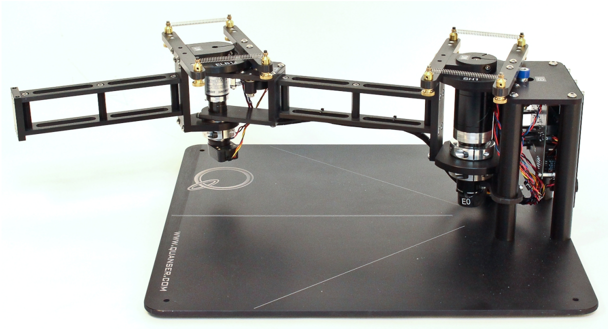
2-DOF Serial Flexible Joint Robot



User Manual

2DSFJE

Quanser Inc.

2015

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1 PRESENTATION

The 2-Degree-Of-Freedom (DOF) Serial Flexible Joint (2DSFJ) Robot is depicted in Figure 1.1. This robot system consists of two DC motors driving harmonic gearboxes (zero backlash) and a two-bar serial linkage. Both links are rigid. The primary link is coupled to the first drive by means of a flexible joint. It carries at its end the second harmonic drive which is coupled to the second rigid link via another flexible joint. Both motors and both flexible joints are instrumented with quadrature optical encoders. Each flexible joint uses two springs that can be changed. A thumbscrew mechanism is available to move each spring end to different anchor points along its support bars, as desired.

The described robotic mechanism emulates torsional compliance and joint flexibility, which are common characteristics in mechanical systems such as high-gear-ratio harmonic drives and lightweight transmission shafts.

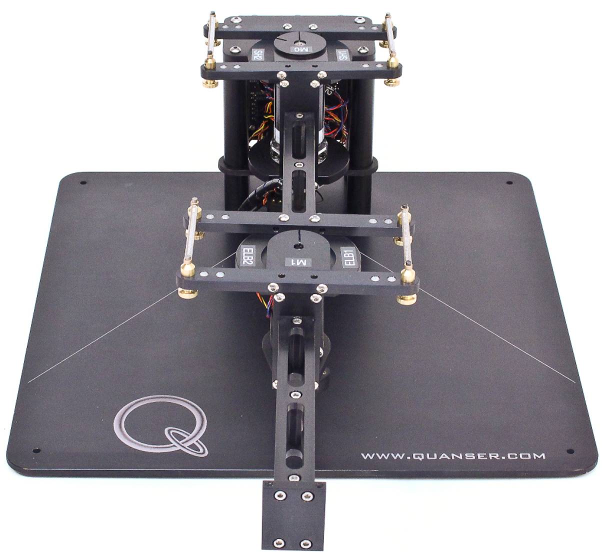


Figure 1.1: 2-DOF Serial Flexible Joint Robot

■ **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 2-DOF Serial Flexible Joint Robot components are identified in Section 2.1, and described in more detail in Section 2.2.

2.1 Component Nomenclature

Table 2.1 provides a list of all the principal elements of the 2-DOF Serial Flexible Joint Robot plant. Every element is located and identified, through a unique identification (ID) number, as represented in Figure 2.1.

