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USER MANUAL

Linear 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 Linear Double Pendulum (DBPEN-LIN) is composed of 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-LIN is coupled to a Linear Servo Base unit (IP02). This slides along a steel shaft and is driven via a rack and pinion system. See the IP02 User Manual for full details regarding the IP02 Base Unit system. The balance control computes a voltage based on the angle measurements from the encoders. This control voltage signal is amplified and applied to the IP02 motor. The linear cart moves accordingly to balance the two links and the process repeats itself.

Figure 1.1: Quanser Linear Double Pendulum (DBPEN-LIN).

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 Linear Double Inverted Pendulum module are identified in Section 2.1. Some of those components are described in Section 2.2.

2.1 Components Nomenclature

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

ID	Component	ID	Component
1	IP02 Cart	5	DBPEN-LIN short pendulum (link 1)
2	IP02 Rack	6	Pendulum encoder connector
3	Shaft	7	link housing
4	Pendulum T-Fitting	8	DBPEN-LIN medium pendulum (link 2)

Table 2.1: Linear Double Inverted Pendulum Components.

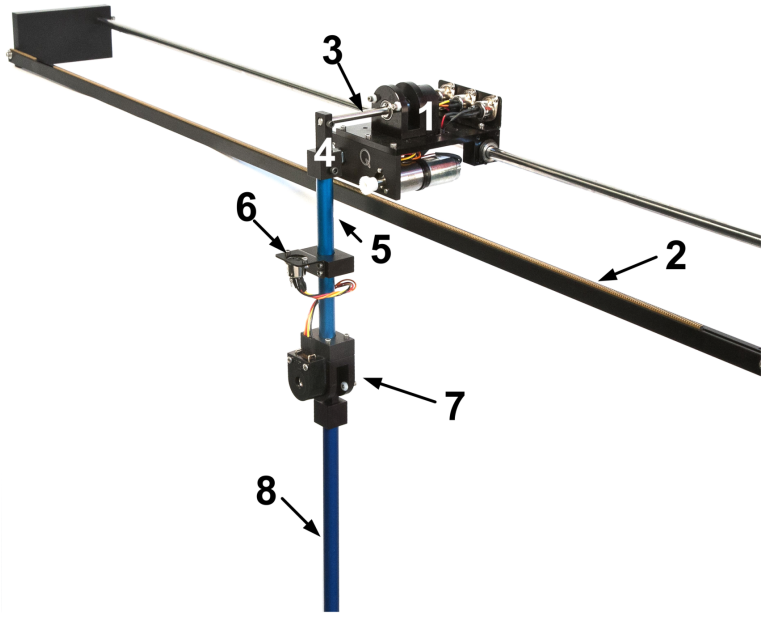


Figure 2.1: Linear Inverted Double Pendulum (DBPEN-LIN).

2.2 Components Description

2.2.1 Encoder

The encoder used to measure the pendulum angle on the DBPEN-LIN 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-LIN module is illustrated in Figure 2.2.

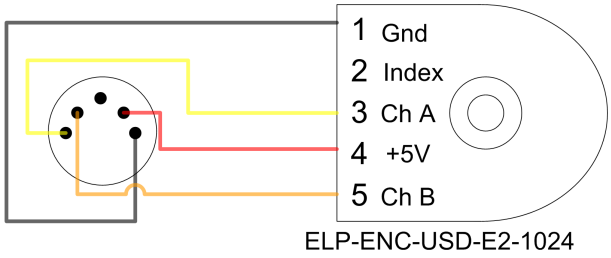


Figure 2.2: Encoder Wiring

3 SPECIFICATION

This section lists and characterizes the model parameters of the Double Inverted Pendulum. See Reference [1] for the parameters associated with the IP02 unit.

Symbol	Description	Value	Unit
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 short and medium pendulum.	0.1410	kg
	Mass of DBPEN-LIN assembly	0.364	kg
K_{enc}	Pendulum encoder resolution	4096 (quadrature)	counts/rev

Table 3.1: Double Pendulum System Parameters.

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 Linear Double Inverted Pendulum module for experimental use:

1. As depicted in Figure 4.1, do not place the additional weight on the IP02 cart.
2. As shown in Figure 4.1 slide the T-Fitting of the pendulum, ID #4 in Figure 2.1, onto the metal shaft, ID #3 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-LIN is facing AWAY from the IP02 cart.

