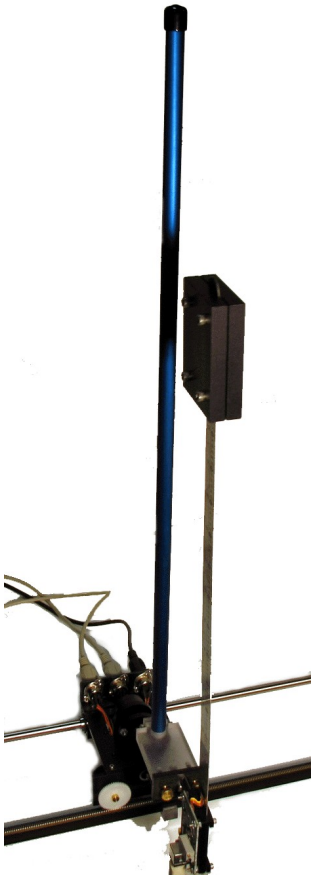
Linear Motion Servo Plant: IP02

Flexible Pendulum (FLEXPEN)



User Manual

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1. Flexible Pendulum (FLEXPEN) Experiment

1.1. System Description

The stiff pendulum is the blue rod shown in Figure 1 that is used in other IP02 experiments and is described in Reference [3]. The flexible pendulum is comprised of a flexible link attached with an end weight and it has a strain gage that measures the deflection of the link. In this document, the FLEXPEN refers to both the stiff and flexible pendula together and the IP02+FLEXPEN is the experiment shown in Figure 1.

The general system description, component nomenclature, specifications, and model parameters is described in Section 2. How to setup the hardware, calibrate the strain gage, and perform the wiring setup is all given in Section 3.

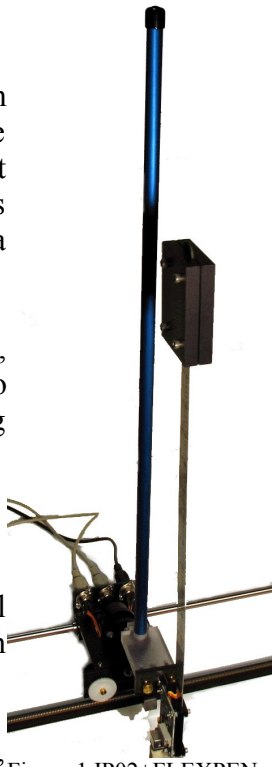

Figure 1 IP02+FLEXPEN experiment.

1.2. Control Challenge

The challenge in this laboratory is to design a state-feedback control system that keeps both a stiff pendulum and a flexible pendulum balanced using a linear cart, as depicted in Figure 1.

The system is supplied with a state-feedback controller but, of course, you may design any other controller you wish. The complete mathematical modelling and system parameters are provided to streamline the implementation of the control theory of your choice. The IP02 Flexible Pendulum – Laboratory Manual describes the modeling, designs a controller, and shows the obtained results when running the feedback control on the Flexible Pendulum device.

2. System Description

2.1. Flexible Pendulum Components

Figure 2 shows the IP02 cart attached with the flexible pendulum assembly. The components comprising FLEXPEN system labeled in Figure 2 are described in Table 1. For more information on the IP02 components see Reference [2].

