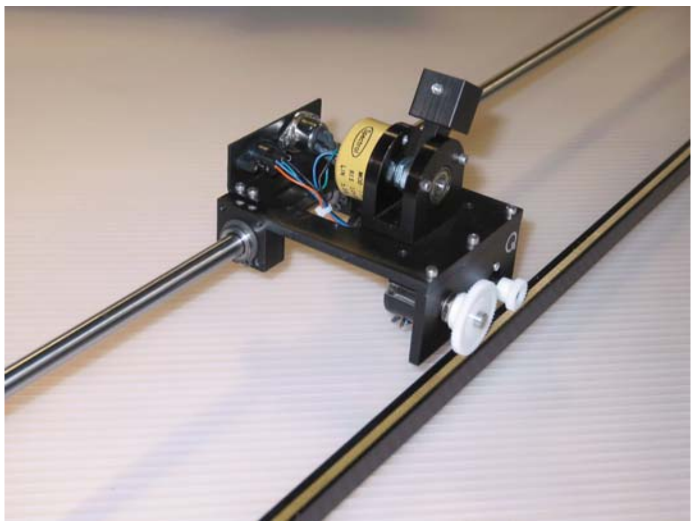
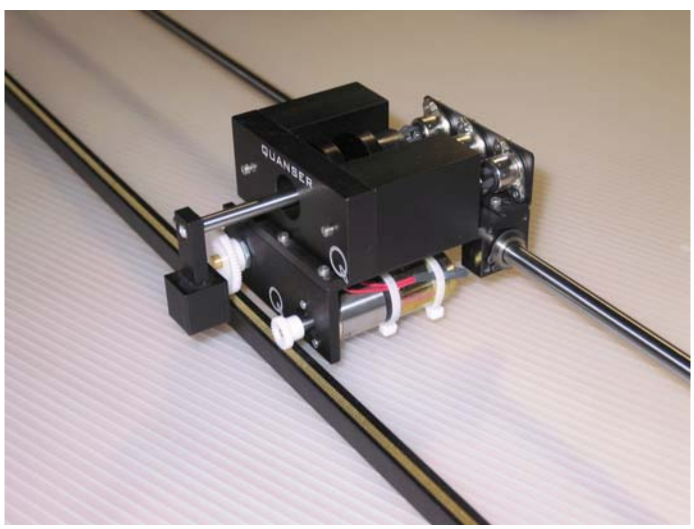
*Linear Motion Servo Plants: IP01 or IP02*

# *IP01 and IP02*






# User Manual

# Table of Contents

# 1. IP01 and IP02 Presentation

## 1.1. General Description

The IP01 and IP02 are fundamental modules for the linear motion experiments.
They consist of a precisely machined solid aluminum cart driven by a high quality DC motor equipped with a planetary gearbox. The cart slides along a stainless steel shaft using linear bearings. The cart is driven via a rack and pinion mechanism as opposed to belts or wheels, in order to eliminate slippage, belt stretching and other undesirable effects. This, therefore, ensures consistent and continuous traction.

The following sections provide more insight into the differences between the IP01 and IP02 and their applications.

## 1.2. IP01 (Inverted Pendulum) Particularities

A typical IP01 is depicted in Figure 1, below. In the case of the IP01, the cart position is sensed via a ten-turn potentiometer. The IP01 cart is also equipped with a rotary joint with ball bearings to which a free turning erected rod can be attached. This rod functions as an "inverted pendulum" in subsequent experiments. The angle of the rod is sensed using a conductive plastic potentiometer.

However, the IP01 pendulum cannot suspend in front of the cart. Should you wish to deploy the pendulum to conduct a full 360-degree rotation the IP02 should be utilized instead.

## 1.3. IP02 (Self-Erecting Inverted Pendulum) Particularities

A typical IP02 is depicted in Figure 2, below. The IP02 pendulum can suspend in front of the cart to perform self-erecting and gantry experiments. Consistently, the IP02 system has encoders, as opposed to potentiometers as in the IP01, to allow for multiple turns.

The IP02 cart position is sensed via an quadrature incremental encoder whose shaft meshes with the track via an additional pinion. The IP02 is also equipped with a rotary joint to which a free-swinging rod can be attached and suspends in front of the cart. This rod functions, in subsequent experiments, as an "inverted pendulum", but more precisely as a self-erecting inverted pendulum as well as a regular inverted pendulum. The angle of the rod inclination about the vertical axis is also measured using a quadrature incremental encoder and is therefore unlimited and continuous over the entire range of motion. The pendulum in itself is a module and can be mounted on or remove from the cart.

Furthermore, in order to run the self-erecting experiment, the supplied extra mass needs to be attached to the cart, so that the swinging inertia of the pendulum does not lift the cart off the track.