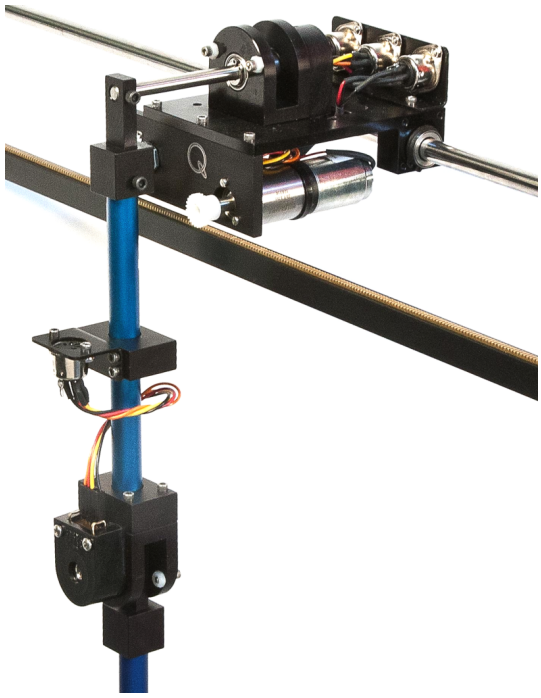


Figure 4.1: Slide the T-Fitting of the pendulum

3. Before running any experiments, it is recommended that the IP02 rack be secured down onto the table.

5 WIRING PROCEDURE

The following is a listing of the hardware components used in the Linear Double Inverted Pendulum experiments:

1. **Power Amplifier:** Quanser VoltPAQ-X1, or equivalent.
2. **Data Acquisition Device:** Q8-USB, QPID/QPIDe, NI DAQ Devices, or equivalent.
3. **Linear Servo Plant:** Quanser IP02 Base Unit.
4. **Module:** Quanser Double Pendulum.

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 IP02, and 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 IP02 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 board (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 Linear Double Inverted Pendulum plant to the amplifier and the data acquisition device. See Reference [1] for the specifications and a description of the main components composing the IP02 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	IP02 "Motor" Connector	Power leads to the IP02 DC motor.
3	Data Acquisition Device: Encoder Input #0	IP02 "Cart Encoder" connector	IP02 Cart position measurement.
4	Data Acquisition Device: Encoder Input #1	IP02 "Pendulum Encoder"' connector	Double pendulum short link angle measurement.
5	Data Acquisition Device: Encoder Input #2	Double pendulum link 2 encoder	Double pendulum long link pendulum angle measurement.

