QUANSER
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SRV02-Series

Rotary Pendulum

User Manual

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ROTPEN - Rotary Pendulum

User Manual

1. Description

The rotary pendulum module consists of a flat arm which is instrumented with a sensor at one end such that the sensor shaft is aligned with the longitudinal axis of the arm. A fixture is supplied to attach the pendulum to the sensor shaft. The opposite end of the arm is designed to mount to a Quanser rotary servo plant (SRV02) resulting in a horizontally rotating arm with a pendulum at the end.

The rotary pendulum module offers the student the opportunity to balance a vertical rod by manipulating the angle at the base. This is the classical pendulum problem only now the trajectory is circular. This module is also configurable in 3 distinct configuration. The module can be used as a classical inverted pendulum; a gantry crane or in the self-erecting inverted pendulum.

2. Purchase Options

The rotary pendulum is equipped with a sensor to measure the rod's angular position. The module can be equipped with either an analog potentiometer or an optical encoder. The potentiometer option allows only for operation in the inverted mode (upright) where the encoder option allows for continuous rotational motion.

Model / Option	*Description*
ROTPEN	Basic Unit – Potentiometer to sense rod's angular position.
(**E**) Option	Encoder Option – 1024 line optical encoder to sense rod's angular position.

Table 1 - ROTPEN Options

2.1 Modular Options

Quanser values itself for the modularity of its experiments. The SRV02 rotary plant module serves as the base component for the rotary family of experiments. This modular philosophy facilitates the change from one experimental setup to another with relative ease of work and a valuable savings in cost. The following table lists the experiments currently available in the rotary family of products utilizing the SRV02 as the base.

Module Name	*Description*
Ball & Beam	The Ball & Beam experiment requires the user to manipulate the position of a rolling ball on a beam.
Flexible Link	The Flexible Link experiment requires the user to command a *tip* position of the flexible link attached to the SRV02.
Flexible Joint	A rigid beam is mounted on a flexible joint that rotates via the SRV02 and the user is to command the tip position of this beam.
Gyro/Stable Platform	The purpose is to maintain the line of sight of an instrument mounted on a rotating platform (SRV02).
Inverted Pendulum	The purpose is to balance the inverted pendulum through a rotary motion arm (SRV02).
Double Inverted Pendulum	The double inverted problem adds to the complexity of the single pendulum by introducing a 2nd pendulum.
2 DOF robot module	This experiment requires the x-y positioning of the “end effector”.
2 DOF Rotary Gantry	This experiment requires the control of the swing of a x-y gantry crane using a 5 DOF linkage.
2 DOF inverted pendulum	Balance a pendulum that is free to fall in 2 directions. The pendulum is attached to the tip of the 2 DOF robot.

Table 2 - Rotary Family Modules

3. System Nomenclature and Components

Figure 1 below depicts the standard rotary inverted pendulum module coupled to the SRV02. Figure 2 Below depicts the ROTPEN – E (encoder option). **Note how the pendulum can rotate a complete 360° with the encoder option.* Refer to the following table to associate the *components* with their corresponding photographs.

1	SRV02 (Base Unit)	6	Fixture
2	Thumbscrews	**7**	Pendulum
3	Coupling Arm	**8**	SRV02 (Base Unit)
4	Pendulum Sensor (Encoder)	**9**	Pendulum Sensor (Potentiometer)
5	Sensor Shaft	**10**	Pendulum

