



# USER MANUAL

## Inverted Pendulum Experiment

Set Up and Configuration



CAPTIVATE. MOTIVATE. GRADUATE.

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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)

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# 1 PRESENTATION

The Quanser Rotary Pendulum, pictured in Figure 1.1, consists of a flat arm, or hub, with a pivot at one end and a metal shaft on the other end. The pivot-end can be mounted on top of the SRV02 load gear shaft and fastened with screws. The actual pendulum link is fastened onto the metal shaft and the shaft is instrumented with a sensor to measure its angle. The result is a horizontally rotating arm with a pendulum at the end.



Figure 1.1: SRV02 ROTPEN system.

As shown in Figure 1.1, the ROTPEN is instrumented with an encoder(1024 line) to obtain a digital measurement of the pendulum and is free to rotate 360 degrees.

**■ 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 ROTPEN components are identified in Section 2.1. Some of those components are then described in Section 2.2.

### 2.1 Component Nomenclature

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

ID #	Component	ID #	Component
1	SRV02	6	Pendulum T-Fitting
2	Thumbscrews	7	Pendulum Link
3	Rotary Arm	8	Pendulum Encoder Connector
4	Shaft Housing	9	Pendulum Encoder
5	Shaft		

Table 2.1: Listing of ROTPEN Components

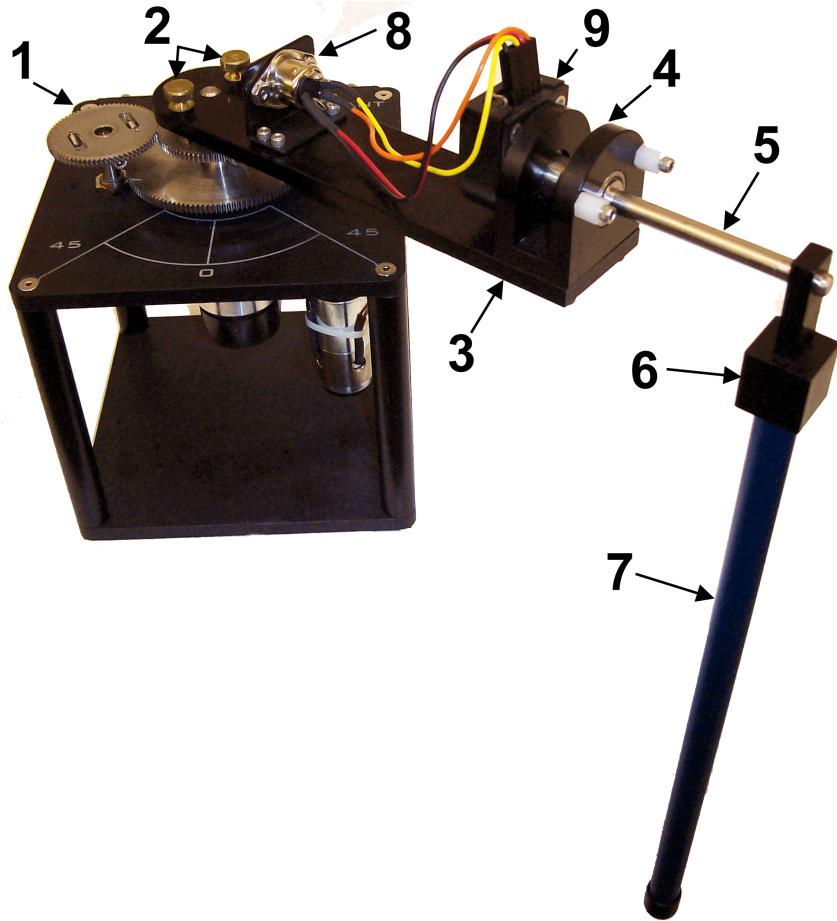


Figure 2.1: ROTPEN Components

## 2.2 Component Description

### 2.2.1 Encoder

The encoder used to measure the pendulum angle on the ROTPEN module is a US Digital S1 single-ended optical shaft encoder. It offers a high resolution of 4096 counts per revolution in quadrature mode (1024 lines per revolution).

The internal wiring of the encoder and the 5-pin DIN connector on the ROTFLEX 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.**

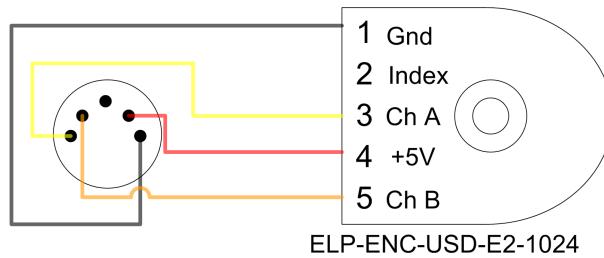


Figure 2.2: Encoder Wiring

# 3 SPECIFICATIONS

Table 3.1, below, lists and characterizes the main parameters associated with the SRV02 Rotary Pendulum module. See Figure 3.1 for an illustration of the device dimensions as well as the servo and pendulum angle definitions. Some of the parameters listed in Table 3.1 are used in the mathematical model.