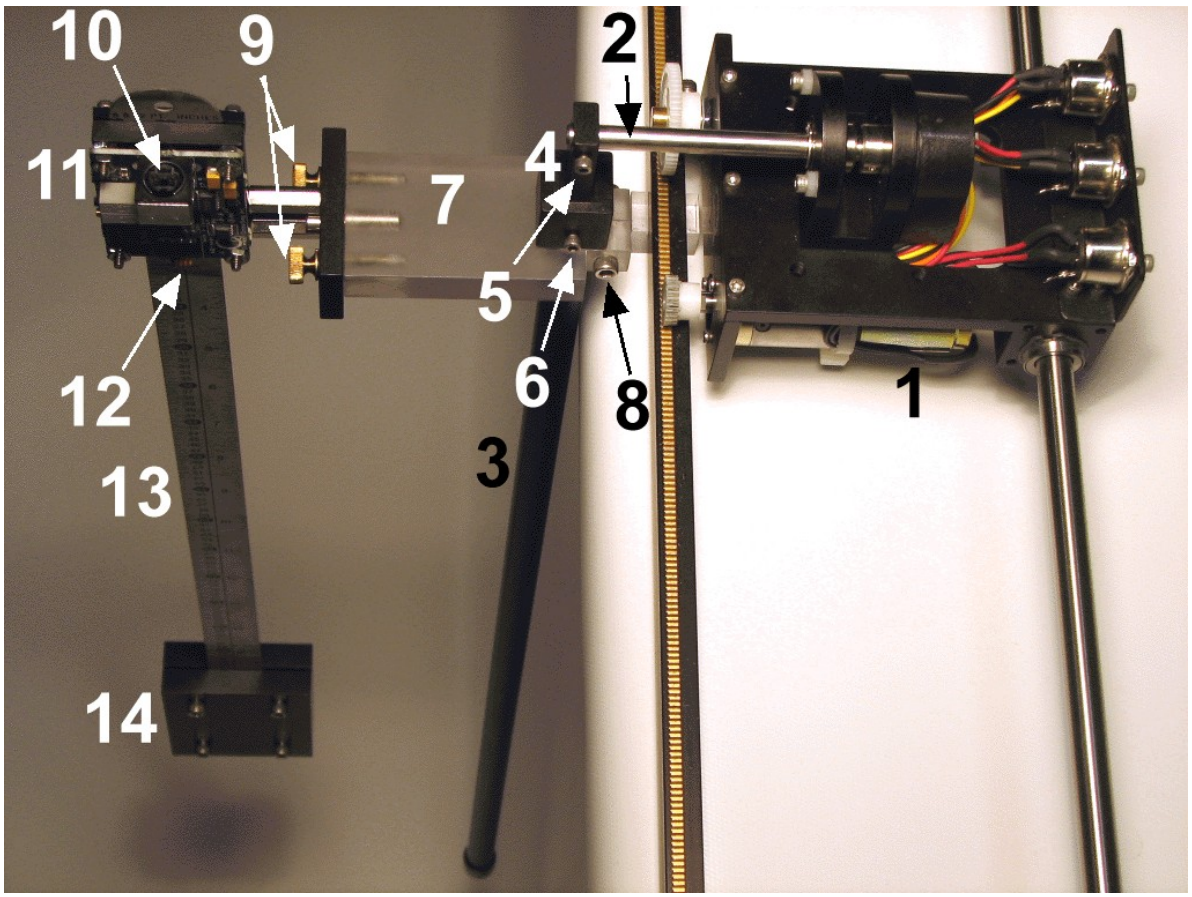

Figure 2 Components of IP02+FLEXPEN system.

ID #	Description	ID #	Description
1	IP02 cart system	8	Flexpen connector set screw: (9/64)"
2	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 set screw: (3/32)"	12	Strain gage.
6	Rod set screw: (3/32)"	13	Flexible pendulum link.
7	Flexible pendulum connector (i.e. flexpen connector).	14	Flexible pendulum weight.

Table 1 IP02+FLEXPEN System Component Nomenclature

2.2. System Specifications and Model Parameters

See Reference [2] for the IP02 cart model parameters. Table 2 below lists the main parameters associated with the Flexible Pendulum experiment. Some of these are used in the mathematical modeling. The model parameters of the long 24-inch pendulum that are used in this experiment are also listed in the table but see Reference [3] for details on the rigid pendulum.

Symbol	Matlab Notation	Description	Value	Unit
M_{sp}	Msp	Stiff pendulum mass.	0.230	kg
l_{sp}	lsp	Stiff pendulum center-of-mass from pivot.	0.3302	m
J_{sp}	Jsp	Stiff pendulum moment of inertia about center-of-mass.	0.0079	$kg.m^2$
B_{sp}	Bsp	Stiff pendulum viscous damping.	0.00	N.m.s/rad
M_{fp}	m_flexpen	Mass Flexible pendulum mass.	0.458	kg
l_{fp}	l_flexpen_cm	Flexible pendulum center-of-mass from pivot.	0.273	m