Table 3 - Component Names

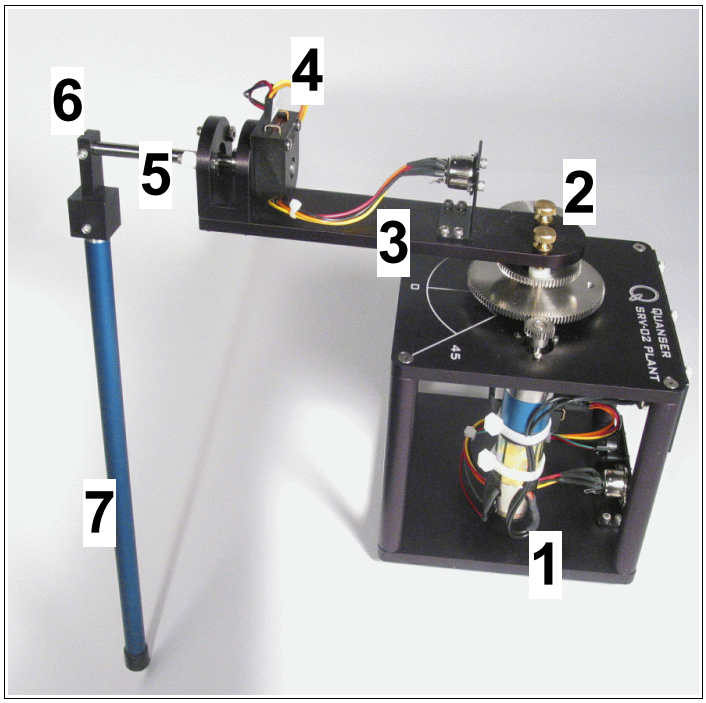


Figure 2 - ROTPEN – Encoder Option

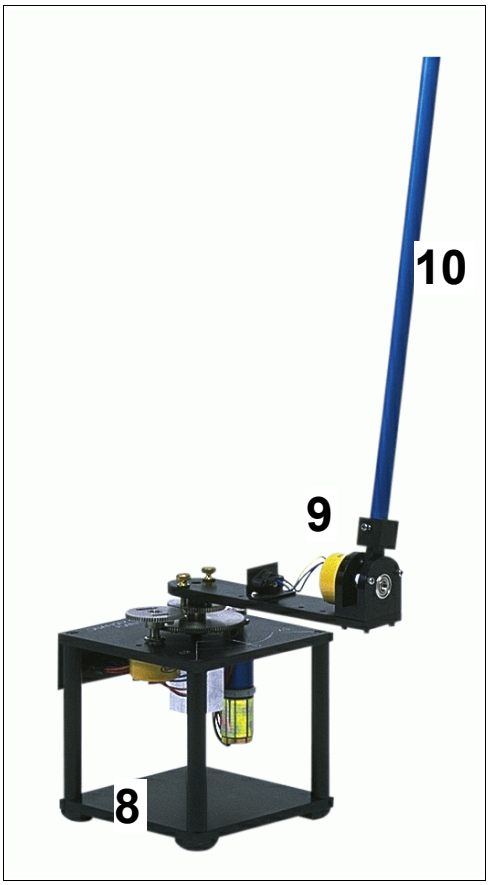


Figure 1 - ROTPEN

4. System Configuration and Assembly

The rotary pendulum module requires very minimal assembly. Figure 3 Below shows the 3 components of the package you should have received.

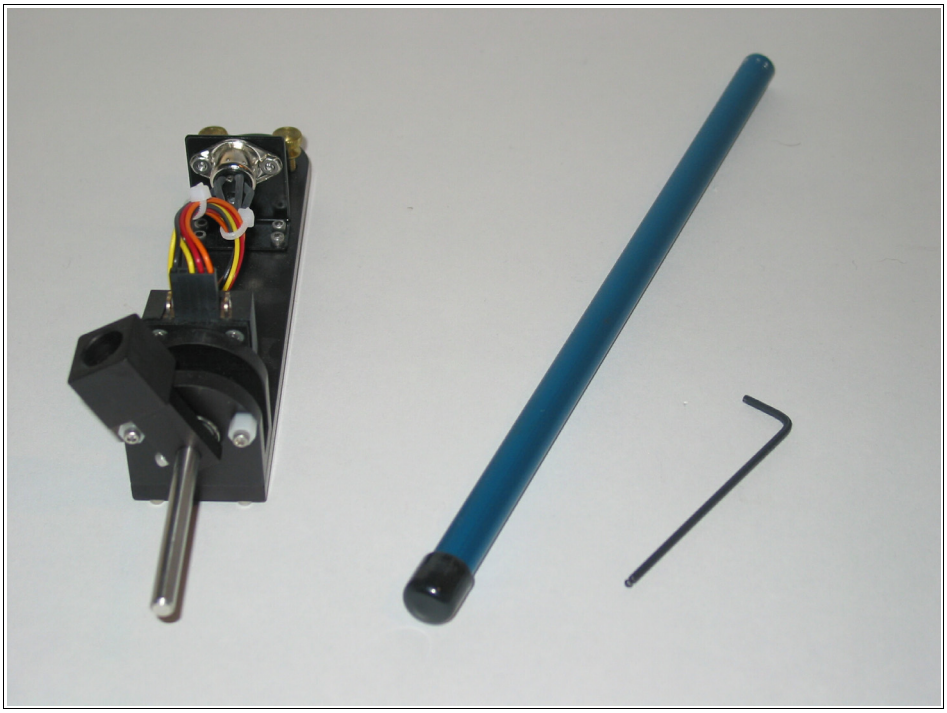


Figure 3 - Contents of ROTPEN Package

The first step is to fasten the pendulum into the fixture. This is done by loosening the setscrew at the side of the fixture, placing the pendulum into the fixture and tightening the setscrew as seen in Figure 4 below.

