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USER MANUAL

Linear Flexible 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

1.1 Description

The Linear Flexible Inverted Pendulum (FLEXPEN) system is comprised of a flexible link attached with an end weight and it has a strain gage that measures the deflection of the link. The stiff pendulum is the blue rod shown in Figure 1.1 that is used in other Quanser Linear Servo (IP02) experiments and it is described as long pendulum in the Single Inverted Pendulum and Gantry (SIP and SPG) User Manual [2]. In this document, the FLEXPEN refers to both the stiff and flexible pendulums together and the IP02+FLEXPEN is the experiment shown in Figure 1.1.

Figure 1.1: IP02+FLEXPEN experiment

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

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

2.1 Component Nomenclature

Please use the ID # to locate each component in the Figure 2.1 below.

ID	Description	ID	Description
1	Linear Servo Base Unit (IP02) cart	8	FLEXPEN connector Cap Screw #8-32
2	Linear Servo Base Unit (IP02) pendulum axis	9	Thumbscrews
3	Long 24-inch pendulum	10	Analog strain gage connector.
4	Rod socket (i.e. T-fitting)	11	Strain gage circuit.
5	Axis Cap Screw #6-32	12	Strain gage.
6	Rod Cap Screw #6-32	13	Flexible pendulum link.
7	Flexible pendulum connector.	14	Flexible pendulum weight.

Table 2.1: IP02+FLEXPEN System Component Nomenclature

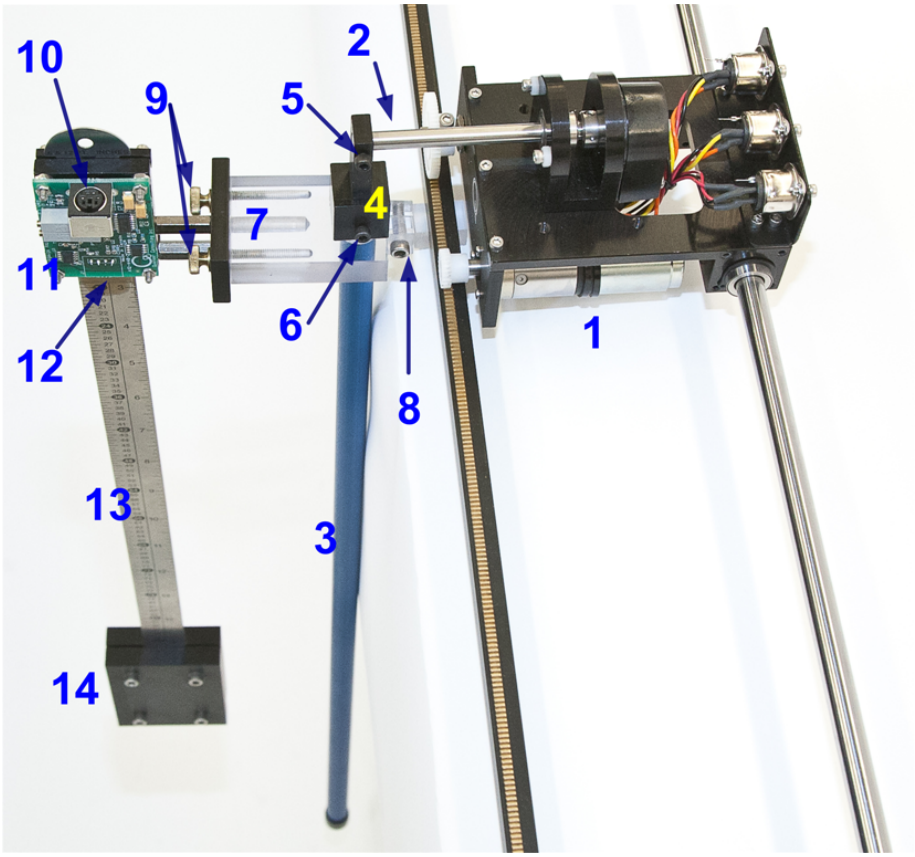

Figure 2.1: Components of IP02 + FLEXPEN System

2.2 Component Description

2.2.1 Quanser Linear Servo Base Unit (IP02)

For more information on the IP02 components see the Quanser Linear Servo (IP02) User Manual [1].