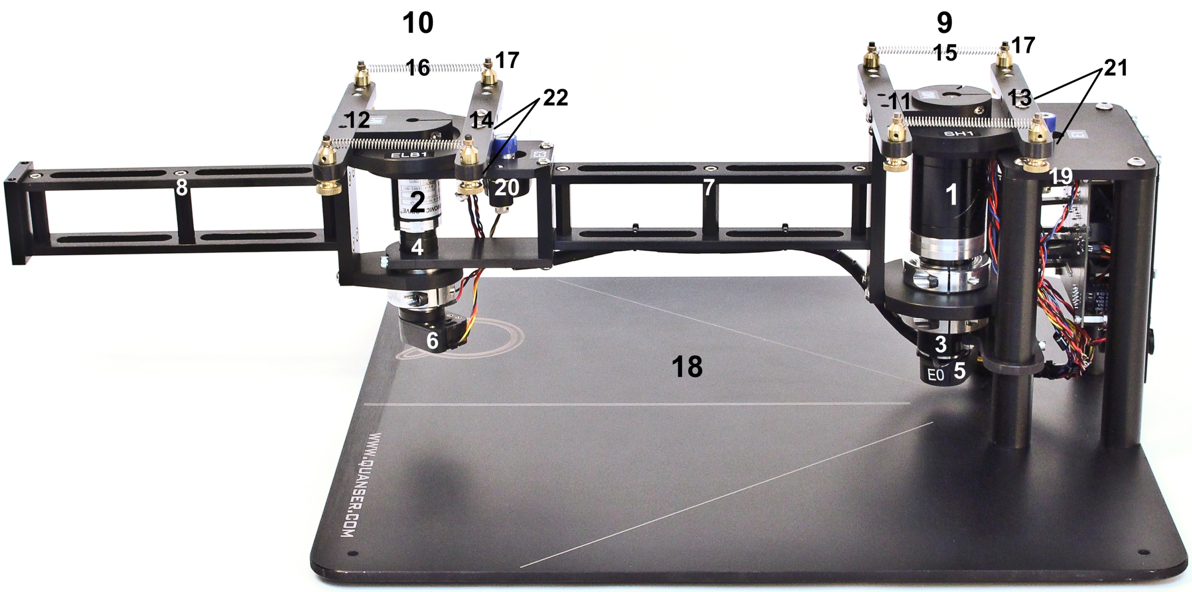


Figure 2.1: 2-DOF Serial Flexible Joint Robot

ID	Description	ID	Description
1	Harmonic Drive #1 (Shoulder)	12	Flexible Joint #1 Load Transition
2	Harmonic Drive #2 (Elbow)	13	Flexible Joint #2 Actuated Transition
3	DC Motor #1 (Shoulder)	14	Flexible Joint #2 Load Transition
4	DC Motor #2 (Elbow)	15	Flexible Joint #1 Spring
5	Motor #1 Encoder	16	Flexible Joint #2 Spring
6	Motor #2 Encoder	17	Spring Fixture Mechanism
7	Rigid Link #1	18	Base Plate
8	Rigid Link #2	19	Flexible Joint #1 Encoder
9	Flexible Joint Assembly #1	20	Flexible Joint #2 Encoder
10	Flexible Joint Assembly #2	21	Flexible Joint #1 Limit Switches
11	Flexible Joint #1 Actuated Transition	22	Flexible Joint #2 Limit Switches

Table 2.1: 2-DOF Serial Flexible Joint Robot Component Nomenclature

Table 2.2 provides a list of all the principal elements composing the 2DSFJ Robot connection back plate. Every element is located and identified, through a unique identification (ID) number, as represented in Figure 2.2.

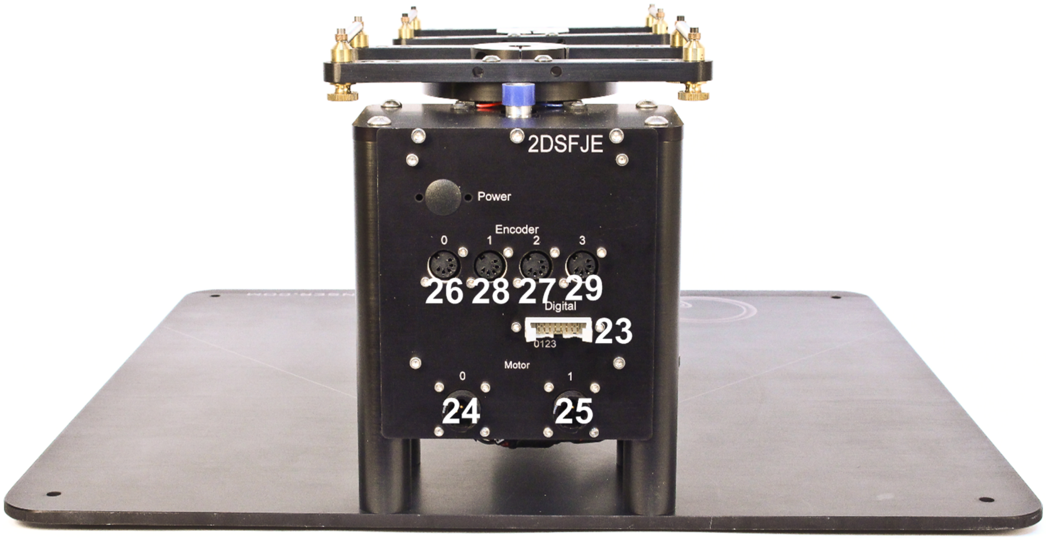


Figure 2.2: 2DSFJ Robot Connection Panel

ID	Description	ID	Description
23	Limit Switch Connector	**27**	Motor #2 Encoder Connector
24	Motor #1 Lead Connector	**28**	Flexible Joint #1 Encoder connector
25	Motor #2 Lead Connector	**29**	Flexible Joint #2 Encoder Connector
26	Motor #1 Encoder Connector		