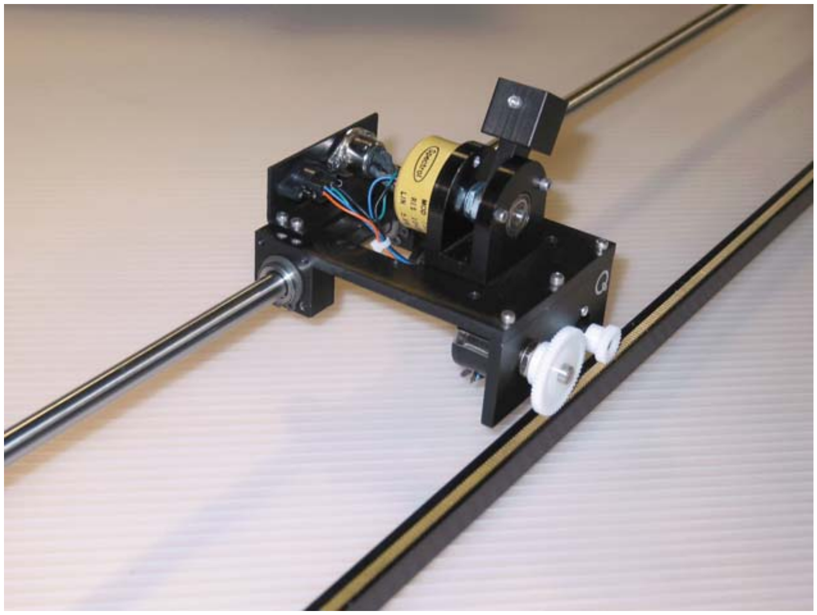


Figure 1 IP01 System

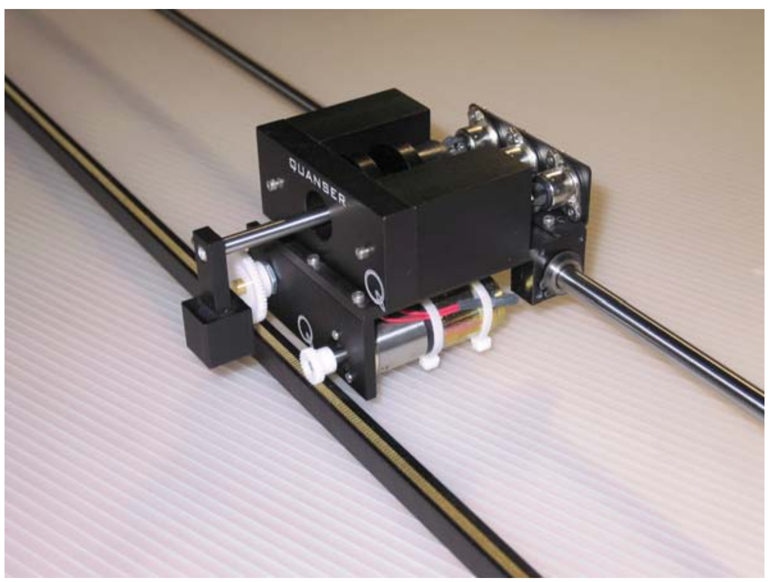


Figure 2 IP02 System

# 2. Module Options: List of Experiments Based on the IP02 Servo Plant

Quanser values itself for the modularity of its experiments. This modular philosophy facilitates the change from one experimental setup to another with relative ease of work.

## 2.1. Linear Family Package

The IP02 linear plant module serves as the base component for the linear family of experiments, also known as the Linear Family Package. The "Linear Family" is a package that has all the modules required to configure 7 completely different challenges based on the IP02 (thus maximizing the return on your investment).

Table 1, below, provides a list of the modules members of the Linear Family Package. Each one of them (individually or in combination) expands the range of possible experiments based on the IP02 linear motion servo plant.

| *Module Name* | *Experiment Description* |
|---|---|
| N/A | Design of a control system to manipulate the position of the IP01 or IP02 cart. |
| N/A | Design of two different control systems to manipulate the speed of the IP01 or IP02 cart. |
| Single Inverted Pendulum (SIP) | Design of a control system that keeps the classical inverted pendulum balanced and tracks the cart to a commanded position. |
| Single Pendulum Gantry (SPG) | Design of a control system to track a desired cart linear position while minimizing the swing of the suspended pendulum. |
| Self-Erecting Single Inverted Pendulum (SESIP) | Design of a control system to swing up the pendulum, keep it upright and maintain the cart position. |
| Single Linear Flexible Joint (SLFJ) | Design of a control system to manipulate the position of a spring driven cart. |
| Seesaw | Design of a control system to balance a seesaw using a sliding powered mass. |

| *Module Name* | *Experiment Description* |
| --- | --- |
| Seesaw with SLFJ | Design of a control system to balance a seesaw using a flexible structure mounted atop of it. |

Table 1 Modules of the Linear Family Package

## 2.2. Module Options for either IP01 or IP02

Table 2, below, provides a list of all the modules compatible with the IP01 and IP02 linear motion servo plants. These modules can be used individually or in combination. Some of them are part of the  Linear Family Package.

| *Module Name* | *Experiment Description* |
| --- | --- |
| Single Inverted Pendulum (SIP) | Design of a control system that keeps the classical inverted pendulum balanced and tracks the cart to a commanded position. |
| Flexible Inverted Pendulum (FLEXPEN) | Design of a control system to balance a flexible inverted pendulum. |
| Linear Flexible Joint Cart (LFJC) | Design of a control system to manipulate the position of a spring driven cart. |
| Single Linear Flexible Joint with Inverted Pendulum (SLFJ with IP) | Design of a control system to balance a pendulum on a spring driven cart. |
| Seesaw | Design of a control system to balance a seesaw using a sliding powered mass. |
| SLFJ on Seesaw | Design of a control system to balance a seesaw using a flexible structure mounted atop of it. |
| Active Mass Damper – 1 Floor (AMD) | Design of a control system to dampen the vibrations in a building-like structure. |

Table 2 IP01- and IP02-Based List of Modules

## 2.3. Module Options Specific to the IP02

Table 3, below, provides a list of the modules only compatible with the IP02 linear motion servo plants. Some of them are part of the  Linear Family Package.

| Module Name | Experiment Description |
|---|---|
| Single Pendulum Gantry (SPG) | Design of a control system to track a desired cart position while minimizing the swing of the linear suspended pendulum. |
| Self-Erecting Single Inverted Pendulum (SESIP) | Design of a control system to swing up the pendulum, keep it upright and maintain the cart position. |
| Double Inverted Pendulum (DBIP) | Design of a control system to balance a double inverted pendulum on a linear motion cart. |