Symbol	*Matlab Notation*	*Description*	*Value*	*Unit*
$J_{fp,pivot}$	J_flexpen_pivot	Flexible pendulum moment of inertia about pivot point.	0.0432	$kg.m^2$
J_{fp}	J_flexpen_cm	Flexible pendulum moment of inertia about center-of-mass.	0.0094	$kg.m^2$
B_{fp}	B_flexpen	Flexible pendulum viscous damping.	0.00	N.m.s/rad
m_{link}	m_link	Mass of the flexible link.	0.0650	kg
$m_{link,s}$	m_link_s	Mass of flexible link with strain gage module attached (strain gage itself and circuitry).	0.1570	kg
m_{weight}	m_weight	Mass of flexible pendulum weight.	0.2560	kg
m_{con}	m_connector	Mass flexible pendulum connector.	0.0450	kg
P_SG	P_SG	Position on flexible link where strain gage begins to measure.	0.0825	m
$L_{sg,pivot}$	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}	L_link	Length from P_SG sensor to the tip of flexible link.	0.3937	m
l_{link}	l_cm_link	Length from pivot to the center-of-mass of link.	0.1873	m
$l_{link,s}$	l_cm_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}	L_sw	Length from strain gage to start of weight.	0.3588	m
L_{weight}	L_weight	Length of flexible pendulum weight.	0.0762	m

Symbol	*Matlab Notation*	*Description*	*Value*	*Unit*
l_{weight}	l_cm_weight	Length from pivot to center-of-mass of flexible pendulum weight.	0.3969	m
f_n	fn	Natural frequency of link with weight attached.	1.25	Hz
ω_n	wn	Natural frequency of link with weight attached.	7.85	rad/s
K_s	Ks	Flexible link stiffness.	2.67	N.m/rad
K_SG	K_SG	Strain gage sensitivity.	1.00	in/V
K_GAGE	K_GAGE	Angle of deflection from stain gage sensitivity.	0.065	rad/in
V_{bias}	V_bias	Strain gage bias power.	±12.0	V
V_{range}	V_range	Strain gage measurement range.	±5.0	V

Table 2 FLEXPEN Model Parameters and System Specifications

3. FLEXPEN Experiment Setup

3.1. Strain Gage Calibration

See Reference [8] for the procedure to calibrate the strain gage on the flexible link.

3.2. Hardware Setup

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

1. Fasten the flexpen connector, ID #7 in Figure 2, above, 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.
2. 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, to fasten the flexible pendulum on the bracket.
3. Attach the T-fitting pivot of the long 24-inch pendulum to the tip of the IP02 cart's

pendulum axis (ID #2), as illustrated in Figure 2. Gently tighten the axis screw, ID #5 shown in Figure 2, as needed to ensure the pendulum is properly fastened to the metal shaft. See Section 4.2 in Reference [3] for details.

4. **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 both pendula. Further, not having the clamps introduces vibrations into the system that may cause bad performance or instability.

3.3. Typical Wiring

Follow this wiring procedure for the IP02+FLEXPEN:

1. Follow the default wiring procedure described in Reference [2]. It describes the details of wiring the IP02 motor and encoders. Table 3 gives a summary of the connections.
2. Connect the **"From ADC"** socket on the amplifier to Analog Inputs #0-3 using the 5-pin-DIN to 4xRCA cable, as illustrated in Figure 3. **Ensure amplifier and PC are off when making this connection.** The signal connected to the S1 & S2 terminal on the amplifier is read in as Analog Input #1 in QUARC. The wiring is summarized in Table 3.
3. Connect the analog connector on the strain gage of the flexible pendulum, ID #10 in Figure 2, 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 3. **Ensure the amplifier is not powered when making this connection.**

Cable #	*From*	*To*	*Function*
1	Terminal Board: Analog Output #0	Amplifier: "Amplifier Command" Connector	Control signal generated by controller running on PC.
2	Amplifier: "To Load" Connector	IP02: “Motor” Connector	Amplified control signal applied to IP02 motor, V_m.
3	Amplifier: "To ADC" connector	Terminal Board: Analog Input Channels #0-3	Carries strain gage analog signal to data acquisition board.
4	IP02: Cart Encoder Connector	Terminal Board: Encoder #0	Measures the linear position of the cart, x_c.
5	IP02: Pendulum Encoder Connector	Terminal Board: Encoder #1	Measures the front pendulum angle, α.