Table 5.2: Quanser DBPEN-LIN system wiring summary

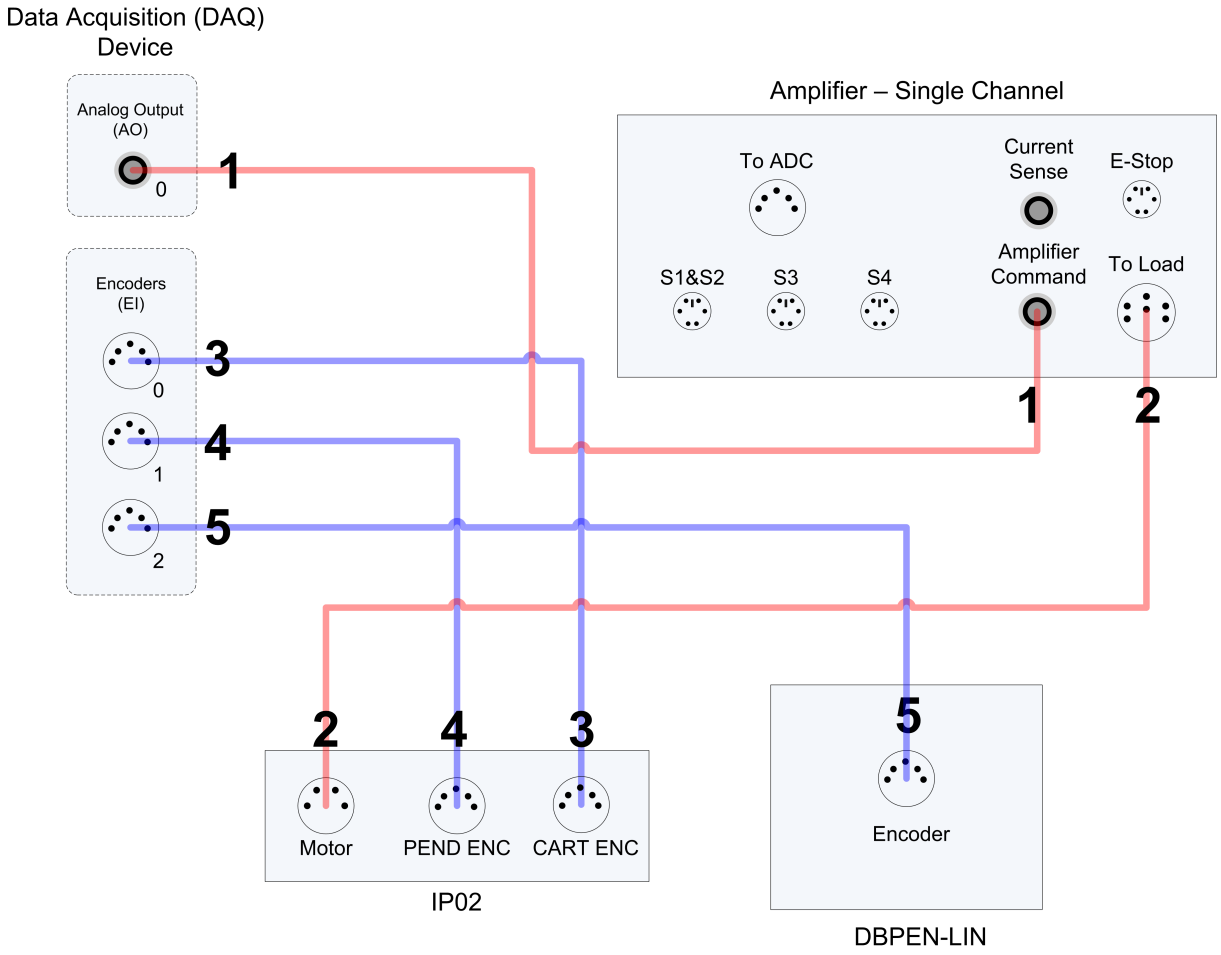


Figure 5.1: IP02 and DBPEN-LIN Module Wiring Diagram

The follow describes in detail the wiring procedure of the Linear Double Inverted Pendulum experiments to a amplifier and DAQ:

1. It is assumed that the data acquisition 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 amplifier.
3. Connect one of the 2x RCA to 2x RCA cable from the *Analog Output Channel #0* on the Data Acquisition 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 IP02. See connection #2 shown in Figure 5.1. The cable transmits the amplified voltage that is applied to the IP02 motor and is denoted V_m.
5. Connect the 5-pin-stereo-DIN to 5-pin-stereo-DIN encoder cable from the *Cart Encoder* connector on the IP02 to *Encoder Input #0* on the Data Acquisition Device, as depicted by connection #3 in Figure 5.1. This carries the cart position measurement and is denoted by the variable X_c.

   Caution: Connect the encoders directly to the data acquisition (DAQ) device using the standard 5-pin DIN cable. **Do NOT connect it to the amplifier.!**
6. Connect the 5-pin-stereo-DIN to 5-pin-stereo-DIN encoder cable from the *Pendulum Encoder* connector on the IP02 to *Encoder Input #1* on the Data Acquisition Device, as depicted by connection #4 in Figure 5.1. This carries the short link pendulum angle and is denoted by the variable α.
7. Connect the 5-pin-stereo-DIN to 5-pin-stereo-DIN encoder cable from the Double Pendulum encoder connector directly to *Encoder Input Channel #2* on the Data Acquisition Device, as depicted by connection #5 in Figure 5.1. It carries the measured long link pendulum angle and is denoted by variable θ.

6 TESTING AND TROUBLESHOOTING

This section describes some functional tests to determine if your Linear Double Pendulum system is operating normally. It is assumed that the IP02 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 IP02 Motor and Sensors

Please refer to [1] for information on testing and troubleshooting the IP02 separately.

6.2 Testing the DBPEN-LIN encoder

Follow this procedure to test the DBPEN-LIN 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 devices 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-LIN 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 [1] 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.

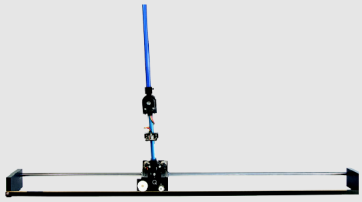
REFERENCES

[1] Quanser Inc. *IP02 User Manual*, 2012.

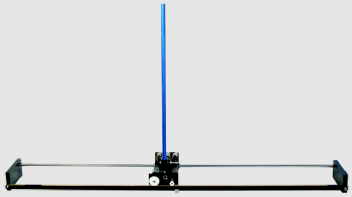
Nine linear motion plants for teaching fundamental and advanced controls concepts

IP02 Base Unit

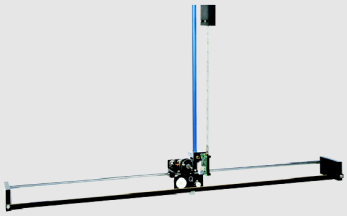
Linear Double Inverted Pendulum



Linear Pendulum

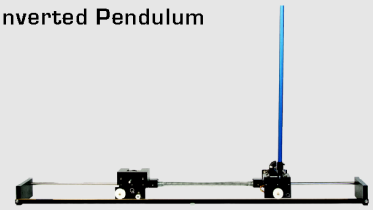


Linear Flexible Inverted Pendulum



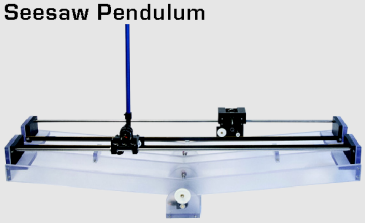
Linear Flexible Joint

Linear Flexible Joint with Inverted Pendulum

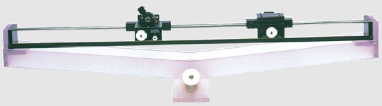


Seesaw

Seesaw Pendulum



Linear Flexible Joint on Seesaw



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