Table 2.2: 2DSFJ Robot Connection Panel Component Nomenclature

2.2 Component Description

This Section provides a description of the individual elements comprising the 2-DOF Serial Flexible Joint Robot.

■ **Caution:** *Exposed moving parts.*

2.2.1 DC Motor #1

The first DC motor is a Maxon 273759 precision brush motor (90 Watts) operating at 27 V max. The motor offers a peak current of 3 A, with a maximum continuous current of 1.2 A.

■ **Caution:** *High Frequency signals applied to a motor will eventually damage the motor brushes. The most likely source for high frequency noise is derivative feedback. If the derivative gain is too high, a noisy voltage will be fed into the motor. To protect your motor, you should always band limit your signal (especially derivative feedback) to a value of* **50Hz**.

2.2.2 Harmonic Drive #1

The harmonic drive #1 uses the harmonic gear head CS-14-100-1U-CC-SP from Harmonic Drive LLC. It offers zero backlash for a gear ratio of 100:1.

2.2.3 DC Motor #2

The first DC motor is a Maxon 118752 precision brush motor (20 Watts) operating at 27 V max. The motor offers a peak current of 3 A, with a maximum continuous current of 1.2 A.

■ **Caution:** *High Frequency signals applied to a motor will eventually damage the motor brushes. The most likely source for high frequency noise is derivative feedback. If the derivative gain is too high, a noisy voltage will be fed into the motor. To protect your motor, you should always band limit your signal (especially derivative feedback) to a value of* **50Hz**.

2.2.4 Harmonic Drive #2

The harmonic drive #2 uses the harmonic gear head CS-8-50-1U-CC-SP from Harmonic Drive LLC. It offers zero backlash for a gear ratio of 50:1.

2.2.5 Motor and Joint Position Measurement: Optical Encoders

Digital angular position measurement of both motors and both flexible joints are obtained by using high-resolution quadrature optical encoders from US Digital. All encoders have 1024 lines per revolution.

2.2.6 Joint Position Limit Switches

As a safety precaution, two limit switches are installed at the minimum and maximum rotational positions of each of the two flexible joints. They are magnetically-operated position sensors powered by an external ±15 VDC power supply which connects to component #23 in Figure 2.2. Specifically, they are the Hamlin 55100 Mini Flange Mount Hall Effect Sensors.

2.2.7 Flexible Joint Springs

The 2DSFJ is provided with three pairs of extension springs, each of which has a different stiffness. Therefore, each flexible joint stiffness can be reconfigured by swapping pairs of springs. All the linear springs are from Associated Spring Raymond. Specifically, their model numbers are: E02040-026-1500S, E0240-029-1500S, and E0240-031-1500S. Spring specifications are given in Table 2.4. The factory default configuration for the 2DSFJ system uses the strongest pair of springs for the first flexible joint (a.k.a shoulder) and the lightest pair for the second flexible joint (a.k.a. elbow).

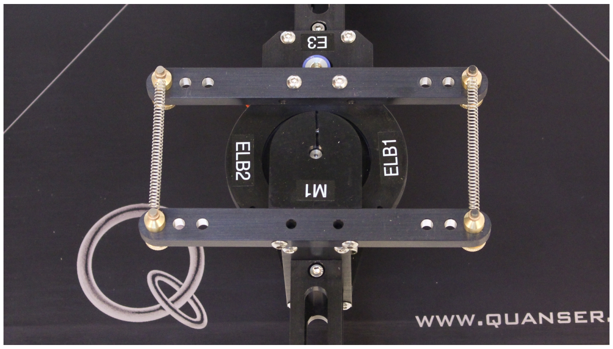


Figure 2.3: Flexible Joint: Default Spring Configuration

The two springs of the flexible joint as illustrated in Figure 2.3 are set up in their default configuration. Both extension springs are mounted on the outer holes of the two opposed support bars of the flexible joint.