2.2.2 Flexible Pendulum Module

The Flexible Pendulum module consists of a stiff 24-inch pendulum rod and a 19-inch flexible link. They are both connected to a fiberglass connector, which can easily connect to the IP02 cart pendulum shaft. The main components of the flexible pendulum module are listed in Table 2.1, and labeled in Figure 2.1.

2.2.3 Strain Gage

The strain gage sensor is depicted in Figure 2.2 with ID #12, and produces an analog signal proportional to the deflection of the tip. The gain and offset potentiometers on the strain gage circuit can be used to calibrate the sensor. See Section 4.4 for the calibration procedure.

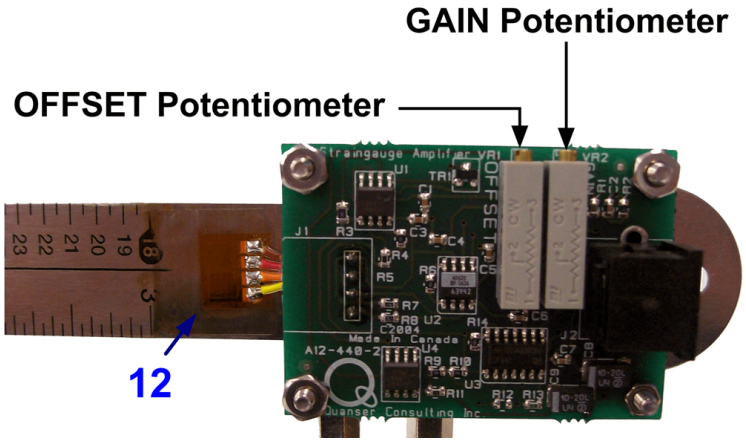

Figure 2.2: Strain Gage

3 SPECIFICATIONS

Table 3.1 below lists the main parameters associated with the Flexible Pendulum experiment. See IP02 User Manual [1] for the IP02 cart model parameters. The model parameters of the long 24-inch pendulum that are used in this experiment are also listed in the table but see Single Inverted Pendulum and Gantry (SIP and SPG) User Manual [2] for details on the rigid pendulum.

Symbol	Description	Value	Unit
M_{sp}	Stiff pendulum mass.	0.230	kg
l_{sp}	Stiff pendulum center-of-mass from pivot.	0.3302	m
J_{sp}	Stiff pendulum moment of inertia about center-of-mass.	0.0079	kg-m^2
B_{sp}	Stiff pendulum viscous damping.	0.004	N-m-s/rad
M_{fp}	Mass Flexible pendulum mass.	0.458	kg
l_{fp}	Flexible pendulum center-of-mass from pivot.	0.273	m
$J_{fp.pivot}$	Flexible pendulum moment of inertia about pivot point.	0.0432	kg-m^2
J_{fp}	Flexible pendulum moment of inertia about center-of-mass.	0.0094	kg-m^2
m_{link}	Mass of the flexible link.	0.0650	kg
$m_{link,s}$	Mass of flexible link with strain gage module attached (strain gage itself and circuitry).	0.1570	kg
m_{weight}	Mass of flexible pendulum weight.	0.2560	kg
m_{con}	Mass flexible pendulum connector.	0.0450	kg
P_SG	Position on flexible link where strain gage begins to measure.	0.0825	m
$L_{sg.pivot}$	Distance between P_SG and pivot point of FLEXPEN, where the pivot point is the middle of the thumbscrew holes on the strain gage module.	0.0413	m
L_{link}	Length from P_SG sensor to the tip of flexible link.	0.3937	m
l_{link}	Length from pivot to the center-of-mass of link.	0.1873	m
$l_{link,s}$	Length from pivot to the center-of-mass of the link when the strain gage module is attached.	0.0698	m
L_{sw}	Length from strain gage to start of weight.	0.3588	m
L_{weight}	Length of flexible pendulum weight.	0.0762	m
l_{weight}	Length from pivot to center-of-mass of flexible pendulum weight.	0.3969	m
f_n	Natural frequency of link with weight attached.	1.25	Hz
ω_n	Natural frequency of link with weight attached.	7.85	rad/s
K_s	Flexible link stiffness.	2.67	N-m/rad
K_SG	Strain gage sensitivity.	1.0	in/V
K_GAGE	Angle of deflection from stain gage sensitivity.	0.065	rad/in
V_{bias}	Strain gage bias power.	$\pm$12.0	V
V_{range}	Strain gage measurement range.	$\pm$5.0	V

