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USER MANUAL

Rotary Double Inverted Pendulum Experiment

Set Up and Configuration

CAPTIVATE. MOTIVATE. GRADUATE.

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

CONTENTS

1 PRESENTATION

The Quanser Rotary Double Pendulum (DBPEN-ROT) is composed of a rotary arm (ROTPEN-SE), a short 7-inch bottom blue rod, an encoder hinge, and a medium 12-inch top blue rod.

As depicted in Figure 2.1, the DBPEN-ROT is attaches to the Rotary Servo Base (SRV-02) unit. The balance control computes a voltage based on the angle measurements from the encoders. This control voltage signal is amplified and applied to the SRV02 motor. The rotary arm moves accordingly to balance the two links and the process repeats itself.

For more information regarding the ROTPEN-SE unit, please see Rotary Inverted Pendulum User Manual [1].

Figure 1.1: Quanser Double Inverted Pendulum (DBPEN-ROT).

■ **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 Quanser Rotary Double Pendulum module are identified in section Section 2.1. Some of those components are described in Section 2.2.

2.1 Components Nomenclature

The components of the Rotary Double Pendulum module are listed in Table 2.1 below and labeled in Figure 2.1.

ID	Component	ID	Component
1	SRV02	7	Pendulum T-Fitting
2	Thumbscrews	8	DBPEN-ROT short pendulum (link 1)
3	Rotary Arm	9	DBPEN-ROT link 2 encoder connector
4	Pendulum encoder connector	10	Links housing
5	Shaft housing	11	DBPEN-ROT medium pendulum (link 2)
6	Shaft		

Table 2.1: Rotary Double Inverted Pendulum Components.

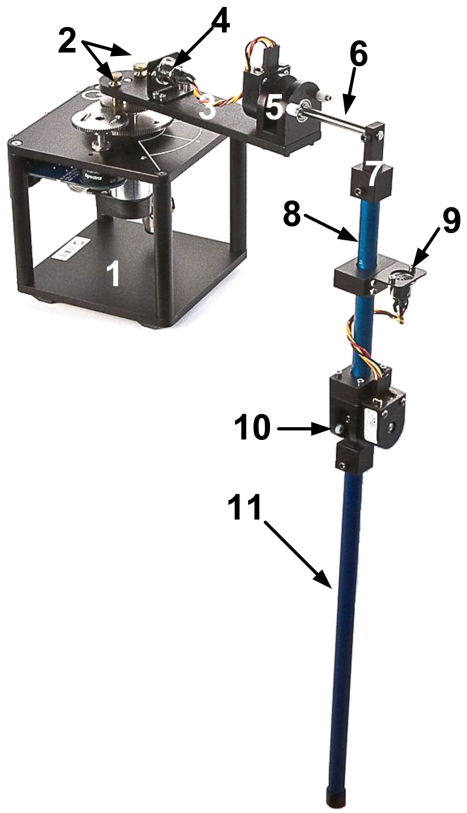

Figure 2.1: Quanser Rotary Double Pendulum (DBPEN-ROT).

2.2 Components Description

2.2.1 Encoder

The encoder used to measure the pendulum angle on the DBPEN-ROT module is a US Digital S1 single-ended optical shaft encoder. It offers a high resolution of 4096 counts per revolution in quadrature mode.

The internal wiring of the encoder and the 5-pin DIN connector on the DBPEN-ROT module is illustrated in Figure 2.2.

■ **Caution:** The Encoder sends a digital signal and should be directly connected to a Quanser terminal board using a standard 5-pin DIN cable. **DO NOT connect the encoder signal to the amplifier**.

