | Radius of ball | 1.27 cm |
| $m_b$ | Mass of ball | 0.064 kg |
| $K_{bs}$ | Ball position sensor sensitivity | -4.25 cm/V |
| $V_{bias}$ | Ball position sensor bias power | $\pm 12$ V |
| $V_{range}$ | Ball position sensor measurement range | $\pm 5$ V |

Table 3.1: Ball and Beam specifications

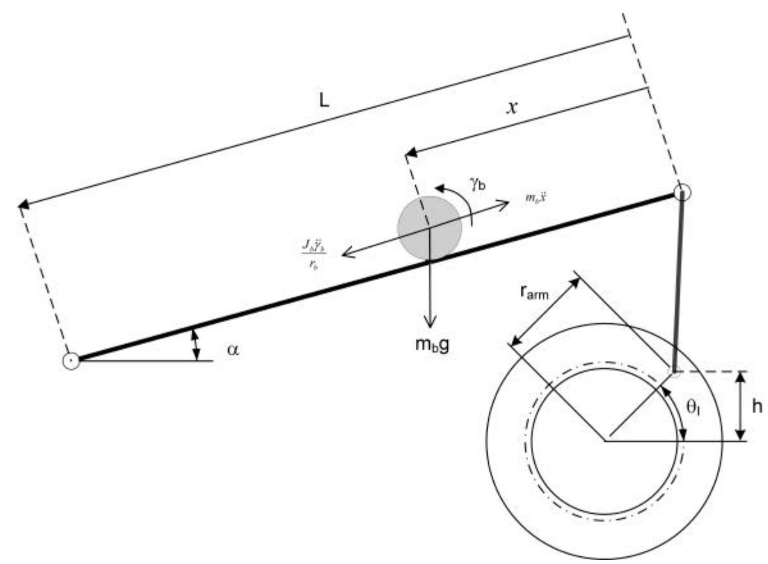



Figure 3.1: Ball and beam lengths and variables

# 4 System Setup

This section describes how to setup the Quanser Ball and Beam (BB01) system for experimental use.

Caution

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

Caution

**Exposed moving parts.**

Follow this procedure to setup the Ball and Beam system:

1. Before beginning, ensure the Rotary Servo is setup in the high-gear configuration as detailed in Rotary Servo User Manual.
2. Lay the calibration base, component #11 in Figure 2.1, flat on a table surface.
3. As pictured in Figure 4.1, place the Rotary Servo on its side such that the potentiometer gear fits into the cut-out section of the calibration base.

Figure 4.1: Place Rotary Servo in calibration base

4. Place the support column of the Ball and Beam into the cut-out section of the calibration base, as shown in Figure 4.2.

Figure 4.2: Place Ball and Beam support column in calibration base

5. Tighten the coupling screw into the screw hole of the large 120-tooth load gear as depicted in Figure 4.3.

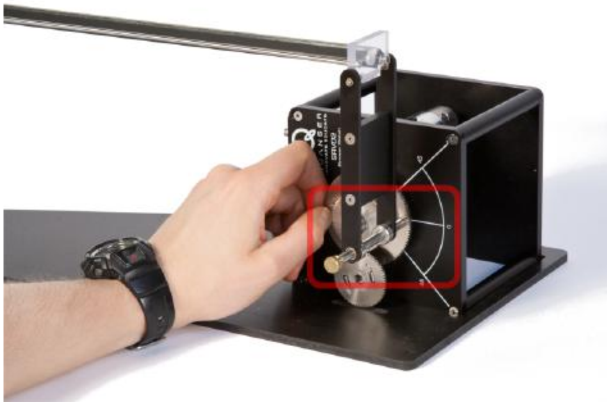


Figure 4.3: Attach Ball and Beam to Rotary Servo and rotate the gear to 0 degrees.

6. As illustrated in Figure 4.3, manually rotate the servo load gear to the 0 degree position. The coupling screw should be aligned with the 0 degree position on the servo.
7. See Figure 4.4. While holding the load gear at 0 degrees, place the ball in the center of the beam and vary the height of the support arm such that the beam is approximately horizontal and the ball does not move.