Table 2.3 provides the characteristic dimensions of the spring mounting holes in the flexible joint.

Joint Dimensions	Symbol	Value	Unit
Distance from The Joint Centerline To The Outer Hole	d_1	86.36	mm
Radius From The Joint Axis Of Rotation To The Outer Hole	r_1	97.60	mm
Distance From The Joint Centerline To The Middle Hole	d_2	73.66	mm
Radius From The Joint Axis Of Rotation To The Middle Hole	r_2	85.56	mm
Distance From The Joint Centerline To The Inner Hole	d_3	60.96	mm
Radius From The Joint Axis Of Rotation To The Inner Hole	r_3	74.91	mm

Table 2.3: Flexible Joint Dimensions

The flexible joint torsional stiffness, K_s, with its two linear springs in the default configuration can be approximated by the following equation:

$$K_s = 2\,K_r\,r_1\,d_1$$

where K_r is the spring rate (a.k.a stiffness constant), as defined in Table 2.4.

Extension Spring E0240-031-1500S:	**Value**	**Unit**
Outside Diameter	0.24	in
Wire Diameter	0.031	in
Free Length (Approximated)	1.5	in
Extended Length	2.64	in
Load At Extended Length	4.415	lb
Initial Tension	0.416	lb
Spring Rate,K_r	3.5	lb/in
Extension Spring E0240-029-1500S:		
Outside Diameter	0.24	in
Wire Diameter	0.029	in
Free Length (Approximated)	1.5	in
Entended Length	2.89	in
Load At Extended Length	3.749	lb
Initial Tension	0.333	lb
Spring Rate, K_r	2.42	lb/in
Extension Spring E0240-026-1500S:		
Outside Diameter	0.24	in
Wire Diameter	0.026	in
Free Length (Approximated)	1.5	in
Extended Length	3.28	in
Load At Extended Length	2.749	lb
Initial Tension	0.249	lb
Spring Rate, K_r	1.33	lb/in

Table 2.4: Extension Spring Specifications

3 MODEL PARAMETERS

Table 3.1, below, lists and characterizes the main parameters associated with the 2-DOF Serial Flexible Joint Robot. Some of these parameters can be used for mathematical modeling of the plant as well as to obtain system equations of motion.

Description	**Value**	**Unit**
Flexible Joint #1 System:		
Motor #1 Torque Constant	0.119	N-m/A
Motor #1 Back-EMF Constant	0.119	V.s/rad
Motor #1 Maximum Continuous Current	0.944	A
Motor #1 Armature Resistacne	11.5	Ω
Drive #1 Armature Inductance	3.16	mH
Harmonic Drive #1 Gear Ratio	100	
Motor #1 Rotor Moment Of Inertia At Motor Shaft	6.28E-6	kg-m^2
Moment Of Inertia Of Drive #1 Transition System	930.91E-6	kg-m^2
Moment of Inertia Of Compounded Load transition System	0.23041858	kg-m^2
Flexible Joint #1 Torsional Stiffness Constant (With Strongest Spring In The Default Position)	9.0	N-m/rad
Motor #1 Mechanical Time Constant	5	ms
Flexible Joint #2 System:		
Motor #2 Torque Constant	0.0234	N-m/A
Motor #2 Back-EMF Constant	0.0234	V-s/rad
Motor #2 Maximum Continuous Current	1.21	A
Motor #2 Armature Resistance	2.32	Ω
Drive #2 Armature Inductance	0.24	mH
Harmonic Drive #2 Gear Ratio	50	
Motor #2 Rotor Moment Of Inertia At Motor Shaft	1.03E-6	kg-m^2
Moment Of Inertia Of Drive #2 Transition System	930.91E-6	kg-m^2
Moment Of Inertia Of Load #2 Transition System	0.010724	kg-m^2
Flexible Link #2 Torsional Stiffness Constant	4.0	N-m/rad
Motor #2 Mechanical Time Constant	4	ms
Linear Current Amplifier (Each Channel):		
Linear Amplifier Maximum Continuous Current	3	A
Linear Amplifier Peak Current	5	A
Linear Amplifier Maximum Continuous Voltage	28	V
Linear Amplifier Peak Power	300	W
Linear Amplifier Bandwidth (Current Mode)	10	kHZ
Linear Amplifier Gain	0.5	A/V