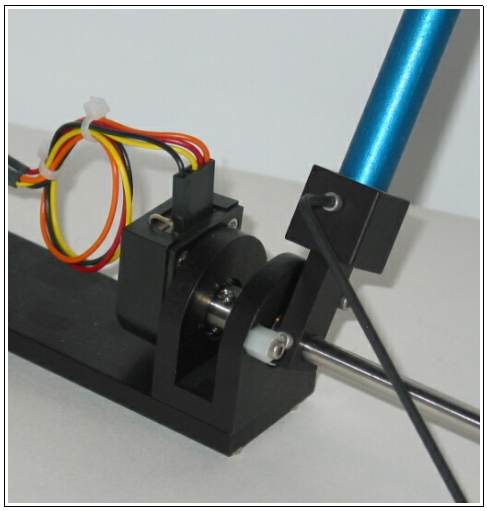


Figure 4 - Tightening the setscrew

The final step is to mount the ROTPEN onto the SRV02. Make sure the SRV02 is configured in the High-Gear configuration. If you are unsure about the SRV02, please refer to the *SRV02 User Guide*. Simply place the ROTPEN onto the load shaft (middle shaft) and secure the ROTPEN in place by tightening the 2 thumbscrews as seen in Figure 5 below.

Figure 5 - Attaching to the SRV02

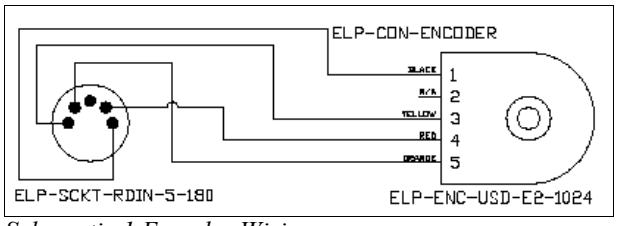
4.1 **Potentiometer** (*Component 9*)

The standard rotary pendulum module (ROTPEN) uses a potentiometer to sense the pendulum angle. The model used is a *Vshay Spectrol model 132* potentiometer. It is a single turn, 10k Ohm sensor with a range of approximately ± 35° due to the hard stops in the fixture. Its electrical range is 352 degrees. It is biased such that a ± 12 V supply results in a ± 5 V range over the full range of 352 degrees. Under normal operations, terminal three should measure +5 V while terminal 1 should measure -5 V. The actual signal is available at terminal 2. The sensor connection is a 6-pin mini DIN which is designed to be connected to a Quanser UPM (Universal Power Supply). The UPM delivers the bias voltage for the potentiometer (± 12 V) and the sensor signal is then available on the corresponding analog input.

4.2 **Encoder** (*Component 4*)

The ROTPEN-E options come with an optical encoder used to measure the pendulum's angular position. The model used is a US Digital Optical Kit Encoder. It offers high resolution (4096 counts in quadrature), and measures the *relative* angle of the shaft (as opposed to the potentiometer which only measure an *absolute* angle from a pre-defined 0° location).

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 UPM**. Schematic 1 Is the wiring diagram of the encoder.



Schematic 1 Encoder Wiring

4.3 Typical Connections for the SRV02 – ROTPEN Experiment

The following table describes the typical setup using the complete Quanser solution. It is assumed that the ROTPEN is being used along with an SRV02, UPM and Q8 DAQ board.

From...	*To...*	*Cable*	*Description*
Pendulum Potentiometer (*Component 9*) **Only required on the ROTPEN model.*	*S3* Connector on *UPM.*	6-pin mini DIN to 6-pin mini DIN.	This cable results in delivering a ±12V bias to the potentiometer and measuring the potentiometer signal voltage on *S3* of the UPM.
Pendulum Encoder (*Component 4*) **Only required on the ROTPEN-E model.*	*Encoder 1* connector on the terminal board.	5-pin Stereo DIN to 5-pin Stereo DIN.	The terminal board should supply the encoder with the +5V and ground. The pendulum signal will then be measure on Encoder channel 1.
SRV02 Encoder **This is the load gear position measurement*	*Encoder 0* connector on the terminal board.	5-pin Stereo DIN to 5-pin Stereo DIN.	The terminal board should supply the encoder with the +5V and ground. The load shaft position signal will then be measure on Encoder channel 0.
'To Load' Connector on *UPM.*	*Motor* on SRV02.	6-pin DIN to 4-pin DIN.	This connects the output of the amplifier to the motor. You can use a variety of cables resulting in a different gain from input to output. The cables available are Gain=1, Gain=3, Gain=5.
Analog Signals (*To A/D)* ** Only required if using analog sensors..*	Analog input channels 0-3 on the DAQ.	5-pin DIN to 4x RCA.	From the *UPM,* connect all the analog sensor signals to the terminal board such that *S1* is measured on analog input 0. *S2* - AI # 1, *S3* - AI # 2, *S4* - AI # 3.
Analog output channel 0 on the DAQ.	*UPM* input (*From D/A)*	RCA to 5-pin DIN.	This is the command output from the DAQ that will be amplified and drive the motor.