Table 3 IP02-Based Modules

## 2.4. Two-Cart (i.e. MIMO) Systems with either IP01 or IP02

Table 4, below, lists some of the possible combinations of the previous modules to configure Multi-Input-Multi-Ouput (MIMO) experiments, based on either the IP01 or IP02.

| Module Name | Experiment Description |
|---|---|
| Seesaw / Inverted Pendulum | Design of a control system to balance an inverted pendulum on top of a seesaw. |
| Active Mass Damper – 2 Floors (AMD-2) | Design of a control system to dampen the vibrations in a building-like structure using a MIMO approach. |

Table 4 IP01- or IP02-Based MIMO Experiments

# 3. IP01 and IP02 Component Description

## 3.1. Component Nomenclature

As a quick nomenclature, Table 5, below, provides a list of all the principal elements composing the IP01 and IP02 systems. Every element is located and identified, through a unique identification (ID) number, on the IP01 and/or IP02 systems represented in Figures 3, 4, 5, and 6, below, as well as Figures 7 and 8.

| ID # | Description | ID # | Description |
|---|---|---|---|
| **1** | IP02 Cart | **2** | Stainless Steel Shaft |
| **3** | Rack | **4** | Cart Position Pinion |
| **5** | Cart Motor Pinion | **6** | Cart Motor Pinion Shaft |
| **7** | Pendulum Axis | **8** | IP02 Cart Encoder |
| **9** | IP02 Pendulum Encoder | **10** | IP02 Cart Encoder Connector |
| **11** | IP02 Pendulum Encoder Connector | **12** | Motor Connector |
| **13** | DC Motor | **14** | Planetary Gearbox |
| **15** | Linear Bearing | **16** | Pendulum Socket |
| **17** | IP02 Weight | **18** | IP01 Cart Potentiometer |
| **19** | IP01 Pendulum Potentiometer | **20** | IP01 Cart |
| **21** | S1 & S2 Connector | **22** | Rack End Plate |
| **23** | Rack Set Screw: (7/64)" | **24** | Track Discontinuity |