Table 3.1: FLEXPEN Specifications

4 SYSTEM SETUP

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

1. **Power Amplifier**: Quanser VoltPAQ-X1, or equivalent.
2. **Data Acquisition (DAQ) Device**: Quanser Q1-cRIO, Q2-USB, Q8-USB, QPID/QPIDe, NI DAQ, or equivalent.
3. **Linear Servo Plant**: Quanser IP02
4. **Linear Flexible Inverted Pendulum**: Quanser FLEXPEN.

See the corresponding documentation for more information on these components. Section 4.2 provides a description of the standad cables used in the wiring of the FLEXPEN. The procedure to connect the above components is given in Section 4.3.

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

4.1 Assembly

The setup procedure for the IP02 with FLEXPEN system is explained in the steps below:

1. Read all instructions before proceeding.
2. Make sure no weight is mounted on the IP02 cart.
3. Fasten the FLEXPEN connector, ID #7 in Figure 2.1, on the long pendulum. This connects the long 24-inch rigid pendulum to the flexible pendulum. Tighten the FLEXPEN connector screw, ID #8, and make sure the connector does not slip about the pendulum rod.
4. Attach the flexible pendulum to the FLEXPEN connector, ID #7, that connects the rigid pendulum with the flexible pendulum, as illustrated in Figure 2. Tighten the two thumb screws, ID #9 in Figure 2.1, to fasten the flexible pendulum on the bracket.
5. Attach the T-fitting pivot of the long 24-inch pendulum to the tip of the IP02 cart's pendulum axis, as illustrated in Figure 4.1. Gently tighten the axis screw, ID #5 shown in Figure 2.1, as needed to ensure the pendulum is properly fastened to the metal shaft. See [2] for details
6. **Make sure each end of the IP02 rack is clamped down tightly on a rigid table.** This will prevent the rack from falling off the table when the cart is balancing the FLEXPEN. Further, not having the clamps introduces vibrations into the system that may cause bad performance or instability.

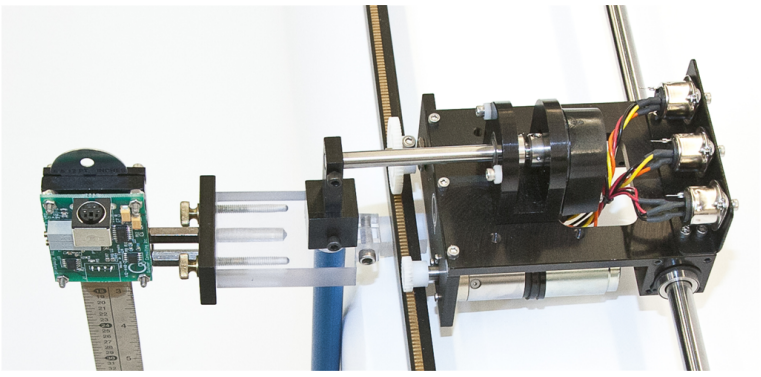

Figure 4.1: FLEXPEN Assembly

4.2 Cable Nomenclature

The cables used to connect the Quanser FLEXPEN system with a power amplifier and data-acquisition device are shown in Table 4.1. Depending on your configuration, not all these cables are necessary.

Cable	Type	Description
 (a) RCA Cable	2xRCA to 2xRCA	This cable connects an analog output of the Data Acquisition (DAQ) Device 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 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 device (to the encoder counter). 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	This cable carries analog signals from the Flexible Pendulum to the amplifier. The cable 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 Channels on the data acquisition device.

Table 4.1: Cables used to connect Flexible Pendulum System to Amplifier and DAQ device

4.3 Typical Connections

This section describes the typical connections used to connect the IP02 and FLEXPEN to a Data Acquisition (DAQ) Device and a power amplifier. The connections are described in detail in the procedure below, summarized in Table 4.2, and pictured in Figure 4.2.