Cable #	*From*	*To*	*Function*
6	Flexible Pendulum: Strain Gage Analog Connector	Amplifier: "S1 & S2" Connector	Measures the angular deflection of the flexible pendulum, γ.

Table 3 IP02+FLEXPEN Wiring Summary

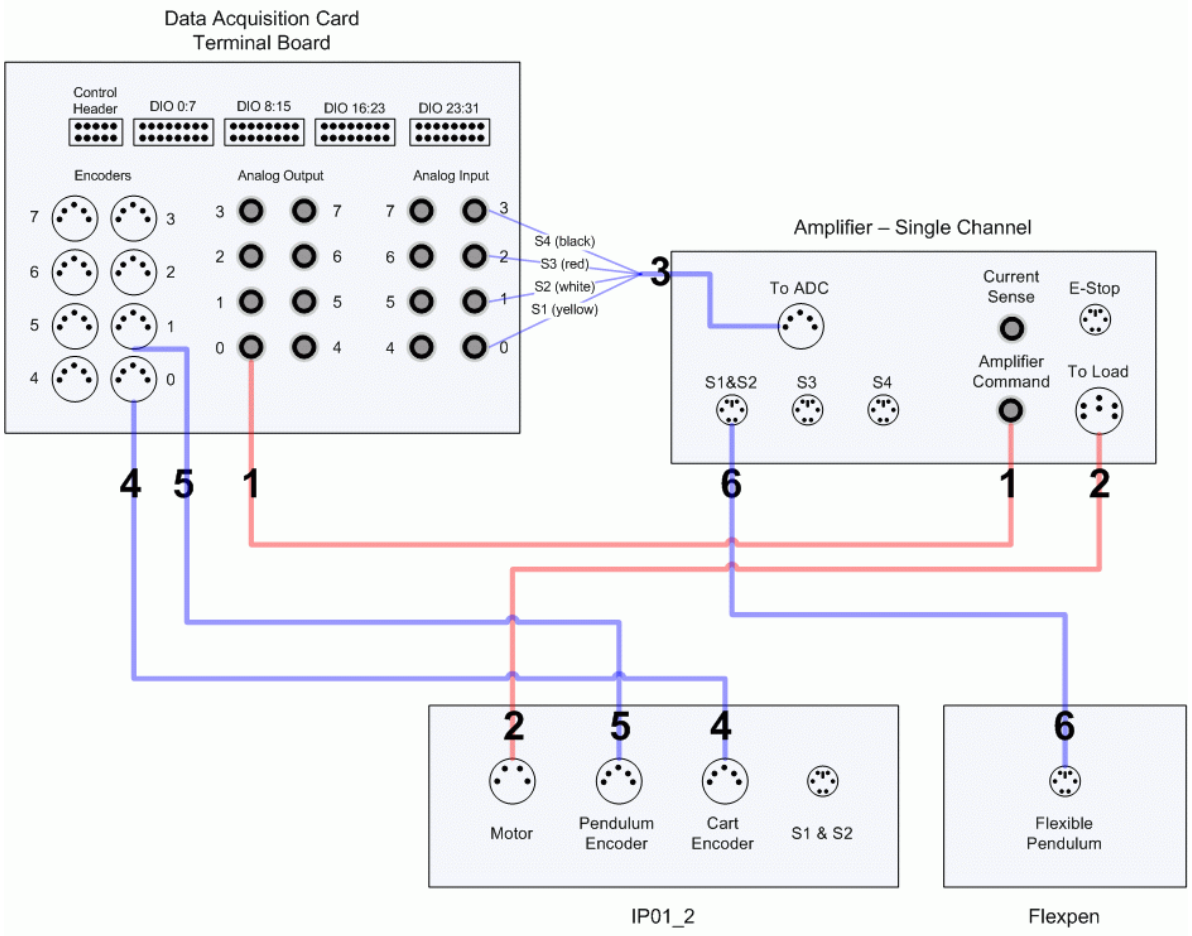

Figure 3: Connections between Quanser Flexible Pendulum, power amplifier, and DAQ board.