Table 5 IP01 and IP02 Component Nomenclature

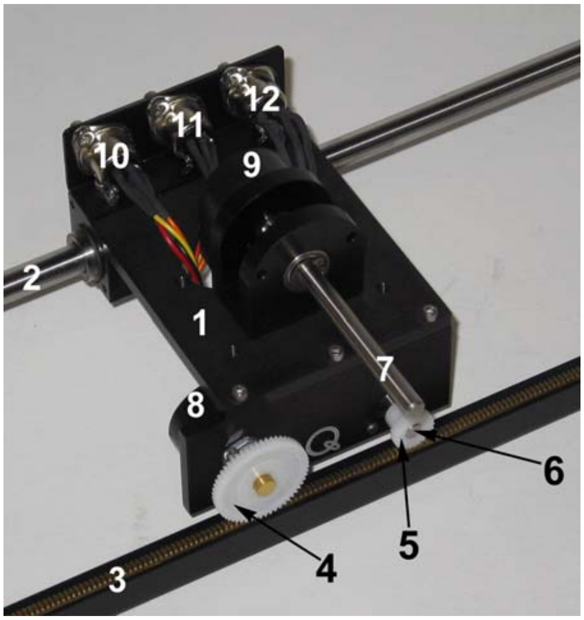


Figure 3 IP02: Front View

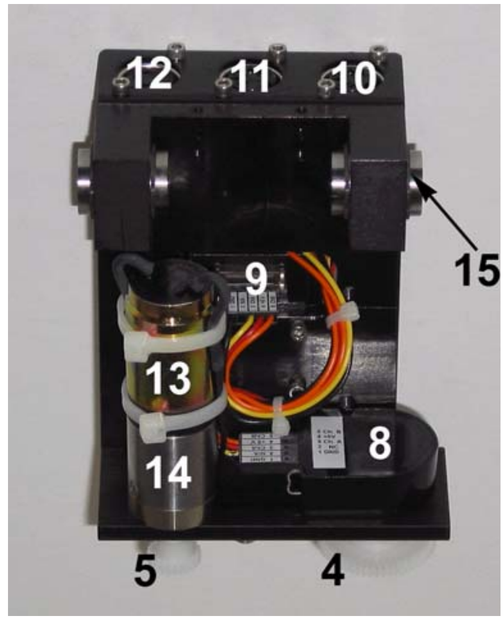


Figure 4 IP02: Bottom View

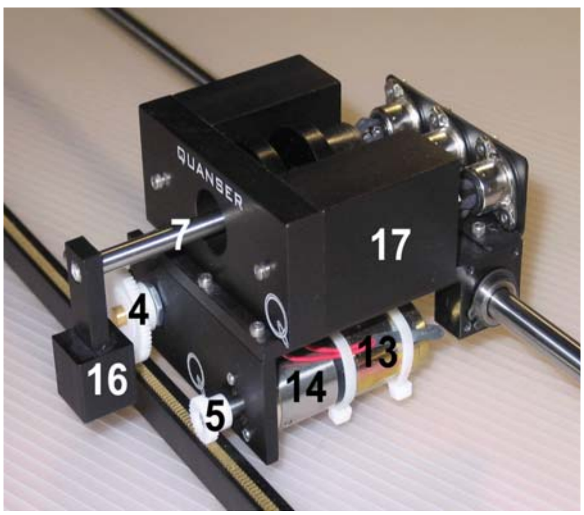


Figure 5 IP02 with Weight: Front View

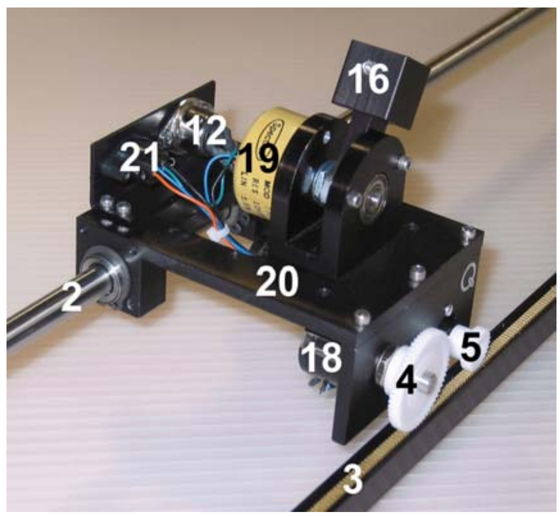


Figure 6 IP01: Front View

## 3.2. Component Description

### 3.2.1. Rack (Component # 3)

Table 6, below, lists and characterizes the overall dimensions of the rack used in the IP01 and IP02 systems:

| *Description* | *Value* | *Unit* |
|---|---|---|
| Overall Rack Length | 1.02 | m |
| Overall Rack Height | 6.10E-002 | m |
| Overall Rack Depth | 0.15 | m |

Table 6 IP01 and IP02 Rack Overall Dimensions

Moreover as illustrated in Figures 7 and 8 below, parts of the track are missing (feature or "component" #24) at both ends of the IP01 or IP02 rack. This feature plays the role of a hardware safety watchdog in preventing the IP01 or IP02 cart from running into one of the track's ends, which could potentially be damaging.

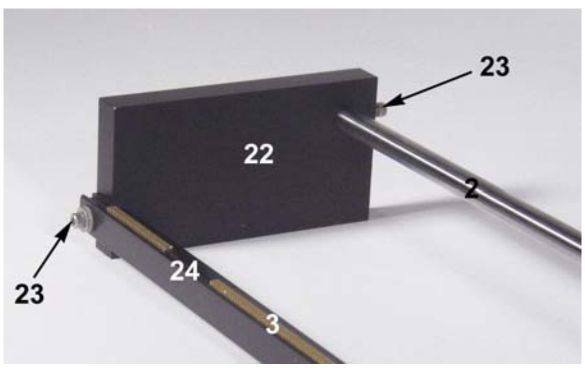


Figure 7 Rack Left End

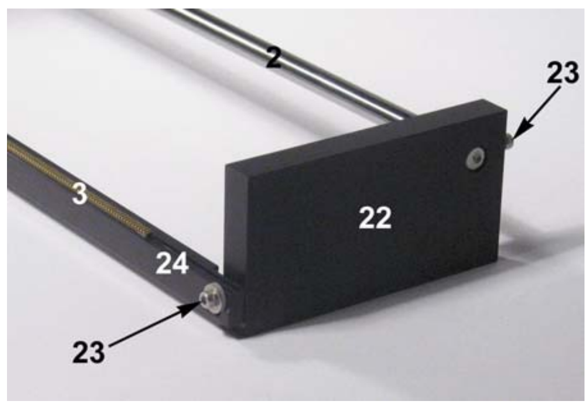


Figure 8 Rack Right End

### 3.2.2. DC Motor (Component # 13)

#### *3.2.2.1. Description*

The IP01 and IP02 incorporate a **Faulhaber Coreless DC Motor (2338S006)**, as shown in Figures 4 and 5 (component # 13), on page 7. This model is a high efficiency low inductance motor resulting in a much faster response than a conventional DC motor. The complete specification sheet of the motor is included in Appendix A.

**CAUTION:**
High Frequency signals applied to a motor will eventually damage the gearbox and/or 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.**

#### *3.2.2.2. Wiring*

The supplied motor cable is designed to connect from a Quanser Universal Power Module to a 4-pin DIN connector, shown as component # 12 in Figures 3, 4, and 6, on page 7.

### 3.2.3. Planetary Gearbox (Component # 14)

In the IP01 and IP02, the DC motor is coupled to a **Faulhaber Planetary Gearhead Series 23/1**, as shown in Figures 4 and 5 (component # 14), on page 7. Its reduction ratio is 3.71:1. The complete specification sheet of the planetary gearbox is included in Appendix B.

### 3.2.4. IP01 Potentiometers (Components # 18 and 19)

#### *3.2.4.1. Description*

The main difference between the IP01 and the IP02 is that the IP01 makes use of two potentiometers to sense both cart and pendulum positions, as opposed to the IP02 which uses two encoders instead.

As depicted in Figure 6 by component # 18, on page 7, the IP01 cart position is sensed by a 10-turn black potentiometer, namely the **Vishay Spectrol model 534-1-1-103**. As illustrated by its wiring diagram in Figure 9, the IP01 cart potentiometer is connected to a ±12 Volt DC power supply through two bias resistors of 7.15 kΩ each. According to the wiring diagram Figure 9 and under normal operations, potentiometer terminal 1 should measure +5VDC while terminal 3 should measure -5VDC. The actual position voltage is available at terminal 2. The total output range of the cart position potentiometer results to be ±5V over its 10 complete turns (i.e. 3600 degrees). The main specifications of the IP01 cart potentiometer are included in Appendix C, on page 24. Regarding the inverted pendulum potentiometer, it is a **Vishay Spectrol model 138-0-0-103**. It is represented in Figure 6 by component # 19. Its wiring diagram is also depicted in Figure 9. No bias resistor is used. On the IP01, the inverted pendulum is mechanically constrained to the upright position and limited to a ±32º-deviation from the vertical, during which the pendulum potentiometer output is within approximately a 5-volt range. The main specifications of the IP01 pendulum potentiometer are included in Appendix D, on page 25. Refer to Table 7, on page 13, for the resulting potentiometer sensitivities.