Cable	From	To	Function
1	Data Acquisition (DAQ) Device: **Analog Output #0**	Amplifier *Amplifier Command* connector	Control signal to the amplifier.
2	Amplifier: *To Load* connector	IP02 *Motor* connector	Power leads to the IP02 dc motor.
3	Amplifier: *To ADC* connector	Data Acquisition (DAQ) Device: **Analog Input #0**. White RCA connector (S2)	Carries strain gage analog signal to data acquisition device.
4	Data Acquisition (DAQ) Device: **Encoder Input #0**	IP02 *Cart Encoder* connector	Measures the linear position of the cart.
5	Data Acquisition (DAQ) Device: **Encoder Input #1**	IP02 *Pendulum Encoder* Connector	Measures the front pendulum angle.
6	Flexible Pendulum: Strain Gage Analog Connector	Amplifier: **S1 & S2** Connector	Measures the angular deflection of the flexible pendulum.

Table 4.2: Linear Flexible Inverted Pendulum Connections

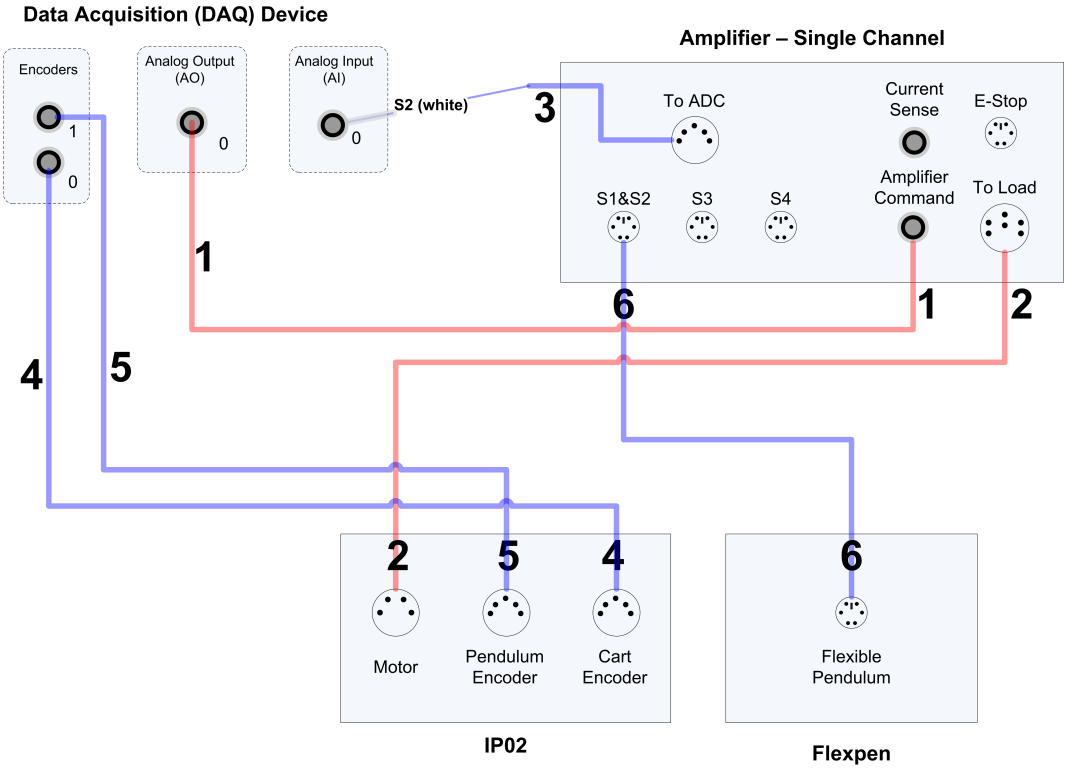

Figure 4.2: Connections between Flexible Pendulum, Power Amplifier, and DAQ Device

Note: Ensure the amplifier and PC are not powered on before performing the connections

1. Follow the default wiring procedure described in the Linear Servo (IP02) User Manual [1]. It describes the details of wiring the IP02 motor and encoders.
2. Connect the **To ADC** socket on the amplifier to Analog Inputs #0 using the 5-pin-DIN to 4xRCA cable, as illustrated in Figure 4.2, ID#3. As illustrated, make sure you connect the **white** RCA connector (S2) to analog input channel #0.
3. Connect the analog connector on the strain gage of the flexible pendulum, ID #10 in Figure 2.1, to the **S1 & S2** socket on the amplifier using a 6-pin-mini-DIN to 6-pin-mini-DIN analog cable. This connection is shown in Figure 4.2,ID #6. **Ensure the amplifier is not powered when making this connection.**

Note: The wiring diagram shown in Figure 4.2 is using a generic data aquisition device. The same connections can be applied for any data-acquisition system that has at least 1x analog output, and 2x encoder inputs.