Description **Drive & Joint Optical Encoders:**	Value	Unit
Encoder Line Count	1,024	lines/rev
Encoder Resolution (In Quadrature)	4,096	counts/rev
Encoder Angular Resolution (In Quadrature)	0.0015	rad/count
Drive #1 Encoder Sensitivity (In Quadrature)	1.524E-5	rad/count
Drive #2 Encoder Sensitivity (In Quadrature)	1.918E-5	rad/count
Flexible Joint Encoder Sensitivity (In Quadrature)	23.968E-5	rad/count
Encoder Type	TTL	
Encoder Signals	A,B, Index	
External Power Supply:		
Power Supply Power	42	W
Power Supply Voltage	$\pm$15	VDC
Current Sense:		
Current Sense Calibration At $\pm$10%	2.0	V/A

Table 3.1: Two-Degree-Of-Freedom Serial Flexible Joint System Specifications

The 2-DOF Serial Flexible Joint Robot main device dimensions and workspace are given in Table 3.2.

Description **Device Geometry**	Value	Unit
Base Plate Length	0.508	m
Base Plate Width	0.508	m
Device Height	0.240	m
2-DOF Flexible Link Total Length	0.610	m
Link #1 Length (From Drive #1 To Drive #2 Shafts)	0.343	m
Link #2 Length (End-Effector Arm) Length	0.267	mm
Maximum Payload (At Link #2 End-Effector)	1.0	kg
Workspace From Mid-Range Position:		
Flexible Joint #1 Maximum Rotation	90	degrees
Flexible Joint #1 Minimum Rotation	-90	degrees
Flexible Joint #2 Maximum Rotation	90	degrees
Flexible Joint #2 Minimum Rotation	-90	degrees

Table 3.2: Two-Degree-Of-Freedom Serial Flexible Joint Robot Dimensions

4 SYSTEM SETUP

4.1 Setting Up The Springs On The Flexible Joint

Three pairs of springs of different stiffnesses are provided with the 2-DOF Serial Flexible Joint Robotsystem.

The procedure to mount the linear springs on the flexible joint is as follows:

1. For each of the two flexible joint, position the four spring anchor mechanisms into the desired mounting holes located on the support bars. Do so by using the anchor thumbscrews. Installed spring anchors can be seen in Figure 4.2.
2. Insert the spring support posts into the previously positioned anchor devices. One of the posts is depicted in Figure 4.1.

Figure 4.1: Spring Mounting Post

3. Insert each spring end hook onto each support post. Then also insert the brass retainer on top of the spring hook. This is illustrated in Figure 4.2. The resulting spring assembly should be similar to the one shown in Figure 4.3.

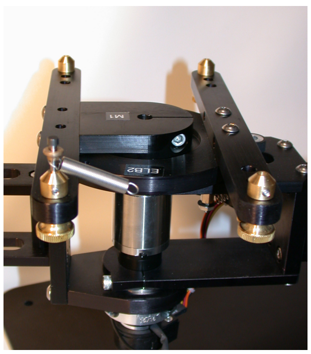


Figure 4.2: Inserting One Spring And Retainer

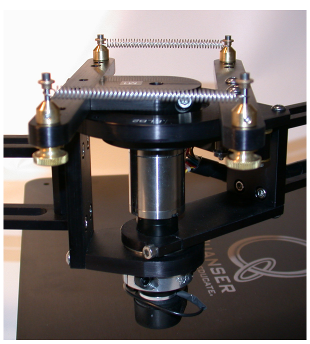


Figure 4.3: Intermediary Spring Assembly

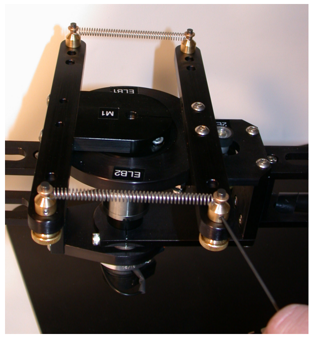


Figure 4.4: tightening The Setscrews

4. Clamp all four mounting posts by tightening the corresponding set-screws. This is shown in Figure 4.4. To do so, use a (1/16)" Allen key.