Table 4 - Typical Connections

4.4 Testing the ROTPEN or ROTPEN-E Sensor

This section describes functional tests to determine if your pendulum sensors are operating normally. It does **not** cover any performance tests. All these tests require an understanding of Simulink (or Labview), WinCon (or equivalent), and Q8 (or equivalent data acquisition board you are using). You should be able to *"build"* a controller that can measure and apply desired signals.

In the following sections, it is also assumed that the SRV02 is connected as described in the *Typical Connections* table above.

- **ROTPEN** with potentiometer sensor - Build a controller that measures analog input # 2 (Make sure the sensor is connected to *S3* on the UPM). Apply a gain block to the signal with a gain of 35.2 (352° over a 10V range). With the controller running, you should be seeing the pendulum's angular position. The signal should read 0° when the pendulum is held upright and should vary between ±35° between the 2 hard stops.

- **ROTPEN-E** with encoder sensor – Build a controller that measures encoder channel # 1 (Make sure the sensor is connected to encoder channel # 1 on the terminal board). Apply a gain block to the signal of 360/4096 (the encoder generates 4096 counts per revolution). With the controller running, you should be measuring the angle of the pendulum. You will realize that the reading is at 0° at the location that the pendulum was in when the controller started. Completing one revolution of the pendulum should result in a 360° reading and rotating back to opposite way should return the reading back to 0°.

Validate that your sensor is behaving according to the normal operation stated above. If the measurements are not as expected, please refer to Table 4 and make sure the connections are made as specified.

For technical support referring to any of the ROTPEN components, please visit us on the web at: www.Quanser.com.

Under our *Technical Support* section, please fill out a *technical support form* indicating your problem in detail and one of our engineers will be happy to respond to your request.

5. Rotary Pendulum Module – Range of Experiments & Features

The Rotary Pendulum Module offers the student the opportunity to balance a vertical rod by manipulating the angle at the base. This is the classical pendulum problem only now the trajectory is circular. This module is also configurable in 3 distinct configuration. The module can be used as a classical inverted pendulum; a gantry crane or in the self-erecting inverted pendulum.

ROTPEN Key Features:

- High Quality Aluminum chassis with precision crafted parts
- High Resolution Encoders to sense rod angle
- Variable Pendulum Rod lengths and mass
- 3 Distinct Configurations / Experiments
- Fully documented system models & parameters
- Fast and Easy attachment to the SRV02 plant
- Open architecture design
- Fully compatible with Matlab/Simulink & Labview

Curriculum Topics:

- Disturbance Rejection
- Tracking Control & Regulation
- Full State-Feedback
- Observer Design & Implementation
- Frequency Analysis
- System Modeling & Simulation
- Pole-Placement Technique
- Root Locus Design
- Nyquist Stability
- Non-Minimum Phase
- Limit Cycle
- Non-Linear Friction
- Hardware in the Loop
- Real-Time Control
- Discrete Time Sampling
- System Identification
- Multivariable Control Design

6. System Requirements & Specifications

The Rotary Pendulum Module (ROTPEN) is designed as an attachment to the SRV02 plant. Along with the SRV02 plant, the following components are required to complete the experimental setup.

Component	*Quanser Recommended (Common Configuration)*	*Alternative*
Power Module	Quanser UPM 1503/2405	Other Power Supply that can deliver the required power.
Data Acquisition	Quanser Q8	dSPACE DS 1104 National Instruments E-Series DAQs Any other DAQ with at least one A/D, one D/A and one Encoder input.
Control Software	Quanser WinCon / SLX / WebLab	The Mathworks – RTWT, xPC dSPACE – ControlDesk National Instruments – Labview RT

Table 5 - System Requirements

6.1 System Specifications

Specification	*Value*	*Units*
Coupled Arm Length	**20**	cm
Long Pendulum Length	**65**	cm
Short Pendulum Length	**35**	cm
Long Pendulum mass	**0.231**	kg
Short Pendulum mass	**0.128**	kg
ROTPEN mass **without pendulum*	**0.278**	kg
Potentiometer Bias Power	**±12**	Volts
Potentiometer Measurement Range	**±5**	Volts
Encoder Resolution	**4096**	Counts/Rev.

Table 6 - ROTPEN Specifications