Figure 4.4: Adjust height of support column until ball is balanced at middle of beam

8. Tighten the 4x screws on the support arm, as illustrated in Figure 4.5, to finalize the calibration of the Ball and Beam.

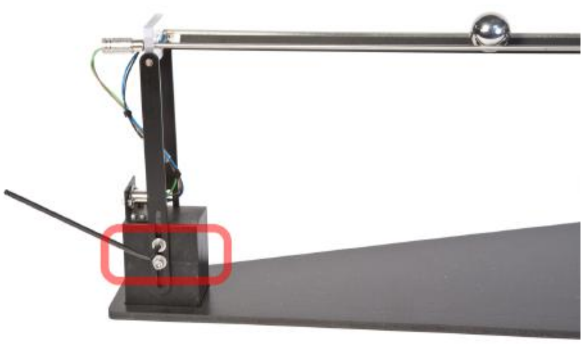


Figure 4.5: Tighten 4x screws on column to fix the height

# 5 Wiring Procedure

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

- **Power Amplifier**: Quanser VoltPAQ-X1, or equivalent.
- **Data Acquisition Board**: Quanser QPIDe, Q8-USB, Q2-USB, or equivalent.
- **Rotary Servo Plant**: Quanser Rotary Servo
- **Ball and Beam**: Quanser Ball and Beam Module

See the corresponding documentation for more information on these components. The cables supplied with the Rotary Servo are described in 5.1 and the procedure to connect the above components is given in 5.2.

Caution

**When using the Quanser VoltPAQ-X1 power amplifier, make sure you set the Gain to 1!**

## 5.1 Cable Nomenclature

The cables used to connect the Quanser Rotary Servo system with a power amplifier and data-acquisition device is shown in Table 5.1. Depending on your configuration, not all these cables may be necessary.

| Cable | Type | Description |
|---|---|---|
|  (a) RCA Cable | 2xRCA to 2xRCA | Connects the analog output channel (D/A) of the data acquisition (DAQ) device to the power amplifier. |
|  (b) Motor Cable | 4-pin-DIN to 6-pin-DIN | Connects the output of the power amplifier to the DC motor. |
|  (c) Encoder Cable | 5-pin-stereo-DIN to 5-pin-stereo-DIN | Connects encoder to the data acquisition device (DAQ) encoder input. Namely, these signals are: +5 VDC power supply, ground, channel A, and channel B. |
|  (d) Analog Cable | 6-pin-mini-DIN to 6-pin-mini-DIN | Connects an analog sensor to the power amplifier so it can be routed to the data acquisition device (DAQ). The calbe also carries a $\pm$ 12 VDC line from the amplifier in order to power a sensor and/or signal conditioning circuitry. |
|  (e) 5-pin-DIN to 4xRCA | 5-pin-DIN to 4xRCA | This cable carries the analog signals, unchanged, from the amplifier to the analog input (D/A) channel on the data acquisition device. |

Table 5.1: Cables used to connect Ball and Beam to amplifier and data acquisition (DAQ) device

## 5.2 Typical Connections

This section describes the typical connections used to connect the Rotary Servo plant to a data-acquisition board and a single-channel power amplifier. The connections are given in Table 5.2 and illustrated in Figure 5.1. The detailed wiring procedure is given below as well.

**Note:** The data acquisition (DAQ) device used in Figure 5.1 is representative for any DAQ device.

Follow these steps to connect the Rotary Servo system:

1. Make sure that your data-acquisition device is installed and is operational. See the corresponding documentation for installation and testing instructions (e.g. Q2-USB Quick Start Guide and User Manual).
2. Make sure everything is powered off before making any of these connections. This includes turning off your

| Cable # | From | To | Signal |
|---|---|---|---|
| 1 | DAQ: Analog Output #0 | Amplifier *Amplifier Command* connector | Connects control signal from Analog Output #0 on DAQ device to the power amplifier. |
| 2 | Amplifier: *To Load* connector | Rotary Servo *Motor* connector | Power leads to the Rotary Servo dc motor. |
| 3 | DAQ: Encoder Input #0 | Rotary Servo *Encoder* connector | Encoder load shaft angle measurement. |
| 4 | Amplifier: *To ADC* connector | DAQ Device: S2 (White RCA) to Analog Input #0 | Connects Ball and Beam ball position measurement to analog input channel #0 on the DAQ device. |
| 5 | Amplifier *S1&S2* connector | Ball and Beam Ball Position Sensor connector | Ball and Beam ball position measurement is on S2 White RCA connector. |

Table 5.2: Ball and Beam Wiring

PC and the amplifier.