#### 3.2.4.2. Wiring

Both IP01 potentiometers are wired to one 6-pin mini DIN socket, as seen in the wiring schematic in Figure 9. A picture of the same 6-pin mini DIN socket, represented as component # 21, is also available in Figure 6. Once the 6-pin mini DIN socket is connected to a Quanser UPM, the potentiometer signals are typically available on *S1* and *S2*, where S1 and S2 are, respectively, the voltages proportional to the IP01 cart position and pendulum angle.

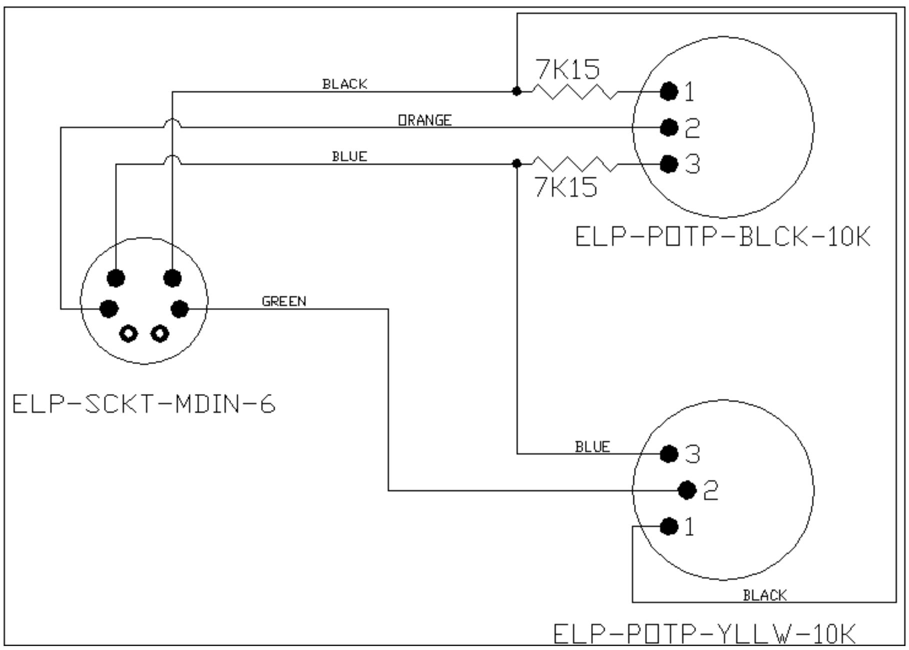



Figure 9 IP01 Wiring of the Two Potentiometers

As a remark, it should be noted that a potentiometer measures an **absolute** position signal. However, the zero position can be modified by manually adjusting the potentiometer "neutral" mounting position.

### 3.2.5. IP02 Encoders (Components # 8 and 9)

#### 3.2.5.1. Description

On the IP02, both cart and pendulum positions are measured with two optical encoders, represented in Figure 3 by components # 8 and 9, respectively. Having an encoder (as opposed to a potentiometer) sensing the pendulum angular position no longer constrains the range of motion of the pendulum to the inverted position. Therefore, self-erecting inverted pendulum experiments become possible. The encoder measuring the IP02 cart linear position does so through a rack-pinion system. Both encoders are typically identical. The encoder model used in the IP02 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 Appendix E. An incremental encoder gives a **relative** position signal.

#### *3.2.5.2. Wiring*

The position signal generated by the encoder should be directly connected to a Quanser terminal board (a.k.a. I/O card) using a standard 5-pin DIN cable. **DO NOT connect the encoder signal to the UPM**. The internal wiring diagram of the IP02 encoder is depicted in Figure 10. The standard 5-pin DIN connector, shown in Figure 10, is also pictured as component # 10 or 11 in Figure 3.

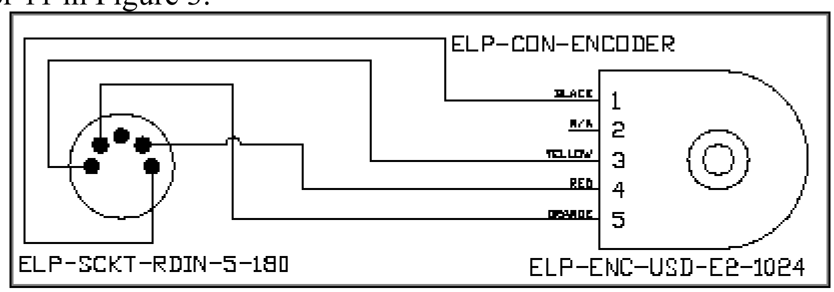


Figure 10 IP02 Encoder Wiring

# 4. IP01 and IP02 Model Parameters

Table 7, below, lists and characterizes the main parameters (e.g. mechanical and electrical specifications, convertion factors) associated with the IP01 and IP02. Some of these parameters can be used for mathematical modelling of the IP01 and IP02 systems.