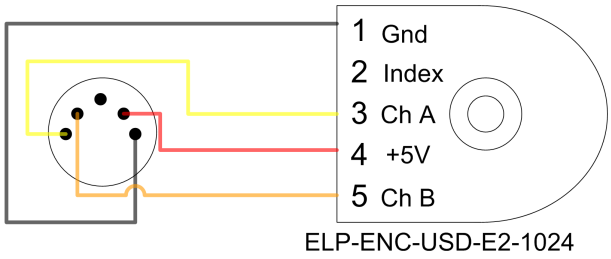

Figure 2.2: Encoder Wiring

3 SPECIFICATION

This section lists and characterizes the model parameters of the rotary double pendulum. See Reference [2] for the parameters associated with the SRV02 unit: R_m, k_t, k_m, K_g, η_g, B_m, J_m, η_m.

When the double pendulum is in the inverted configuration, the lower pendulum is the short pendulum that is attached to the SRV02 rotary arm (ROTPEN-SE) and the upper pendulum is the longer pendulum that is attached to the lower pendulum. As described in Figure 3.1 the lower and upper pendulums are also referred to as link 1 and link 2, respectively.

Symbol	Description	Value	Unit
r	Rotary arm: length from pivot to tip	0.2159	m
m_{arm}	Rotary arm: mass	0.2570	kg
J_m	Equivalent moment of inertia of SRV02 motor and the rotary arm	0.0041	kg-m^2
m_1	Short pendulum: mass	0.097	kg
B_1	Short pendulum: viscous damping	0.0024	N-m-s/rad
L_1	Short pendulum: length from pivot to tip	0.2	m
l_1	Short pendulum: length from pivot to center-of-mass	0.1635	m
m_2	Medium pendulum: mass	0.127	kg
B_2	Medium pendulum: viscous damping	0.0024	N-m-s/rad
L_2	Medium pendulum: length from pivot to tip	0.3365	m
l_2	Medium pendulum: length from pivot to its center-of-mass	0.1778	m
m_h	Mass of encoder hinge located between the lower and upper pendulum.	0.1410	kg
	Mass of double inverted pendulum	0.364	Kg
K_{enc}	Pendulum encoder resolution	4096 (quadrature)	counts/rev

Table 3.1: Double Pendulum System Parameters.

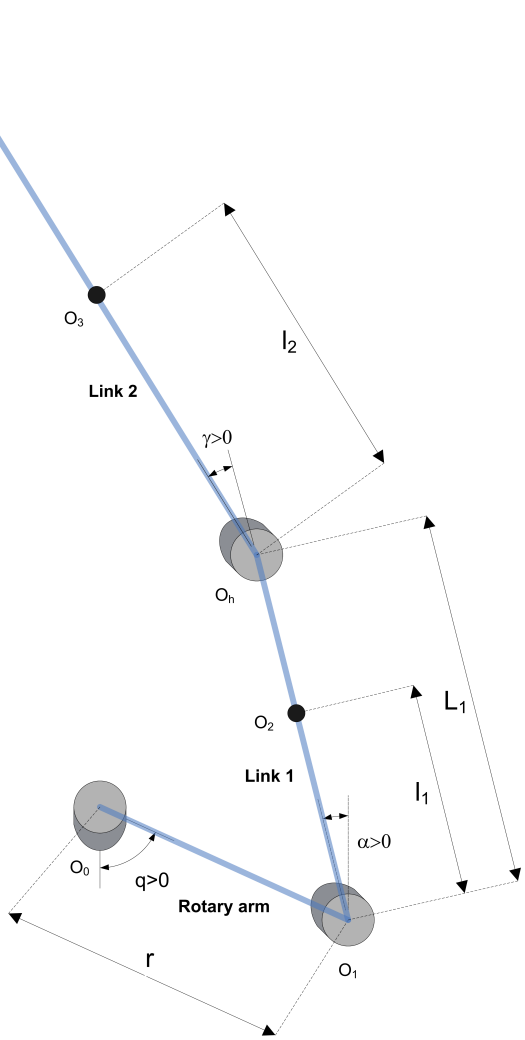

Figure 3.1: Angles and Lengths of Rotary Double Pendulum System.

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.

