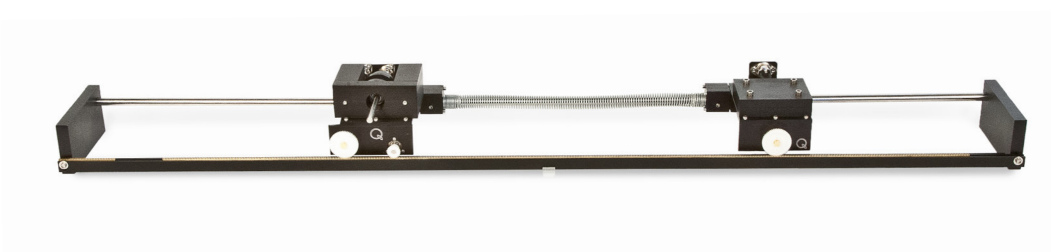
USER MANUAL

Linear Flexible Joint Experiment

Set Up and Configuration



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CE Compliance CE

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)

CONTENTS

1 PRESENTATION

1.1 Description

The Linear Flexible Joint Cart (LFJC-E) experiment consists of a system of two carts sliding on an IP02 track, as shown in Figure 1.1. The IP02 cart drives the system, and the second passive cart is coupled to the first one through a linear spring. The shafts of these elements are mounted to a rack and pinion mechanism in order to input the driving force to the system, and to measure the two cart positions. When the motor turns, the torque created at the output shaft is translated to a linear force which results in the cart's motion. When the carts move, the encoder shafts turn and the resulting signals are calibrated to obtain the actuated and load carts' positions.

Figure 1.1: Quanser LFJC-E system

As illustrated in Figure 1.1, the cart on the left is an IP02 cart with the extra weight mounted atop of it in order to reduce slippage. To run the LFJC experiment, the cart on the right can be either an LFJC-E, or LFJC-PEN-E module. The carts are passive (not motor-driven) and made of solid aluminum. All of them use linear bearings to slide along a ground stainless steel shaft. Moreover, two masses are available for attachment to the cart. These two weights, mounting on the load cart, can be used for assessing the robustness of the controller and the effects of variations in parameters.

The IP02 is a solid aluminum cart. It is driven by a rack and pinion mechanism using a 6-Volt DC motor, ensuring consistent and continuous traction. The cart slides along a ground stainless steel shaft using linear bearings. The cart position is measured using a sensor coupled to the rack via an additional pinion. Please review [3] for a complete description of the IP02 system.

■ **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 LFJC-E COMPONENTS

The LFJC-E components are identified in Section 2.1. Some of the those components are then described in Section 2.2.

2.1 LFJC-E Component Nomenclature

The LFJC-E components listed in Table 2.1 below are labeled in Figure 2.1.

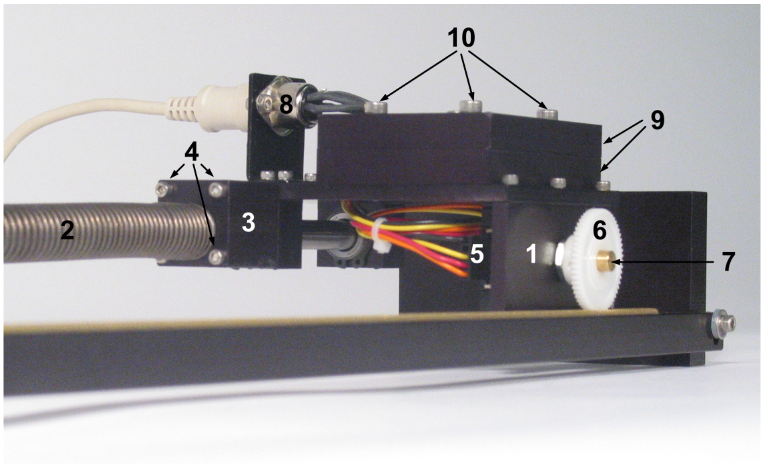


Figure 2.1: Quanser LFJC-E components

ID	Component	ID	Component
1	LFJC-E	6	Cart Position Pinion
2	Compression Spring	7	Cart Position Axis
3	Spring Fitting	8	Cart Encoder Connector
4	Spring Fitting Set Screws (7/64")	9	Load Weight
5	Cart Encoder	10	Load Weight Set Screws (9/64")