4.4 Calibration

The Flexible Pendulum has a strain gage mounted at its base to measure the deflection of the pendulum's tip (ID#12, in Figure 4.3). The unit is calibrated before shipment. Therefore no calibration should be required upon receiving the system. However, if the system needs be re-calibrated the instructions are given below.

As depicted in Figure 4.3, the strain gage circuit has two adjustable potentiometers, one to adjust the **OFFSET** and another to adjust the **GAIN**.

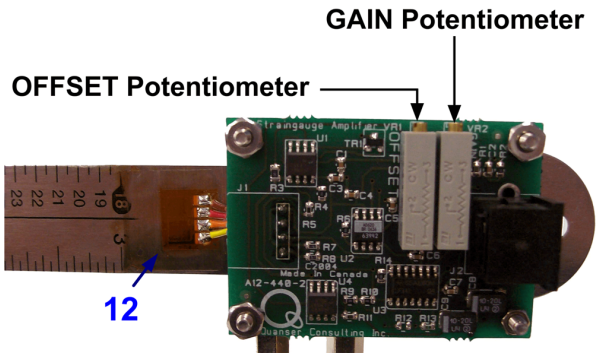

Figure 4.3: Gain and Offset Potentiometers on the Strain Gage Circuit

Please follow the steps below to complete the calibration process:

1. Loose the four screws shown in Figure 4.4 and remove the weight using the Allen key #8-32 provided with the system.

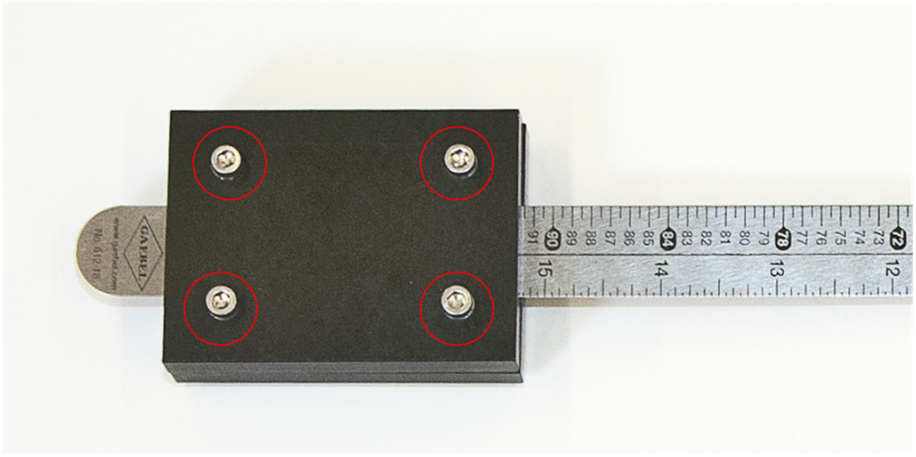

Figure 4.4: Removing the weight

2. Ensure the system has been wired using cables #6 and #3 shown in Figure 4.2
3. Get the calibration base and calibration comb that were supplied with the Quanser FLEXPEN system, shown in Figure 4.5a and Figure 4.5b.

(a) Calibration Base (b) Calibration Comb

Figure 4.5: Calibration Compoments for Flexible Pendulum

4. After removing the weight, mount the flexible pendulum on the calibration base as depicted in Figure 4.6 using the thumb screws.

Figure 4.6: Mounting Flexible Pendulum on calibration base.

5. Place the tip in the middle tooth of the comb as seen in Figure 4.7 below.

Figure 4.7: Tip Placed in the Middle Calibration Comb Slot

6. **Offset adjustment:** Measure the voltage of the strain gage. It should be measuring 0 V. If not, adjust the **OFFSET** potentiometer until your measurement reads 0 V.

   Note: To measure the voltage, you can use the QUARC® or LabVIEW™ files that are supplied with the system. Alternatively, you can use a voltmeter to measure the strain gage voltage.