3. Connect one end of the 2xRCA to 2xRCA cable from the Analog Output Channel #0 on the data acquisition (DAQ) device to the *Amplifier Command* connector on the amplifier, i.e. use both white or both red RCA connectors. See cable #1 shown in Figure 5.1. This carries the attenuated motor voltage control signal, $V_m/K_a$, where $K_a$ is the amplifier gain.
4. Connect the 4-pin-stereo-DIN to 6-pin-stereo-DIN cable from *To Load* connector on the amplifier to the *Motor* connector on the Rotary Servo. See connection #2 shown in Figure 5.1. The cable transmits the amplified voltage that is applied to the Rotary Servo motor and is denoted $V_m$.
5. Connect the 5-pin-stereo-DIN to 5-pin-stereo-DIN cable from the *Encoder* connector on the Rotary Servo panel to Encoder Input # 0 on the DAQ device, as depicted by connection #3 in Figure 5.1. This carries the load shaft angle measurement and is denoted by the variable $\theta_l$.

   **Note:** In this setup, it is assumed the Rotary Servo encoder is used for position feedback (i.e. not using the potentiometer).

**Caution**

**Any encoder should be directly connected to the data-acquisition device using a standard 5-pin DIN cable. DO NOT connect the encoder cable to the amplifier!**

6. Connect the *To ADC* socket on the amplifier to Analog Input channel #0 on the DAQ device using the 5-pin-DIN to 4xRCA cable. Connect the white (S2) RCA connector to Analog Input Channel #0.

   **Note:** The colour convention for the RCA cables are: yellow (S1), white (S2), red (S3), black (S4).

7. Connect the *Ball Position Sensor* connector from the Ball and Beam to the *S1&S2* socket on the amplifier using the 6-pin-mini-DIN to 6-pin-mini-DIN cable. See connection #5 in Figure 5.1. This carries the the measured ball position from the beam potentiometer and is denoted by variable $x$.