Table 2.1: LFJC-E Components

2.2 Component Description

2.2.1 Linear Spring

The linear spring used in the LFJC-E is a compression spring coiled left hand from Ashfield Springs Limited (UK). It has the following dimensions: an outside diameter of 15.90mm (0.625"), a wire diameter of 1.40 mm (0.056"), with approximately 3.54 coils/cm (9 coils/inch), for a length of around 304 mm (12"). The part stock number is: S.618. Both ends of the linear spring are equipped with a square fitting that mates with the IP02 cart on one side and the LFJ cart on the other, obtaining a linear spring-mass system.

2.2.2 Encoder

The LFJC-E has an optical encoder which is used to measure the cart position, represented in Figure 2.1 by components # 5. The encoder measuring the LFJC-E cart linear position does so through a rack-pinion system. The encoder model used in the LFJC-E is a US Digital S1 single-ended optical shaft encoder. It offers a high resolution of 4096 counts per revolution (i.e. 1024 lines per revolution with two channels in quadrature). The complete specification sheet of the S1 optical shaft encoder is included in [1]. Remark that incremental encoders measure the relative angle of the shaft.

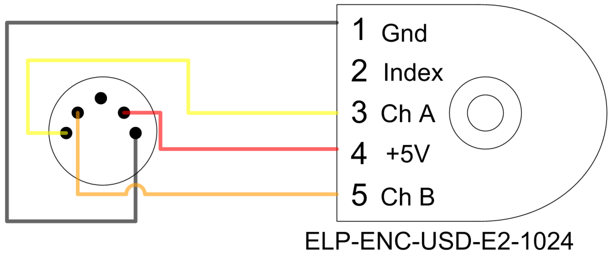


Figure 2.2: LFJC-E encoder wiring

The position signal generated by the encoder can be directly connected to the data-acquisition device using a standard 5-pin DIN cable. The internal wiring of the encoder and the 5-pin DIN connector on the LFJC-E is illustrated in Figure 2.2.

■ **Caution:** Make sure you connect the encoder directly to your data-acquistion device and not to the power amplifier.

3 LFJC-E SPECIFICATIONS

Table 3.1 lists and characterizes the main parameters associated with the LFJC-E. Some of these are used in the mathematical model.

Symbol	Description	Value
M_{c2_c}	Cart Mass	0.220 kg
M_{w2}	Weight Mass	0.125 kg
$B_{eq_{jc}}$	Equivalent Viscous Damping Coefficient as seen at the Cart Position Pinion	2.2 N.s/m
K_s	Equivalent Spring Stiffness	142 N/m
M_s	Spring Assembly Mass	0.145 kg
L_s	Spring Length	0.29 m
N_{pp2}	Position pinion number of teeth	56
r_{pp2}	Position pinion radius	1.48×10^{-2} m
P_{pp2}	Position pinion pitch	1.664×10^{-3} m/tooth
K_{ec}	Position encoder resolution	2.275×10^{-5} m/count

Table 3.1: LFJC-E Specifications

4 LFJC-E SETUP

See Section 4.1 for instructions on how to assemble the Linear Flexible Joint Cart system.

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

4.1 Assembly

The setup procedure for the default configuration, as previously described, is as follows:

1. Do not mount the pendulum rod on your IP02 cart. Remove it if necessary.
2. Mount your LFJC-E module on your IP02 track. To do so, first remove one of your IP02 rack end plates by unfastening the two corresponding set screws, as shown in Figure 4.1. Consult the IP02 User Manual [3] if necessary.