Follow this procedure to setup the Quanser Rotary Double Pendulum module for experimental use:

1. Before beginning, ensure the SRV02 is setup in the high-gear configuration as detailed in Reference [2].
2. Mount the ROTPEN-SE module onto the load output shaft of the SRV02 as shown in Figure 4.1 Make sure the long side of the arm can be lined up the 0 degree marked on the SRV02.

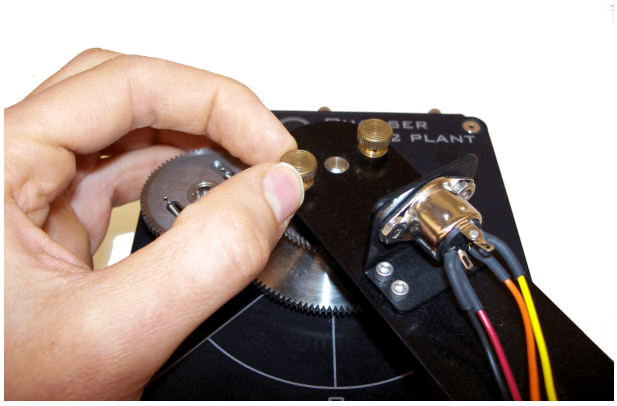

Figure 4.1: Mount arm on SRV02 output shaft and tighten thumbscrews

3. Tighten both thumbscrews to fasten the rotary arm module onto the load shaft of the servo unit.
4. As shown in Figure 4.2 slide the T-Fitting of the pendulum, ID #6 in Figure 2.1, onto the metal shaft, ID #5 in Figure 2.1, and tighten the set-screw on the T-Fitting to brace the pendulum on the metal shaft.
   Note: Make sure the encoder connector on the DBPEN-ROT is facing AWAY from the servo.

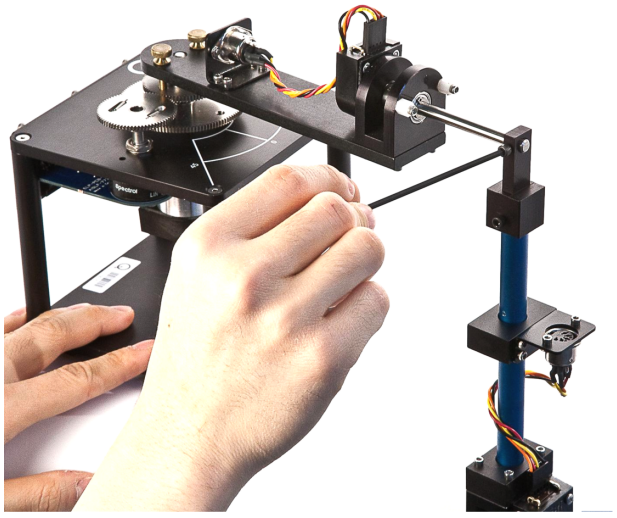

Figure 4.2: Slide the T-Fitting of the pendulum

5. Before running any experiments, it is recommended that the SRV02 be secured down onto an edge of a table.

5 WIRING PROCEDURE

The following is a listing of the hardware components used in the DBPEN-ROT experiments:

1. **Power Amplifier:** Quanser VoltPAQ-X1, or equivalent.
2. **data acquisition device:** Q8-USB, QPID/QPIDe, NI DAQ Devices, or equivalent.
3. **Rotary Servo Plant:** Quanser SRV02-ET.
4. **Plant:** Quanser DBPEN-ROT.

See the references listed in Section 8 for more information on these components. The required cables are described in Section 5.1 and the procedure to connect the above components is given in Section 5.2.

■ **Caution:** When using the Quanser VoltPAQ power amplifier, **make sure set the Gain to 1!**.

5.1 Cable Nomenclature

Table 5.1, below, provides a description of the standard cables used in the wiring of the SRV02, and Rotary Double pendulum.