5 WIRING PROCEDURE

This section describes the standard and common wiring procedure for the 2-DOF Serial Flexible Joint Robot. The hardware components used in this experiment are:

1. **Power Amplifier:** Quanser AMPAQ current amplifier, or equivalent.
2. **Data Acquisition Device:** Q8-USB, QPID/QPIDe, or equivalent.
3. **Experiment Platform:** Quanser 2-DOF Serial Flexible Joint Robot.

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

5.1 Cable Nomenclature

The different types of cables, which are supplied with the system, are described in Table 5.1. They are used in the wiring of the 2-DOF Serial Flexible Joint Robot system.

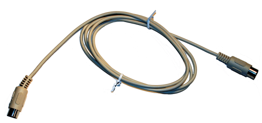
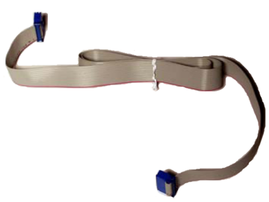
Cable	Type	Description
 (a) RCA Cable	2xRCA to 2xRCA	This cable connects a pair of analog outputs of the Data Acquisition Device (DAQ) to the Amplifier Input port for proper amplification. To monitor the current measurement signal another cable can be used to connect the Sense ports 0 and 1 on the AMPAQ [1] to analog input ports 0 and 1 on the Data Acquisition Device (DAQ).
 (b) AMPAQ to Motor Cable	AMPAQ to Motor Cable	This cable connects the output ports of the Amplifier (AMPAQ module), after amplification, to the desired DC motors on the 2DSFJ plant.
 (c) 5-pin-stereo-DIN to 5-pin-stereo-DIN	5-pin-stereo-DIN to 5-pin-stereo-DIN	This cable carries the encoder signals between an encoder connector on the plant and one on the DAQ. Namely, these signals are: +5VDC power supply, ground, channel A, and channel B. Typically connectors labeled Encoders 0, 1, 2 and 3 on the 2DSFJ plant are connected to Encoder input channels 0, 1, 2 and 3 on the Data Acquisition Device using 4 of these cables.
 (d) Digital Cable	Digital Signal Cable	This cable connects the limit switch digital signals on the 2DSFJ plant to the Digital Input connector on the DAQ. These limit switch signals are outlined in Table 5.3.

Table 5.1: Cable Nomenclature

5.2 Typical Connections

Please follow the wiring procedure detailed below in Table 5.2 and Table 5.3, and illustrated in Figure 5.1.