Figure 4.1: Remove the rack end plate

3. Then slip both linear spring and the LFJC-E cart onto the IP02 stainless steel shaft, as shown in Figure 4.2. Finally once the LFJC-E system can slide smoothly on the guide rail, you can then mount the rack end plate back and tighten the two set screws.

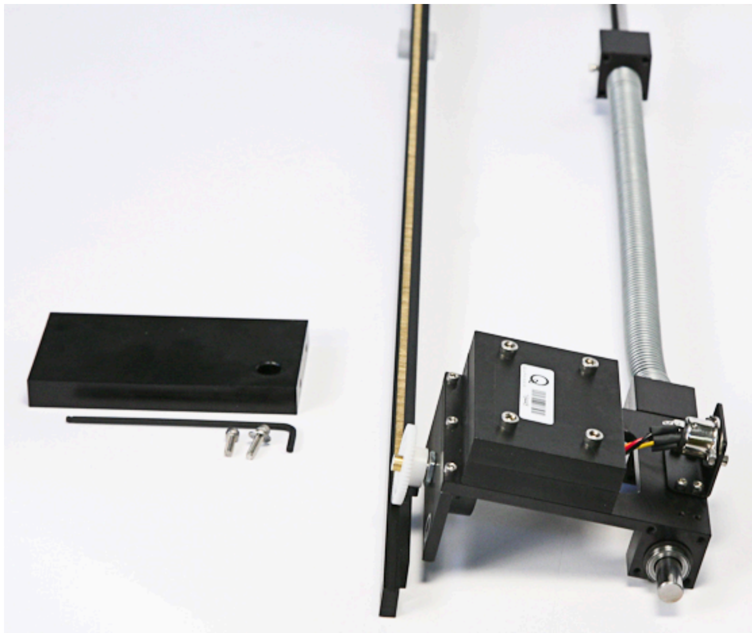


Figure 4.2: Slip LFJC onto the IP02 shaft

4. Attach the linear spring square fitting (component #3 in Figure 2.1) to your IP02 cart using the four set screws provided, as shown in Figure 4.3. To do so, fasten the set screws (component #4 in Figure 2.1) diagonally while moving the cart along the track. If the movement of the IP02 and LFJC assembly becomes stiff, loosen the screws until the movement is uncompromised.

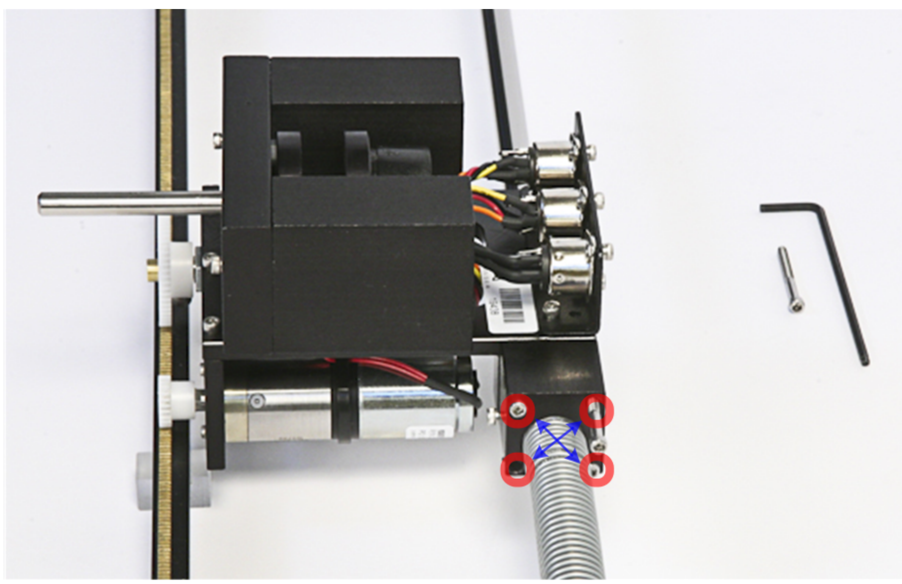


Figure 4.3: Attach the linear spring square fitting

5. Place the additional weight on your IP02 cart, if not already done.
6. Mount the two additional weights (components #9 in Figure 2.1) on top of your LFJC-E system, if not already done. The additional weights are shown in Figure 4.4. To that effect, fasten the set screws (component #10 in Figure 2.1).