3.3.1. Special Case: Wiring with Q3 ControlPAQ-FW

Follow the wiring described in Table 4 and shown in Figure 4 when connecting the IP02+FLEXPEN to the Quanser Q3 ControlPAQ-FW device.

Cable #	*From*	*To*	*Function*
1	Q3: "Motor 0" Connector	IP02: “Motor” Connector	Amplified control signal applied to IP02 motor, V_m.
2	IP02: Cart Encoder Connector	Q3: “Encoder 0” connector	Measures the linear position of the cart, x_c.
3	IP02: Pendulum Encoder Connector	Q3: “Encoder 1” connector	Measures the front pendulum angle, α.
4	Flexpen: Strain Gage Connector	Q3: "Analog Input" Connector	Measures the angular deflection of the flexible pendulum, γ.

Table 4 IP02+FLEXPEN Wiring Summary

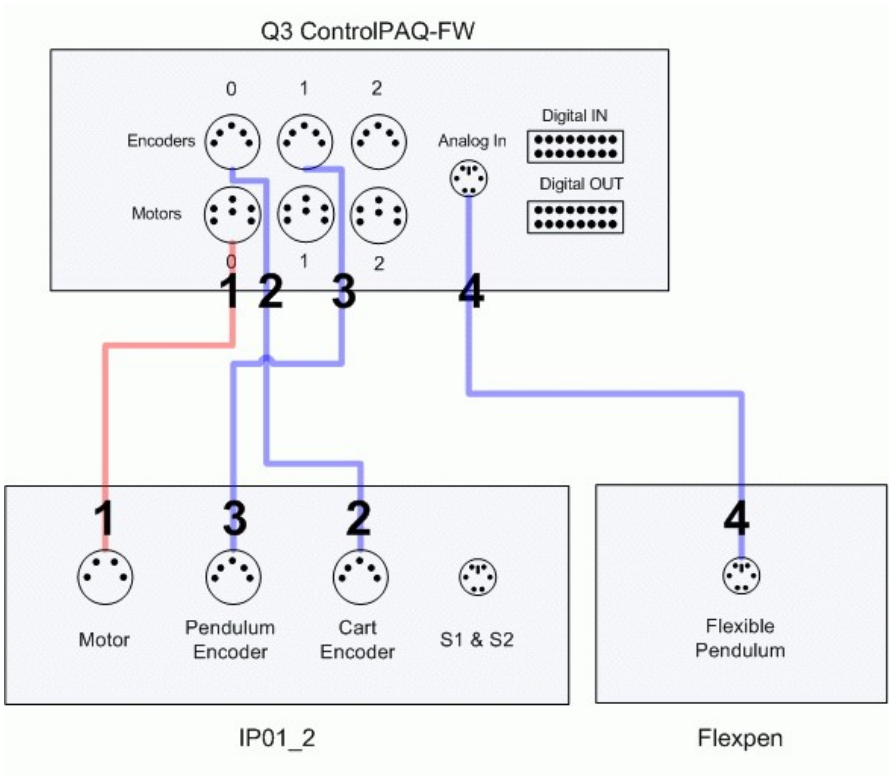

Figure 4: IP02+FLEXPEN wiring to Q3 ControlPAQ-FW.

4. Obtaining Support

Note that a support contract may be required to obtain 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 requested software version and hardware information and a description of the problem encountered. Submit the form. Be sure to include your email address and a telephone number where you can be reached. A qualified technical support person will contact you.

5. References

[1] IP01 and IP02 – Linear Experiment #0: Integration with QUARC – Student Handout.
[2] IP01 and IP02 User Manual.
[3] IP01 and IP02 – Single Inverted Pendulum User Manual.
[4] Data Acquisition User Manual.
[5] Power Amplifier User Manual.
[6] QUARC User Manual (type `doc quarc` in Matlab to access)
[7] IP01 and IP02 – Single Inverted Pendulum – Linear Experiment #5: LQR Control – Student Handout.
[8] SRV02 Rotary Flexible Link User Manual.
[9] IP02 Flexible Pendulum – Laboratory Manual