| *Symbol* | *Description* | *Value* | *Unit* |
|---|---|---|---|
| $V_{nom}$ | Motor Nominal Input Voltage | 6.0 | V |
| $fv_{max}$ | Motor Input Voltage Maximum Frequency | 50 | Hz |
| $R_m$ | Motor Armature Resistance | 2.6 | Ω |
| $L_m$ | Motor Armature Inductance | 0.18 | mH |
| $K_t$ | Motor Torque Constant | 0.00767 | N.m/A |
| $\eta_m$ | Motor Efficiency | 100 | % |
| $K_m$ | Back-ElectroMotive-Force (EMF) Constant | 0.00767 | V.s/rad |
| $J_m$ | Rotor Moment of Inertia | 3.90E-007 | $kg.m^2$ |
| $K_g$ | Planetary Gearbox Gear Ratio | 3.71 | |
| $\eta_g$ | Planetary Gearbox Efficiency | 100 | % |
| $M_{c1}$ | IP01 Cart Mass | 0.52 | kg |
| $M_{c2}$ | IP02 Cart Mass | 0.57 | kg |
| $M_w$ | IP02 Cart Weight Mass | 0.37 | kg |
| $L_t$ | Track Length | 0.990 | m |
| $T_c$ | Cart Travel | 0.814 | m |
| $P_r$ | Rack Pitch | 1.664E-003 | m/tooth |
| $r_{mp}$ | Motor Pinion Radius | 6.35E-003 | m |
| $N_{mp}$ | Motor Pinion Number of Teeth | 24 | |
| $r_{pp}$ | Position Pinion Radius | 0.01482975 | m |
| $N_{pp}$ | Position Pinion Number of Teeth | 56 | |
| $K_{EC}$ | IP02 Cart Encoder Resolution | 2.275E-005 | m/count |
| $K_{EP}$ | IP02 Pendulum Encoder Resolution | 0.0015 | rad/count |
| $\alpha_{range}$ | IP01 Inverted Pendulum Mechanical Range | $\pm 32^{o}$ | $^{o}$ |

| *Symbol* | *Description* | *Value* | *Unit* |
|---|---|---|---|
| $K_{PC}$ | IP01 Cart Potentiometer Sensitivity | 0.0931 | m/V |
| $K_{PP}$ | IP01 Pendulum Potentiometer Sensitivity | -0.2482 | rad/V |

Table 7 IP01 and IP02 System Paremeters

# 5. Wiring Procedure For The IP01 And IP02

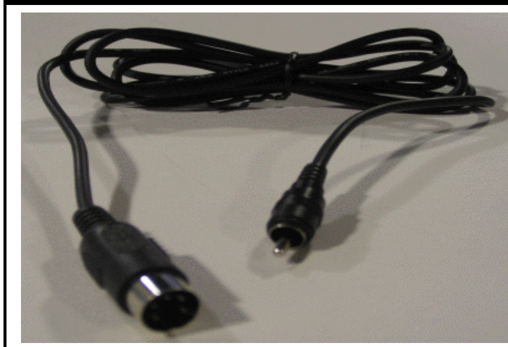
This section describes the standard wiring procedure for both IP01 and IP02.

The following hardware, accompanying the IP01 or IP02, is assumed:

- Data Acquisition Board: Quanser MultiQ-PCI / MultiQ-3 or equivalent.
- Power Amplifier: Quanser UPM 1503 / UPM 2405 or equivalent.

## 5.1. Cable Nomenclature

Table 8, below, provides a description of the standard cables used in the wiring of the IP01 and IP02.

| ***Cable*** | ***Designation*** | ***Description*** |
| --- | --- | --- |
|  Figure 11 "From Digital-To-Analog" Cable | 5-pin-DIN to RCA | This cable connects an analog output of the data acquisition terminal board to the power module for proper power amplification. |
|  Figure 12 "To Load" Cable | 4-pin-DIN to 6-pin-DIN | This cable connects the output of the power module, after amplification, to the desired actuator (i.e. IP01 or IP02 motor). One end of this cable contains a resistor that sets the amplification gain. The cable gains currently available are: 1, 3, or 5. Every cable carries a label, at both ends, with its particular gain on it. |

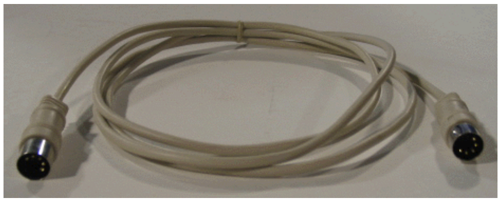
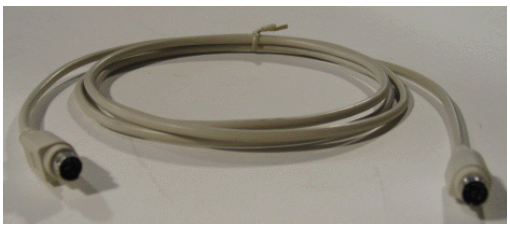
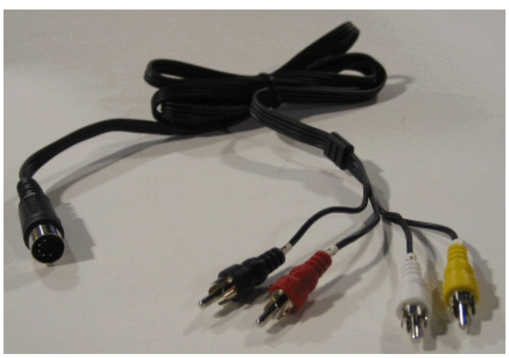
| Cable | Designation | Description |
| --- | --- | --- |
|  Figure 13 "Encoder" Cable | 5-pin-stereo-DIN to 5-pin-stereo-DIN | This cable is specific to the IP02 system. It carries the encoder signals between an encoder connector and the data acquisition board (to the encoder counter). Namely, these signals are: +5VDC power supply, ground, channel A, and channel B. |
|  Figure 14 "From Analog Sensors" Cable | 6-pin-mini-DIN to 6-pin-mini-DIN | This cable is specific to the IP01 system. It carries analog signals between one or two plant sensors and the UPM, where the signals can be either monitored and/or used by an analog controller. For example, connected to the IP01, the cable provides a ±12VDC bias to the two potentiometers and carries the two wiper voltages to S1 and S2 on the UPM. |
|  Figure 15 "To Analog-To-Digital" Cable | 5-pin-DIN to 4xRCA | This cable is needed by the IP01 system. It carries the analog signals, previously taken from the plant sensors, unchanged, from the UPM to the Digital-To-Analog input channels on the data acquisition terminal board. |

Table 8 Cable Nomenclature

## 5.2. Typical Connections For The IP01 And IP02

Figure 16 and Figure 17, below, show the MultiQ-PCI Terminal Board and the Universal Power Module (UPM) with a cabling necesary to interface to an IP01 or IP02.