7. **Gain adjustment**: The strain gage should read 1 V per 1 inch of tip deflection. Each slot or tooth in the calibration comb corresponds to a tip displacement of $\frac{1}{4}$ inch. Move the tip 4 slots in the counter-clockwise direction as shown in Figure 4.8. The strain gage measurement should be reading 1 V. If not, gently adjust the **GAIN** potentiometer until it reads 1 V.

8. Move the tip 8 slots in the clockwise direction (i.e., 4 slots away from 0) and verify it is reading -1 V.

9. Return the tip to the zero position and confirm that it is reading 0 V again. If not, adjust the **OFFSET** potentiometer once again to read 0 V.

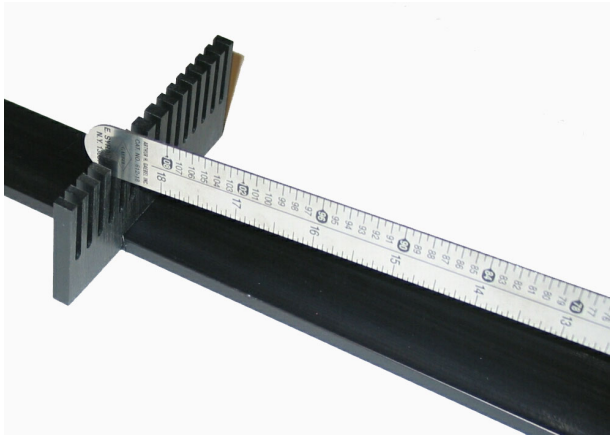

Figure 4.8: Flexible Link Tip Displaced by 1 inch in the Counter-clockwise Direction

5 TROUBLESHOOTING

5.1 IP02 Motor and Sensors

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

5.2 Strain Gage Sensor

5.2.1 Testing

You can test the strain gage sensor in a fashion similar to calibrating it which is discussed in Section 4.4. Follow the procedure below to ensure that your strain gage sensor is operating correctly.

1. Read the Analog Input channel #0 to the strain gage.
2. If the sensor is reading but the measurement seems incorrect (e.g. there is an offset, low amplitude), then the strain gage may need to be calibrated. Go to Section 4.4 for calibration instructions.

6 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. *Linear Servo Base Unit (IP02) User Manual*, 2012.

[2] Quanser Inc. *Single Inverted Pendulum and Gantry (SIP and SPG) User Manual*, 2012.

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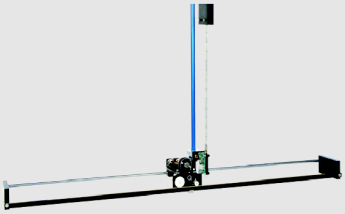
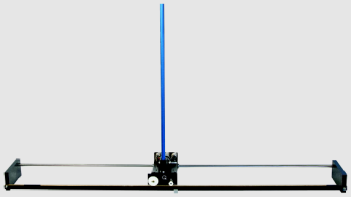
IP02 Base Unit

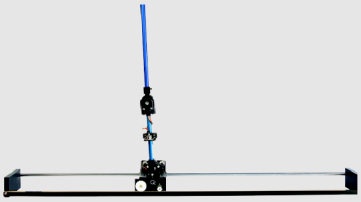
Linear Flexible Inverted Pendulum



Linear Pendulum

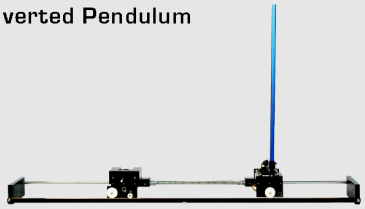


Linear Double Inverted Pendulum



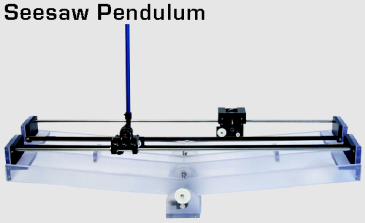
Linear Flexible Joint

Linear Flexible Joint with Inverted Pendulum

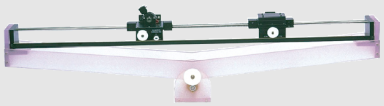


Seesaw

Seesaw Pendulum



Linear Flexible Joint on Seesaw



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