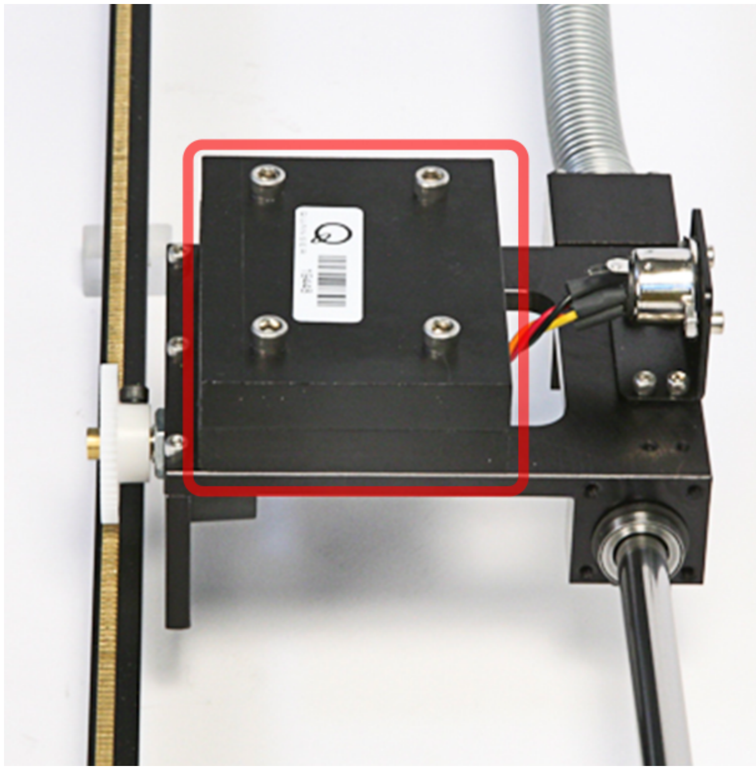


Figure 4.4: Mount the additional weights

7. We highly recommend that you can clamp the IP02 track down to the table using its end plates.

5 WIRING PROCEDURE

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

1. **Power Amplifier**: Quanser VoltPAQ-X1, or equivalent.
2. **Data Acquisition Board**: Quanser Q1-cRIO, Q2-USB, Q8-USB, QPID/QPIDe, NI DAQ, or equivalent.
3. **Linear Servo Plant**: Quanser IP02
4. **Linear Flexible Joint Cart**: Quanser LFJC-E, or LFJC-PEN-E module.

See the corresponding documentation for more information on these components. The cables supplied with the LFJC-E are described in Section Section 5.1 and the procedure to connect the above components is given in Section 5.2.

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

5.1 Cable Nomenclature

The cables used to connect the Quanser LFJC-E system with a power amplifier and data-acquisition device is shown in Table 5.1. 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 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 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 board (to the encoder counter). Namely, these signals are: +5 VDC power supply, ground, channel A, and channel B

Table 5.1: Cables used to connect IP02 to amplifier and DAQ device

5.2 Typical Connections

This section describes the typical connections used to connect the LFJC plant to a data-acquisition board and a power amplifier. The connections are described in detail in the procedure below, summarized in Table 5.2, and pictured in Figure 5.1.

Note: The wiring diagram shown in Figure 5.1 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.

Cable	From	To	Signal
1	Terminal Board: 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	Terminal Board: Encoder Input #0	IP02 *Cart Encoder* connector	IP02 Cart encoder position measurement.
4	Terminal Board: Encoder Input #1	LFJC-E *Cart Encoder* connector	LFJC-E Cart encoder position measurement.