■ **Caution: Perform all connections with the PC, and the AMPAQ turned off.**

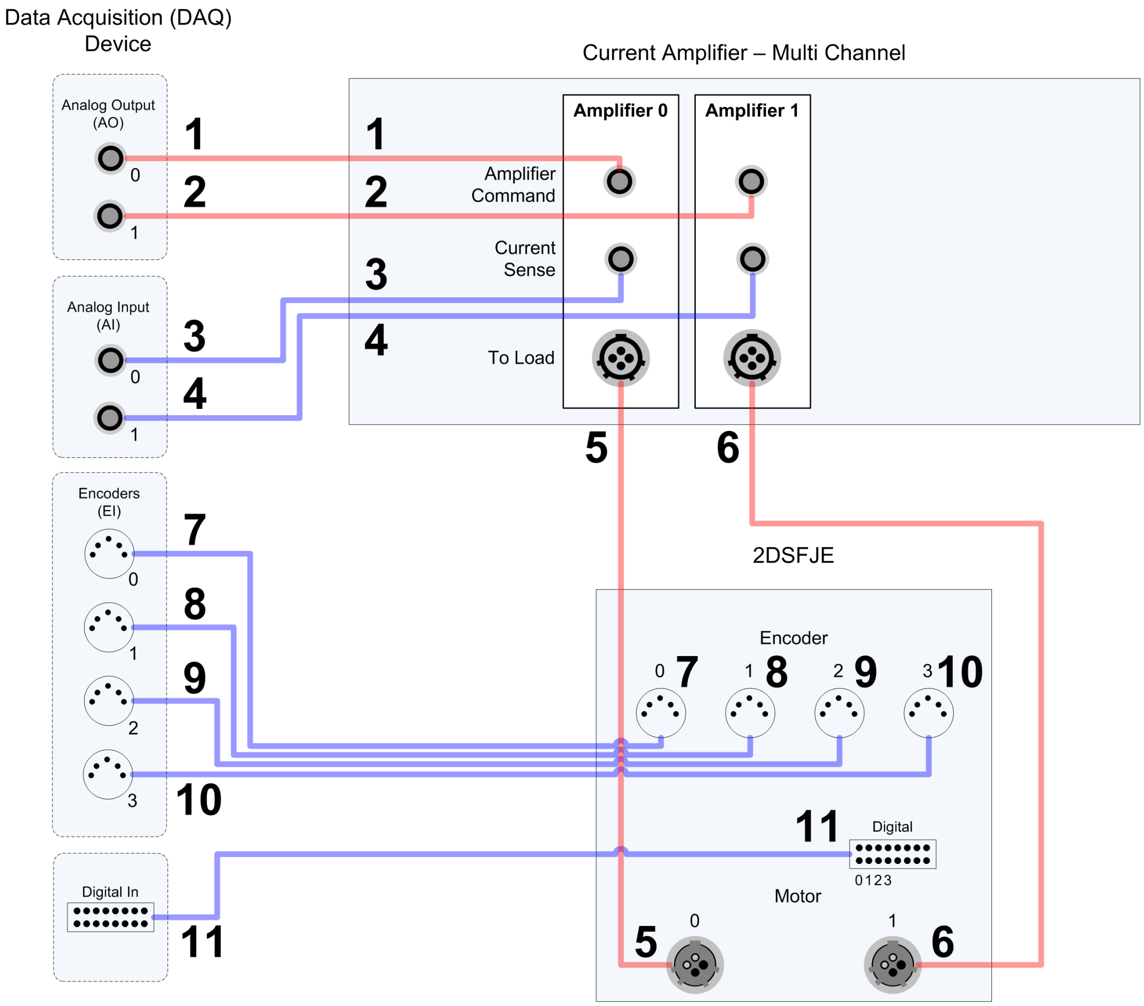


Figure 5.1: 2-DOF Serial Flexible Joint Robot Wiring Diagram

Cable	From	To	Signal
1	DAQ **Analog Output #0**	Amplifier **Command 0**	Motor 0 control signal to the amplifier.
2	DAQ **Analog Output #1**	Amplifier **Command 1**	Motor 1 control signal to the amplifier.
3	DAQ **Analog Input #0**	Amplifier **Current Sense 0**	Motor 0 current measurement signal from amplifier.
4	DAQ **Analog Input #1**	Amplifier **Current Sense 1**	Motor 1 current measurement signal from amplifier.
5	Amplifier **To Load #0**	2DSFJ **Motor #0**	Power leads to DC motor 0 (shoulder).
6	Amplifier **To Load #1**	2DSFJ **Motor #1**	Power leads to DC motor 1 (elbow).
7	DAQ **Encoder #0**	2DSFJ **Encoder #0**	Encoder motor 0 output shaft position signal.
8	DAQ **Encoder #1**	2DSFJ **Encoder #1**	Encoder joint 0 flexible joint position signal.
9	DAQ **Encoder #2**	2DSFJ **Encoder #2**	Encoder motor 1 output shaft position signal.
10	DAQ **Encoder #3**	2DSFJ **Encoder #3**	Encoder joint 1 flexible joint position signal.
11	DAQ **Digital In**	2DSFJ **Digital**	Digital limit switch signals from the 2DSFJ.

Table 5.2: 2-DOF Serial Flexible Joint RobotSystem Wiring Summary

Digital Channel	Signal	High: 1	Low: 0
Digital #8	Limit Switch #0 (SH1)	Inactivated	Activated
Digital #9	Limit Switch #1 (SH2)	Inactivated	Activated
Digital #10	Limit Switch #2 (ELB1)	Inactivated	Activated
Digital #11	Limit Switch #3 (ELB2)	Inactivated	Activated

Table 5.3: 2-DOF Serial Flexible Joint Robot Limit Switch Connections

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. *AMPAQ User Manual*, 2012.