Symbol	Description	Value	Unit
$m_p$	Mass of pendulum	0.127	kg
$L_p$	Total length of pendulum	0.337	m
$l_p$	Distance from pivot to center of mass	0.156	m
$J_{p,cm}$	Pendulum moment of inertia about center of mass	0.0012	kg.m <sup>2</sup>
$B_p$	Pendulum viscous damping coefficient as seen at the pivot axis	0.0024	N.m.s/rad
$m_{arm}$	Mass of rotary arm with two thumb screws	0.257	kg
$r$	Rotary arm length from pivot to tip	0.216	m
$l_{arm}$	Rotary arm length from pivot to center of mass	0.0619	m
$J_{arm,cm}$	Rotary arm moment of inertia about its center of mass	$9.98 \times 10^{-4}$	kg.m <sup>2</sup>
$m_b$	Rotary arm viscous damping coefficient as seen at the pivot axis	0.0024	N.m.s/rad
$J_{arm}$	Rotary arm moment of inertia about pivot	0.0020	kg.m <sup>2</sup>
$K_{enc}$	Pendulum encoder resolution	4096	counts/rev

Table 3.1: Rotary Pendulum system specifications.

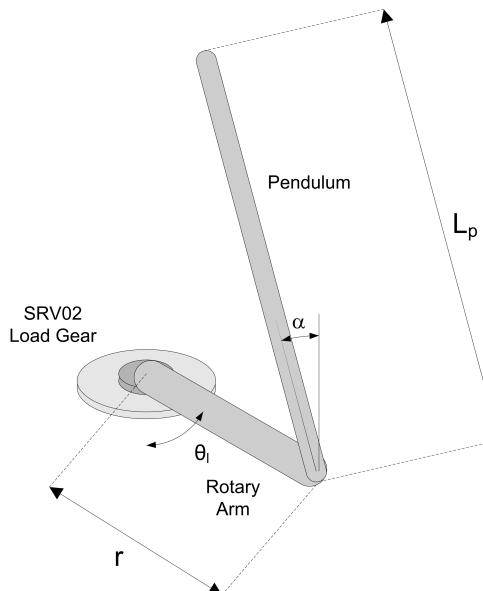


Figure 3.1: Schematic of Rotary Pendulum

# 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.

■ **Caution:** Exposed moving parts.

Follow this procedure to setup the Quanser Rotary Pendulum (ROTPEN) module for experimental use:

1. Before beginning, ensure the Quanser Rotary Servo (SRV02) is setup in the high-gear configuration as detailed in SRV02 User Manual [2].
2. As shown in Figure 4.1, insert the pendulum rod into the T-Fitting using the set-screw. **Do not excessively tighten the set screw!**

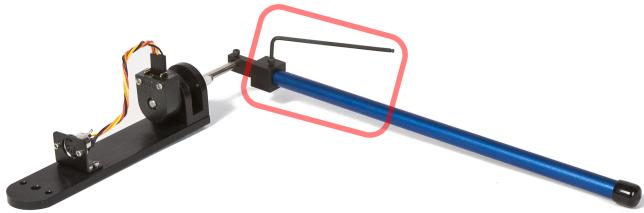


Figure 4.1: Insert pendulum into T-Fitting using set-screw

3. Make sure T-Fitting is at the end of the metal shaft on the rotary arm and properly fastened using the set screw, as shown in Figure 4.1. The ROTPEN module may have been shipped with the T-Fitting positioned close to the encoder.
4. Mount the ROTPEN module on the load output shaft of the SRV02 as shown in Figure 4.2 using the two thumb screws.



Figure 4.2: Mount ROTPEN module on servo using thumb screws

5. Place the servo on a table with the pendulum hanging downwad. **The pendulum should be free to rotate 360 degrees.** It is also recommended that the SRV02 be clamped down onto an edge of a table as shown in Figure 4.3.



Figure 4.3: Clamp down SRV02 onto table edge

# 5 WIRING PROCEDURE

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

- **Power Amplifier:** Quanser VoltPAQ or equivalent.
- **Data Acquisition Board:** Quanser QPID, QPIDe, Q2-USB, Q8-USB, or equivalent.
- **Rotary Servo Plant:** Quanser SRV02, SRV02-T, SRV02-E, SRV02-EHR, or SRV02-ET.
- **Rotary Pendulum Module:** Quanser ROTPEN module

See the references listed at the end of this document for more information on these components. The cables supplied with the ROTPEN package are described in 5.1 and the procedure to connect the above components is given in 5.2.