Cable	Type	Description
 (a) RCA Cable	2xRCA to 2xRCA	Used to connect analog output of data acquisition device to amplifier. It carries amplifier command signal.
 (b) Motor Cable	4-pin-DIN to 6-pin-DIN	Applies the amplified command signal to the SRV02 DC motor.
 (c) Encoder Cable	5-pin-stereo-DIN to 5-pin-stereo-DIN	This cable carries the encoder signals between an encoder connector and the data acquisition (DAQ) device (to the encoder counter). Namely, these signals are: +5 VDC power supply, ground, channel A, and channel B

Table 5.1: Cables Nomenclature

5.2 Typical Connections

This section explains how to connect the SRV02+DBPEN-ROT plant to the amplifier and the data acquisition device. See reference [2] for the specifications and a description of the main components composing the SRV02 system.

The connections are given in Table 5.2 and illustrated in Figure 5.1. The detailed wiring procedure is given below.

Cable #	From	To	Signal
1	Data Acquisition device: Analog Output #0	Amplifier Command connector	Control signal to the amplifier.
2	Amplifier "To Load" connector	SRV02 "Motor" Connector	Power leads to the SRV02 DC motor.
3	Data Acquisition device: Encoder Input #0	SRV02 "Encoder"' connector	Encoder load shaft angle measurement.
4	Data Acquisition device: Encoder Input #1	ROTPEN-SE Encoder connector	DBPEN-ROT short link pendulum angle measurement.
5	Data Acquisition device: Encoder Input #2	DBPEN-ROT link 2 encoder	DBPEN-ROT long link pendulum angle measurement.