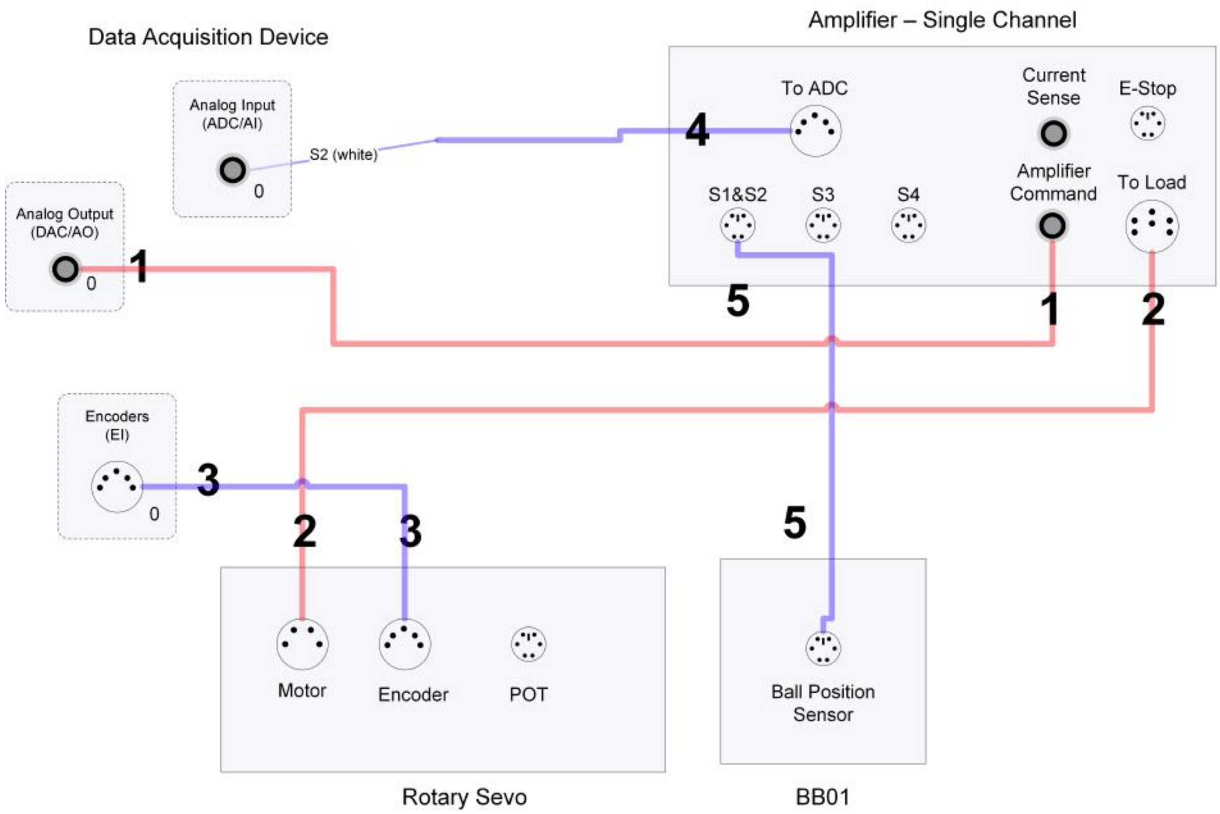



Figure 5.1: Ball and Beam connections using generic DAQ with a single-channel amplifier

# 6 Testing and Troubleshooting

This section describes some functional tests to determine if the Ball and Beam system is operating properly. It is assumed that the system is connected as described in the Section 5, above. To carry out these tests, it is preferable if the user uses a software such as QUARC® or LabVIEW™ to read sensor measurements and ouput voltages to the motor. See QUARC Help documentation to learn how to interface the Rotary Servo with QUARC. Alternatively, these tests can be performed with a signal generator and an oscilloscope.

## 6.1 Rotary Servo Motor and Encoder

See Rotary Servo User Manual for information on testing and troubleshooting the Rotary Servo separately.

## 6.2 Ball Position Sensor

### 6.2.1 Testing

Test the ball position sensor from the Ball and Beam or SS01 with the following procedure:

1. Measure analog input channel #2 to test the Ball and Beam sensor or analog input channel #3 to test the SS01 sensor (unless the sensors are connected on a different channels).
2. A typical signal response of the ball position sensor is illustrated in Figure 6.1. For the Ball and Beam, the ball position sensor should output a voltage of about 4.5 V when it is closest to the Rotary Servo. As the ball is rolled away from the Rotary Servo the measured voltage signal should be decreasing down to approximately -4.5 V when the ball reaches the other end of the beam.

Caution

**Sometimes when the ball is sitting at the very end of the beam it may not be in contact with the sensor. In this case the reading will initially be 0 V but when the ball begins moving the sensor signal will jump up to about 4.5 V and then begin decreasing.**

3. Beside the ends of the beam, the signal should have no discontinuities and little noise. Similarly for the SS01 sensor, the voltage signal should decreasing from approximately 4.5 V to -4.5 V as the ball travels towards the end of the beam with the analog connector.