Table 5.2: LFJC-E Wiring

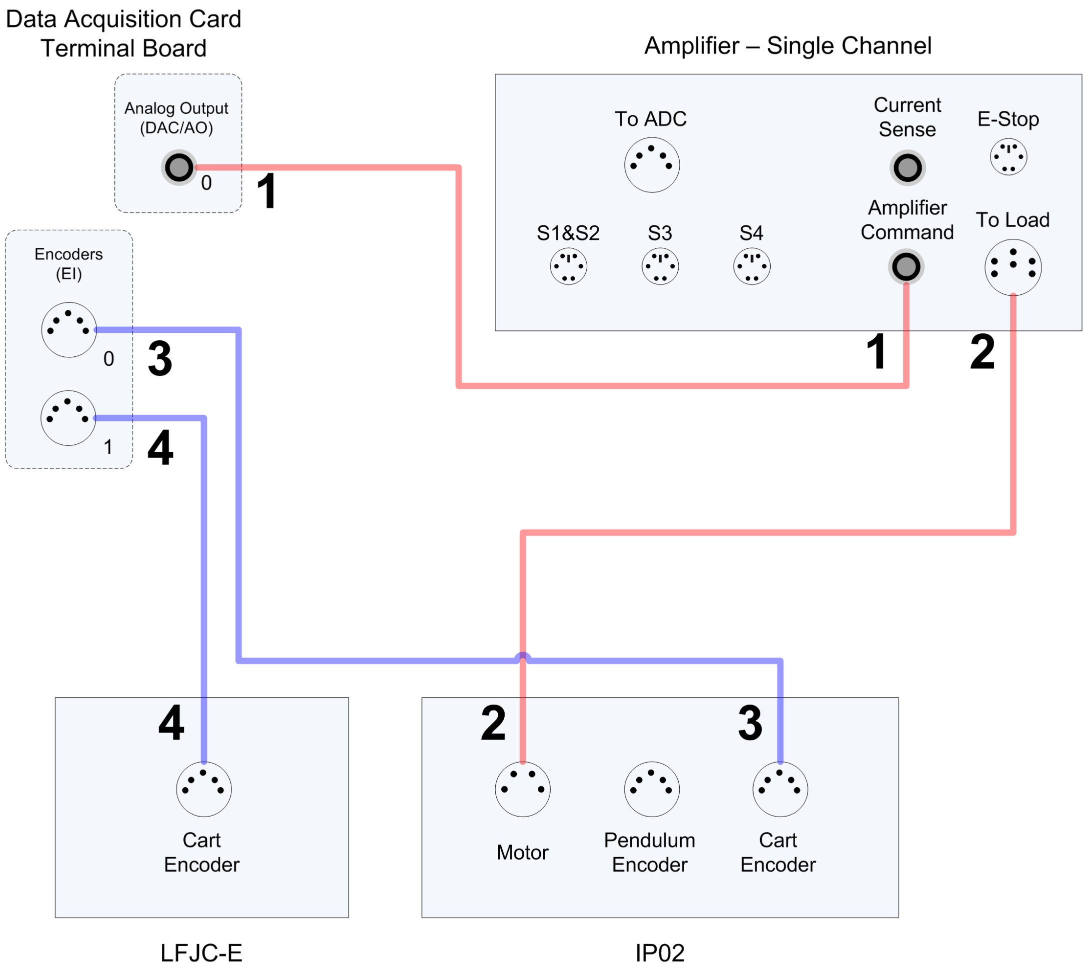


Figure 5.1: Connecting the LFJC module to a Single-Channel Amplifier and Two-Channel DAQ

Follow these steps to connect the LFJC system:

1. Make sure that your data-acquisition device is installed and is operational. For example, if using the Quanser Q2-USB see Reference [4].
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 end of the 2xRCA to 2xRCA cable from the Analog Output Channel #0 on the terminal board to the *Amplifier Command* connector on the amplifier, i.e. use both white or both red RCA connectors. 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 that is labeled 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 SRV02 motor and is denoted V_m.
5. Connect the 5-pin-stereo-DIN to 5-pin-stereo-DIN cable from the *Cart Encoder* connector on the IP02 panel to Encoder Input # 0 on the terminal board, as depicted by connection #3 in Figure 5.1. This carries the IP02 cart position measurement.
6. Connect the 5-pin-stereo-DIN to 5-pin-stereo-DIN cable from the *Cart Encoder* connector on the LFJC-E panel to Encoder Input # 1 on the terminal board, as depicted by connection #4 in Figure 5.1. This carries the LFJC cart position measurement.