Table 5.2: Quanser DBPEN-ROT system wiring summary

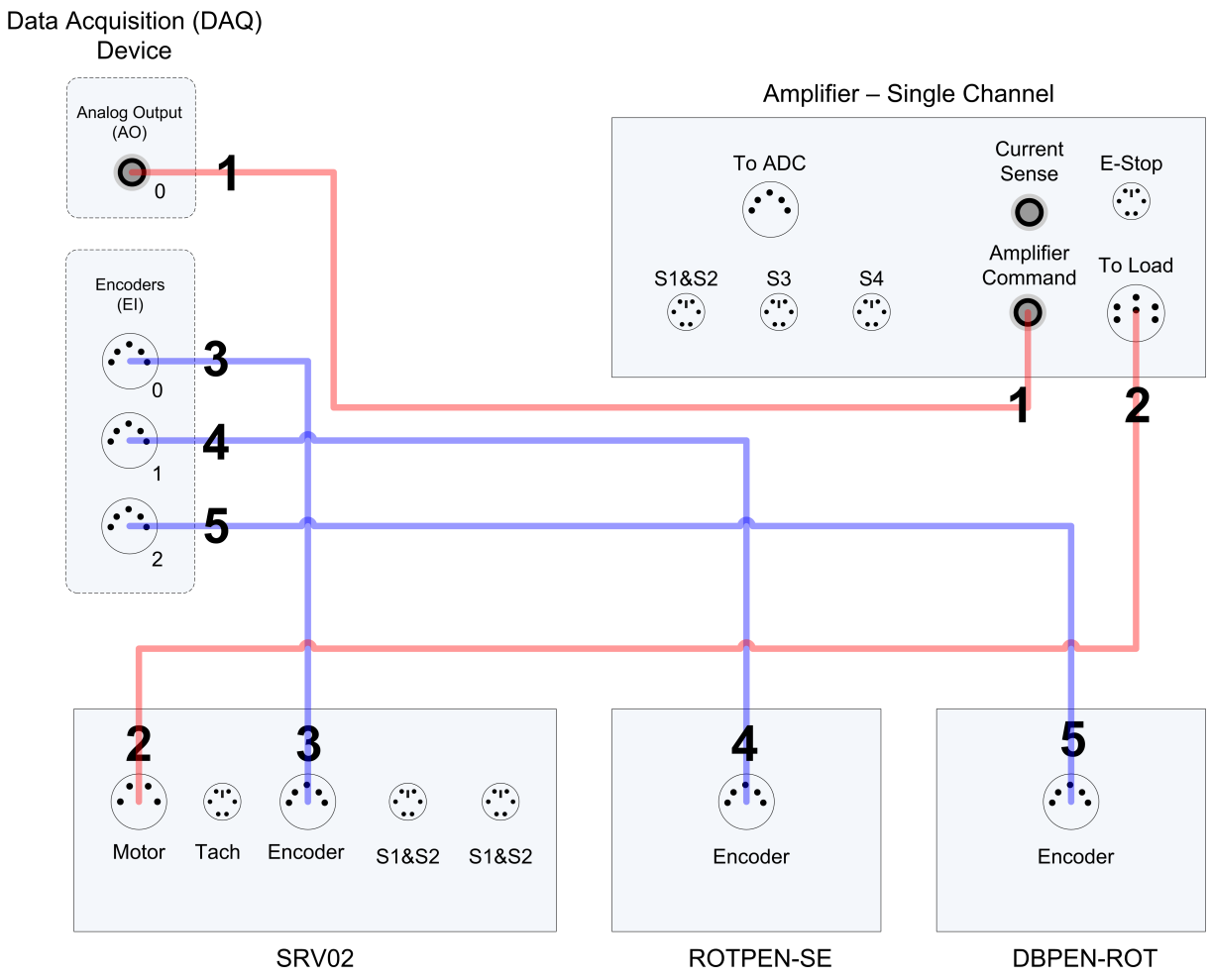

Figure 5.1: SRV02 and DBPEN-ROT Module Wiring Diagram

The follow describes in detail the wiring procedure of the SRV02 and DBPEN-ROT to a amplifier and DAQ:

1. It is assumed that the data acquisition (DAQ) device is already installed as discussed in its user manual.
2. Make sure everything is powered off before making any of these connections. This includes turning off your PC and the amplifiers.
3. Connect one of the connectors on the 2x RCA to 2x RCA cable from the *Analog Output Channel #0* on the data acquisition (DAQ) device to the *Amplifier Command* Connector on the Quanser amplifier. 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 from *To Load* on the amplifier to the *Motor* connector on the SRV02. See connection #2 shown in Figure 5.1. The cable transmits the amplified voltage that is applied to the SRV02 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 SRV02 panel to *Encoder Input #0* on the data acquisition (DAQ) device, as depicted by connection #3 in Figure 5.1. This carries the load shaft angle measurement and is denoted by the variable θ_1.

   ■ **Caution:** Any encoder should be directly connected to the data acquisition (DAQ) device (or equivalent) using a standard 5-pin DIN cable. **DO NOT connect the encoder cable to the amplifier!**

6. Connect the encoder connector on the ROTPEN-SE directly to *Encoder Input Channel #1* on the data acquisition (DAQ) device, as depicted by connection #4 in Figure 5.1. It carries the measured short link pendulum angle and is denoted by variable α.

7. Connect the encoder connector on the DBPEN-ROT directly to *Encoder Input Channel #2* on the data acquisition (DAQ) device, as depicted by connection #5 in Figure 5.1. It carries the measured medium link pendulum angle and is denoted by variable γ.

5.3 Typical Connections using the SRV02-ETS

The SRV02-ETS is an SRV02-ET system mounted with a slip ring to allow a load to move 360 degrees without any cable obstructions. See [2] for more information about the SRV02-ETS device.