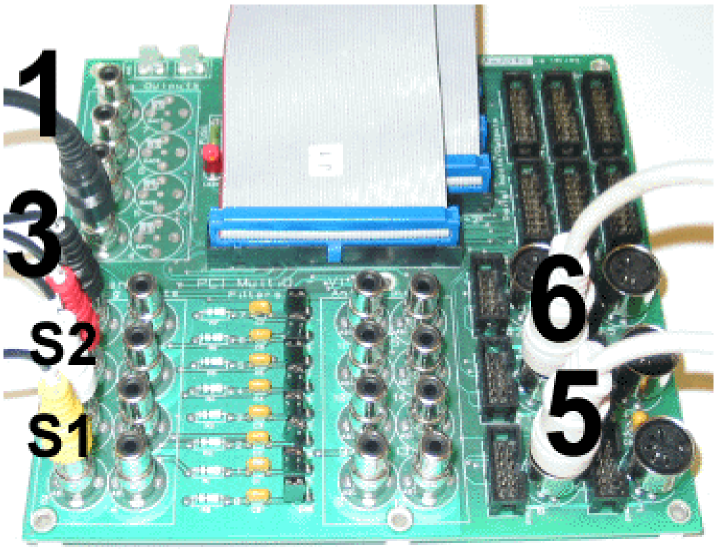


Figure 16 MultiQ-PCI Terminal Board

Figure 17 Universal Power Module (UPM)

### 5.2.1. Connections Common To Both IP01 And IP02

As both IP01 and IP02 share the same DC motor, the "power" connections for both IP01 and IP02 are identical. These connections are described below:

- **Connect the "From Digital-To-Analog" Cable**
  The "From Digital-To-Analog" cable is the 5-pin-DIN-to-RCA cable described in Table 8 and shown in Figure 11. Connect the RCA end of this cable to the **Analog Output 0** (i.e. DAC # 0) of the MultiQ-PCI terminal board and its 5-pin-DIN connector to the socket labelled **"From D/A"** on the UPM. These two connections are illustrated by cable # 1 in Figures 16 and 17, above.
- **Connect the "To Load" Cable**
  The "To Load" cable is the 4-pin-DIN-to-6-pin-DIN cable described in Table 8 and shown in Figure 12. First, connect the cable 4-pin-DIN connector to the IP01 or IP02 **motor connector**, which is shown as component # 12 in Figure 6 for the IP01 or

Figure 3 for the IP02. Then connect the cable 6-pin-DIN connector to the UPM socket labelled **"To Load"**. The connection to the UPM is illustrated by cable # 2 in Figure 17, above.

### 5.2.2. Connections Specific To The IP01

In the case of the IP01, the two potentiometers have to be connected. To do so, follow the two steps described below:

- **Connect the "From Analog Sensors" Cable**
  The "From Analog Sensors" cable is the 6-pin-mini-DIN-to-6-pin-mini-DIN cable described in Table 8 and shown in Figure 14. First connect one end of the cable to the IP01 **S1 & S2 Connector**, which is shown as component # 21 in Figure 6. Then connect its other end to the UPM socket labelled **"S1 & S2"**, which is contained inside the UPM "From Analog Sensors" front panel. The connection to the UPM is illustrated by cable # 4 in Figure 17, above.
- **Connect the "To Analog-To-Digital" Cable**
  The "To Analog-To-Digital" cable is the 5-pin-DIN-to-4xRCA cable described in Table 8 and shown in Figure 15. First, connect the cable 5-pin-DIN connector to the UPM socket labelled **"To A/D"**, as illustrated by cable # 3 in Figure 17, above. The other end of the cable is split into four RCA connectors, each one labelled with a single digit ranging from one to four. This numbering corresponds to the four possible analog sensor signals passing through the UPM, namely S1, S2, S3 and S4. In order for the analog signals to be used in software, you should then connect all four RCA connectors to the first four analog input channels of your MultiQ terminal board. Specifically, connect **S1 to Analog Input 0, S2 to Analog Input 1**, S3 to Analog Input 2, and S4 to Analog Input 3, as illustrated by cable #3 in Figure 16, above.

### 5.2.3. Connections Specific To The IP02

In the case of the IP02, the two encoders have to be connected. To do so, follow the two steps described below:

- **Connect the Cart Position "Encoder" Cable**
  The "Encoder" cable is the 5-pin-stereo-DIN-to-5-pin-stereo-DIN cable described in Table 8 and shown in Figure 13. First connect one end of the cable to the **IP02 Cart Encoder Connector**, which is shown as component # 10 in Figure 3. Then connect the other cable end to the **Encoder Input 0** on your MultiQ terminal board, just as illustrated by cable # 5 in Figure 16, above.
- **Connect the Pendulum Angle "Encoder" Cable**
  The "Encoder" cable is the 5-pin-stereo-DIN-to-5-pin-stereo-DIN cable described in Table 8 and shown in Figure 13. First connect one end of the cable to the **IP02 Pendulum Encoder Connector**, which is shown as component # 11 in Figure 3.

Then connect the other cable end to the **Encoder Input 1** on your MultiQ terminal board, just as illustrated by cable # 6 in Figure 16, above.