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

6 TESTING AND TROUBLESHOOTING

This section describes some functional tests to determine if your IP02 is operating normally. It is assumed that the IP02 is connected as described in the Section 5, above. 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. See Reference [2] to learn how to interface the LFJC-E with QUARC. Alternatively, these tests can be performed with a signal generator and an oscilloscope.

6.1 IP02 Motors and Sensors

See the *IP02 User Manual* [3] for more information on testing and troubleshooting the IP02 seperately.

6.2 Encoder

6.2.1 Testing

Follow this procedure to test the LFJC-E encoder:

1. Measure Encoder Input Channel #0 using, for instance, the QUARC software.
2. Move the LFJC-E cart towards the right side of the track. This motion should result in a positive change in the cart encoder counts at a rate of +4096 counts per rotation.

   Note: Some data acquisition systems do not measure in quadrature and, in this case, one-quarter of the expected counts are received. 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.

6.2.2 Troubleshooting

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.

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] US Digital. *E2 Optical Kit Encoder*, 2007.

[2] Quanser Inc. *IP02 QUARC Integration*, 2008.

[3] Quanser Inc. *IP02 User Manual*, 2009.

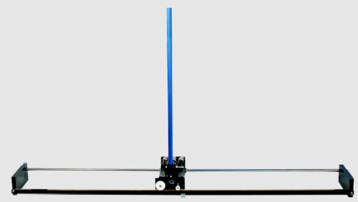
[4] Quanser Inc. *Q2-USB Data-Acquisition System User's Guide*, 2010.

Nine linear motion plants for teaching fundamental and advanced controls concepts

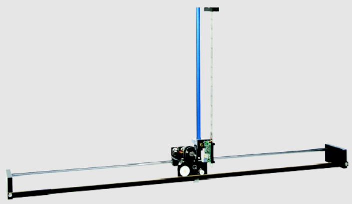
IP02 Base Unit

Linear Flexible Joint

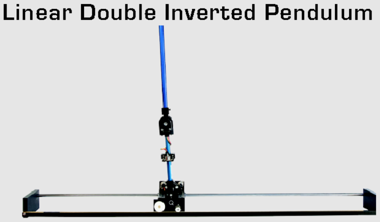
Linear Pendulum



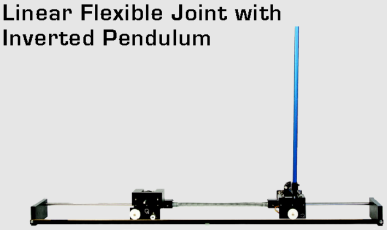
Linear Flexible Inverted Pendulum



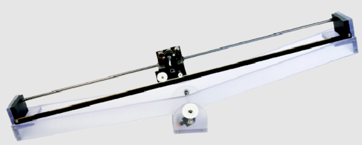
Linear Double Inverted Pendulum



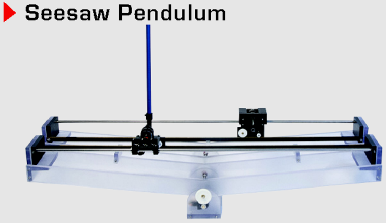
Linear Flexible Joint with Inverted Pendulum



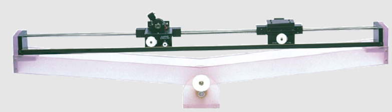
Seesaw



Seesaw Pendulum



Linear Flexible Joint on Seesaw



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