When using the SRV02-ETS system with a ROTPEN-SE and an amplifier, the pendulum encoder connection is passed through the slip ring and is therefore different than the wiring described for the SRV02-ET explained earlier. The connections on the SRV02-ETS system are shown in Figure 5.2 and summarized in the steps below:

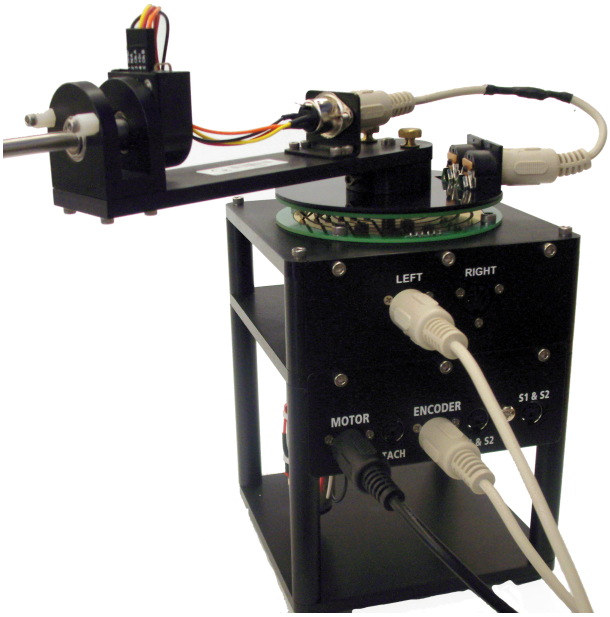

Figure 5.2: SRV02-ETS and ROTPEN

1. Connect the *Left* connector on the SRV02 to the *Encoder Input #1* connector on the data acquisition (DAQ) device using the 5-pin-stereo-DIN to 5-pin-stereo-DIN cable. It carries the measured pendulum angle from the ROTPEN-SE encoder to the PC and is denoted by the variable α.

2. Connect the *Encoder* connector on the ROTPEN module to the *Left* connector on the slip ring using the short 5-pin-stereo-DIN to 5-pin-stereo-DIN cable. It carries the pendulum angle measured by the ROTPEN-SE encoder to the SRV02 *Left* connector.

The rest of the connections remain the same as described in Section 5.2 according to the amplifier type and DAQ that you are using.

6 TESTING AND TROUBLESHOOTING

This section describes some functional tests to determine if your Rotary Pendulum or Double pendulum system is operating normally. It is assumed that the SRV02 is connected as described in the 5 To carry out these tests, it is preferable if the user can use a software such as QUARC® or LabVIEW™ to read sensor measurements and feed voltages to the motor. Alternatively, these tests can be performed with a signal generator and an oscilloscope.

6.1 SRV02 Motor and Sensors

Please refer to [2] for information on testing and troubleshooting the SRV02 separately.

6.2 Testing the DBPEN-ROT

Follow this procedure to test the DBPEN-ROT encoder:

1. Measure *Encoder Input Channel #2*.
2. Rotate the pendulum link and verify that your are obtaining a reading.
3. If it is measuring, make sure it is reading the correct angle. For example, rotate the link 180 degrees and ensure you are reading 360 degrees, which is about 4096 counts in quadrature mode, in the software.

   Note: Some data acquisition systems do not measure in quadrature and, in this case, one-quarter of the expected counts are received, i.e. 1024 counts. In addition, some data acquisition systems measure in quadrature but increment the count by 0.25 (as opposed to having an integer number of counts). Make sure the details of the data-acquisition system being used is known. The counters on the Quanser DAQ boards measure in quadrature and therefore a total of four times the number of encoder lines per rotation, e.g. a 1024-line encoder results in 4096 integer counts (quadrature mode) for every full rotation.

6.3 Troubleshooting

Follow the steps below if the encoder on the DBPEN-ROT model is not measuring properly: If the encoder is not measuring properly, go through this procedure:

- Check that the data-acquisition device is functional.
- Check that both the A and B channels from the encoder are properly generated and fed to the data-acquisition device. Using an oscilloscope, there should be two square waves, signals A and B, with a phase shift of 90 degrees. If this is not observed then the encoder may be damaged and need to be replaced. Please see Section 7 for information on contacting Quanser for technical support. See [2] for information on troubleshooting an encoder.