### 6.2.2 Troubleshooting

Follow the steps below if the potentiometer is not measuring correctly:

- Verify that the power amplifier is functional. For example when using the Quanser VoltPAQ device, is the green LED lit? Recall the analog sensor signal go through the amplifier before going to the data-acquisition device (except when using the Q3 ControlPAQ). Therefore the amplifier needs to be turned on to read the potentiometer.
- Check that the data-acquisition board is functional, e.g. ensure it is properly connected, that the fuse is not burnt.
- Measure the voltage across the potentiometer. Ensure the potentiometer is powered with a $\pm 12$ V at the 6-pin-mini DIN connector on the Ball and Beam, component #10 in Figure 2.1. The two bottom pins of the DIN connector are ground pins and the leftmost pin, i.e. where the green cable is connected to, outputs the voltage of the ball.
- Using a voltmeter, connect one probe to the middle-left pin and the other to the bottom ground pins. The voltage should vary between about $\pm 4.5$ V as the ball position is changed. Please see Section 7 for information on contacting Quanser for technical support.

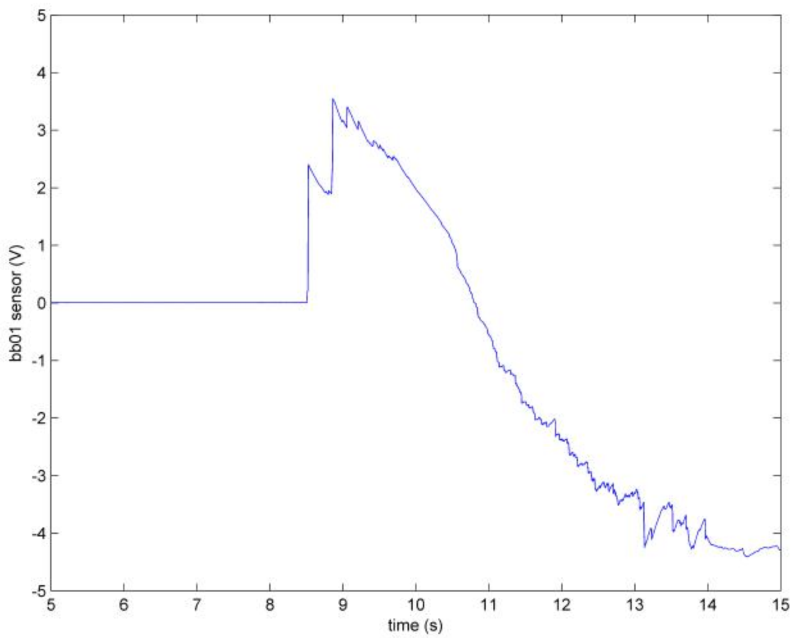



Figure 6.1: Typical voltage signal measured by the Ball and Beam ball position sensor

# 7 Technical Support

To obtain support from Quanser, go to http://www.quanser.com/ and click on the Tech Support link. Fill in the form with all the requested software and hardware information as well as a description of the problem encountered. Also, make sure your e-mail address and telephone number are included. Submit the form and a technical support person will contact you.

## Over ten rotary experiments for teaching fundamental and advanced controls concepts

**Rotary Servo Base Unit**

**Inverted Pendulum**

**Flexible Link**

**Flexible Joint**

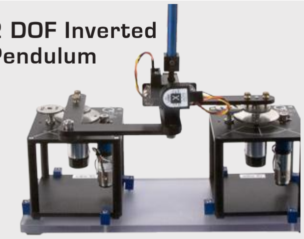
**Ball and Beam**

**Double Inverted Pendulum**

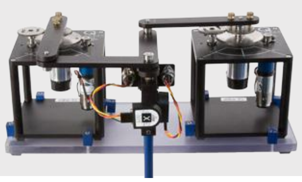
**Gyro/Stable Platform**

**2 DOF Robot**

**2 DOF Inverted Pendulum**



**2 DOF Gantry**



**Multi-DOF Torsion**

**2 DOF Ball Balancer**

Quanser's rotary collection allows you to create experiments of varying complexity – from basic to advanced. Your lab starts with the Rotary Servo Base Unit and is designed to help engineering educators reach a new level of efficiency and effectiveness in teaching controls in virtually every engineering discipline including electrical, computer, mechanical, aerospace, civil, robotics and mechatronics. For more information please contact info@quanser.com.



QUANSER
INNOVATE · EDUCATE

INFO@QUANSER.COM +1-905-940-3575 QUANSER.COM

Solutions for teaching and research. Made in Canada.