■ **Caution:** When using a Quanser VoltPAQ power amplifier, **make sure you 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 Rotary Pendulum system.

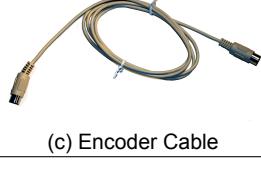
Cable	Designation	Description
 (a) RCA Cable	2xRCA to 2xRCA	This cable connects an analog output channel of the data acquisition terminal board to the power module for proper power amplification.
 (b) Motor Cable	4-pin-DIN to 6-pin-DIN	This cable connects the output of the power module, after amplification, to the desired DC motor on the servo.
 (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 board (to the encoder counter). Namely, these signals are: +5 VDC power supply, ground, channel A, and channel B.

Table 5.1: Cable Nomenclature

## 5.2 Typical Connections

This section describes the typical connections used to connect the SRV02 and ROTPEN-E system to a data acquisition device and power amplifier. The connections are given in 5.2 and illustrated in Figure 5.1. The wiring procedure details are given below.

Cable #	From	To	Signal
1	Terminal Board: Analog Output #0	Amplifier "From D/A" connector	Control signal to the amplifier.
2	Amplifier "Motor" connector	SRV02 "Motor" Connector	Power leads to the SRV02 DC motor.
3	Terminal Board: Encoder Input #0	SRV02 "Encoder" connector	Encoder load shaft angle measurement.
4	Terminal Board: Encoder Input #1	ROTPEN Encoder connector	Encoder pendulum angle measurement.