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.

REFERENCES

[1] Quanser Inc. *Rotary Pendulum User Manual*, 2012.

[2] Quanser Inc. *SRV02 User Manual*, 2012.

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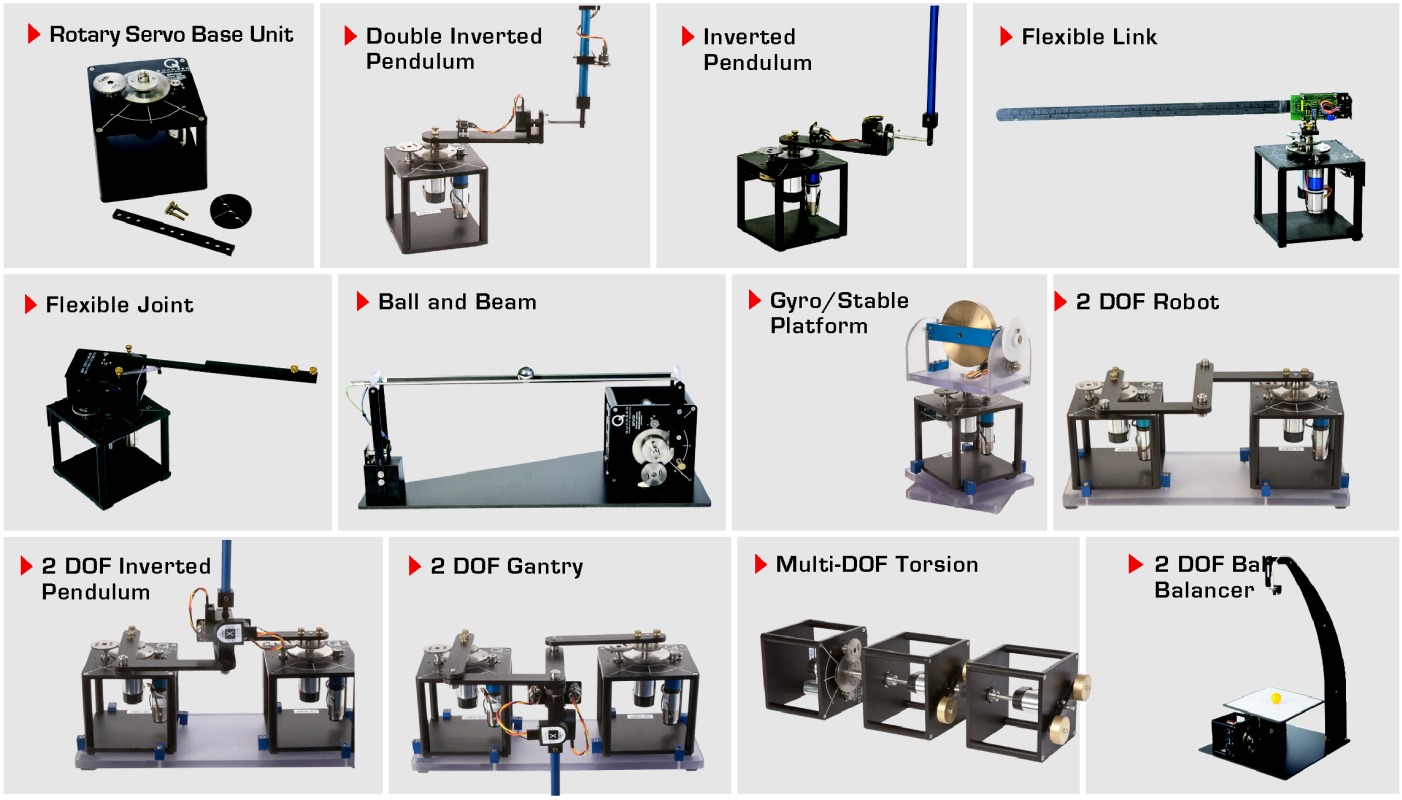

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