Table 5.2: Quanser ROTPEN system connections

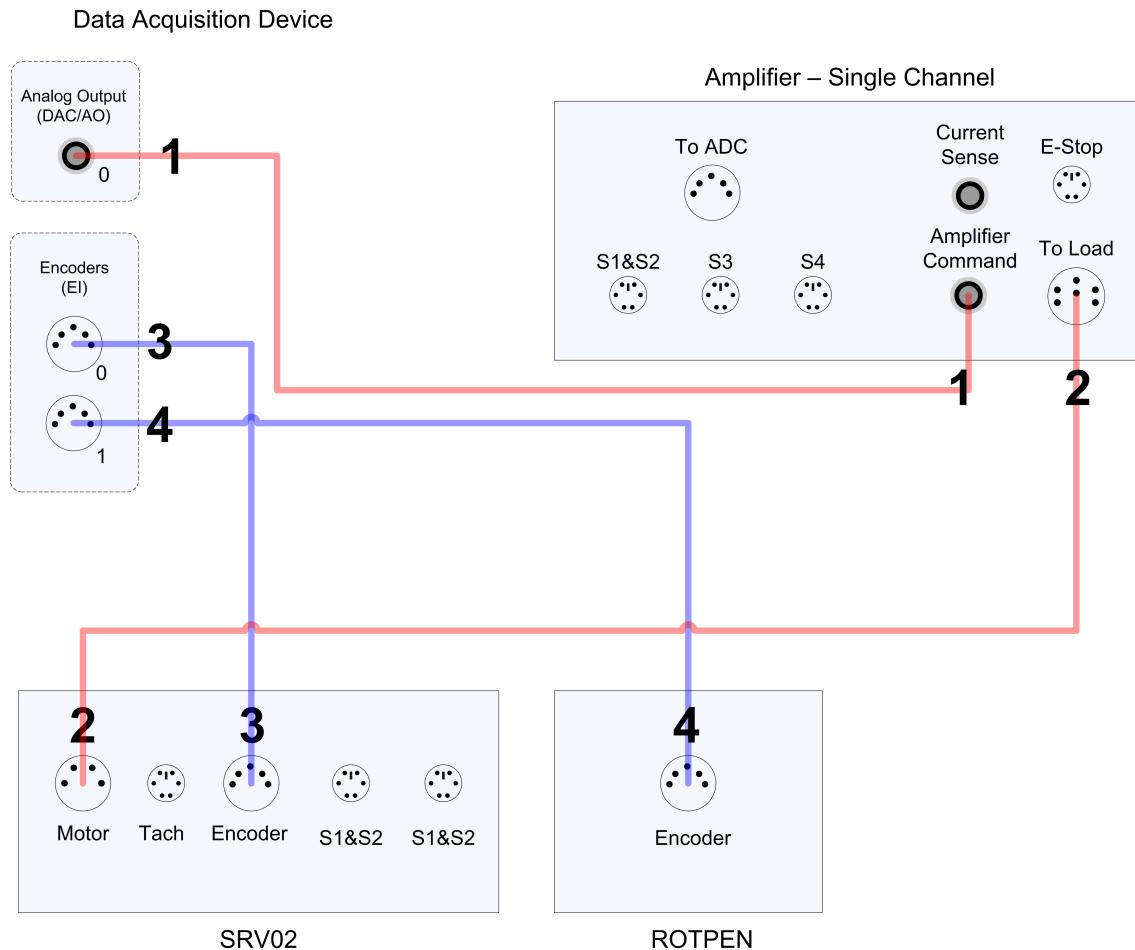


Figure 5.1: Quanser ROTPEN connection diagram

Follow these steps to connect the Rotary Pendulum system:

1. It is assumed that the Quanser DAQ board is already installed as discussed in [3]. If another data-acquisition

device is being used, e.g. NI M-Series board, then go to its corresponding documentation and ensure it is properly installed.

2. Make sure everything is powered off before making any of these connections. This includes turning off your PC and the amplifier.
3. Connect one of the connectors on the 2x RCA to 2x RCA cable from the *Analog Output Channel #0* on the terminal board 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 terminal board, as depicted by connection #3 in Figure 5.1. This carries the load shaft angle measurement and is denoted by the variable  $\theta_1$ .  
**■ Caution:** Any encoder should be directly connected to the Quanser terminal board (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 directly to *Encoder Input Channel #1* on the terminal board, as depicted by connection #4 in Figure 5.1. It carries the measured pendulum angle from the ROTPEN encoder and is denoted by variable  $\alpha$ .

### 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 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:

1. Connect the *Left* connector on the SRV02 to the *Encoder Input #1* connector on the terminal board using the 5-pin-stereo-DIN to 5-pin-stereo-DIN cable. It carries the measured pendulum angle from the ROTPEN encoder to the PC and is denoted by the variable  $\alpha$ .
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 encoder to the SRV02 *Left* connector.

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

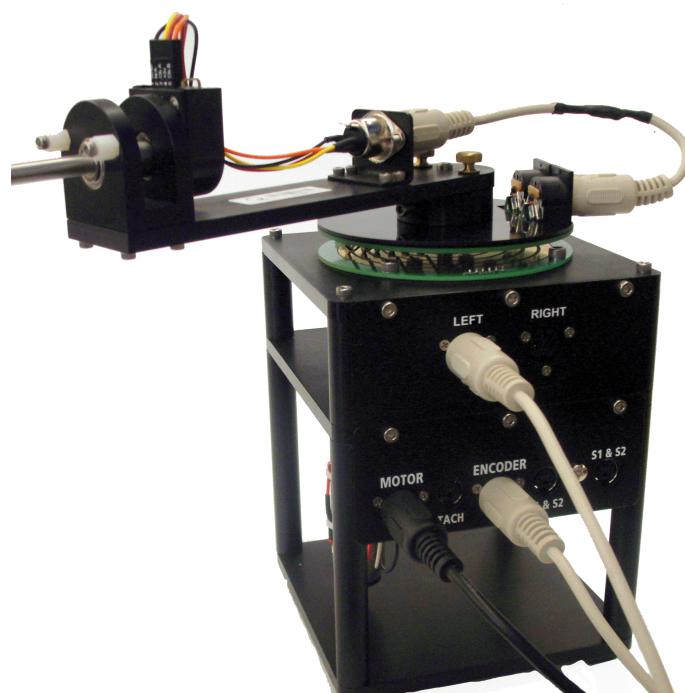


Figure 5.2: SRV02-ETS and ROTPEN

# 6 TESTING AND TROUBLESHOOTING

This section describes some functional tests to determine if your Rotary Pendulum system is operating normally. It is assumed that the SRV02 is connected as described in the 5.2. 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. You can refer to [1] to learn how to interface the SRV02 with QUARC. 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 ROTPEN

Follow this procedure to test the ROTPEN encoder:

1. Measure *Encoder Input Channel #1* using, for instance, the QUARC software.
2. Rotate the pendulum link and verify that you 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 180 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 for every full rotation.

## 6.3 Troubleshooting

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

- Check that the data-acquisition board is functional, e.g. ensure it is properly connected, that the fuse is not burnt.
- 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 representative will contact you.

**Note: Depending on the situation a support contract may be required to obtain technical support.**

# REFERENCES

- [1] Quanser Inc. *SRV02 QUARC Integration*, 2008.
- [2] Quanser Inc. *SRV02 User Manual*, 2009.
- [3] Quanser Inc. *Q2-USB Data-Acquisition System User's Guide*, 2010.

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