**CAUTION:**
Any encoder should be directly connected to the Quanser terminal board (or equivalent) using a standard 5-pin DIN cable. **DO NOT connect the encoder cable to the UPM!**

# 6. Testing and Troubleshooting

The present section, and following subsections, describe some basic functional tests to determine if your IP01 or IP02 is operating normally. It is assumed that the IP01 or IP02 have been entirely connected as described in Section Wiring Procedure For The IP01 And IP02, above. To carry out the testing (and troubleshooting, if necessary) described hereafter, you should be able to create and use a "controller" that can measure and apply desired signals. You can do so very conveniently in software by using the WinCon and Simulink implementation, or SimuLinuxRT, or LabView, or equivalent. Alternatively, the IP01 or IP02 testing can also be achieved by using a signal generator and an oscilloscope. To learn how to interface and use your IP01 or IP02 with WinCon, please refer to the manual titled *IP01 or IP02 / WinCon Integration*.

## 6.1. The IP01 or IP02 DC Motor

### 6.1.1. Testing

Apply a small voltage (e.g. around 1V) to analog output channel 0 of the MultiQ terminal board, using, for example, WinCon and Simulink.
A positive voltage should result in a motion of the cart to the right, when facing the IP01 or IP02 (i.e. when facing the position and motor pinions in front of the cart, with the cables connected to the back of the cart). Likewise a negative voltage should result in a motion of the cart to the left part of the track, when facing the IP01 or IP02.

### 6.1.2. Troubleshooting

If the motor is not responding to any signals applied, you should:

- check that the power amplifier (e.g. UPM) is functional (e.g. is the power switched on?).
- check that the MultiQ is functional, i.e. the desired voltage is being generated. The red LED (i.e. Light Emitting Diode) on the board should be on. If it is not, the fuse may be burnt and need replacement.

- check that the voltage is actually reaching the motor terminals (use a voltmeter or an oscilloscope). If the motor terminals are receiving the signal and the motor is still not turning, your motor might be damaged and will need to be repaired. Please refer to Section Obtaining Support on page 21 for information on contacting Quanser for technical support.

## 6.2. The IP01 Potentiometers

### 6.2.1. Testing

Assuming that all the connections in relation to the IP01 have been made as described in Section Wiring Procedure For The IP01 And IP02, on page 14, you should be able to measure and monitor the two IP01 potentiometer signals (i.e. S1 and S2). Using, for example, WinCon and Simulink, the two potentiometer voltages can be traced on WinCon Scopes and/or displayed on WinCon Digital Meters. On the MultiQ terminal board, the cart position potentiometer voltage (i.e. S1) is available on the analog input channel 0 and the pendulum angle potentiometer voltage (i.e. S2) on the analog input channel 1.

Pushing manually the IP01 cart to the right side of the track, when facing it, should result in a positive change in the cart position potentiometer voltage, which should gradually increase up to +5V. Likewise, pushing the IP01 cart towards the left side of the track, when facing it, should result in a negative change in the cart position potentiometer voltage, which should gradually decrease down to -5V. Combining this with the observations made in Section The IP01 or IP02 DC Motor, on page 18, it is seen that a positive motor voltage results in an increasing cart position potentiometer voltage, and vice-versa.

On a similar manner, rotating manually the inverted pendulum (or pendulum socket) clockwise (CW), when facing the cart, should result in a positive change in the pendulum potentiometer voltage, gradually increasing to +2.5V. Likewise, rotating the inverted pendulum counter-clockwise (CCW), when facing the cart, should result in a negative change in the pendulum potentiometer voltage, gradually decreasing to -2.5V.

### 6.2.2. Troubleshooting

If one of the potentiometers does not measure correctly, you should:

- check that the MultiQ is functional. The red LED on the board should be on. If it is not, the fuse may be burnt and need replacement. To check the analog-to-digital conversion from the analog input channel that you are using on the MultiQ, you could run the analog loopback example provided in the *WinCon User's Guide* manual.
- check that the power amplifier (e.g. UPM) is functional. The power to the UPM needs to be switched on in order for it to supply both potentiometers with ±12VDC.

- measure the voltage across the potentiometer. Prior to doing that, ensure that the potentiometer is powered with ±12VDC at the 6-pin-mini-DIN connector, as shown in Figure 9. You should observe ±5VDC at the cart position potentiometer terminals, and ±12VDC at the pendulum potentiometer terminals. Moreover, if the voltage from the wiper does not change when you rotate the potentiometer shaft (measuring with, for example, a voltmeter or an oscilloscope), your potentiometer may need to be replaced. To obtain technical assistance, please refer to Section Obtaining Support on page 21 for information on contacting Quanser.

## 6.3. The IP02 Encoders

### 6.3.1. Testing

Assuming that all the connections in relation to the IP02 have been made as described in Section Wiring Procedure For The IP01 And IP02, on page 14, you should be able to measure and monitor the two IP02 encoder signals. For example, with WinCon and Simulink, the two encoder counters can be read by the Encoder Input block, corresponding to your MultiQ, and traced on WinCon Scopes and/or displayed on WinCon Digital Meters. On the MultiQ terminal board, the cart encoder signal is available on the encoder input channel 0 and the pendulum encoder signal on the encoder input channel 1.
Moving the IP02 cart, when facing it, to the right side of the track should result in a positive change (i.e. increase) in the cart position encoder counts, which should increase at a rate of +4096 counts per revolution of the position pinion. Likewise, moving the IP02 cart, when facing it, towards the left side of the track should result in a negative change in the cart position (i.e. decrease) in the cart position encoder counts, which should decrease at a rate of -4096 counts per revolution of the position pinion. Combining this with the observations made in Section The IP01 or IP02 DC Motor, on page 18, it is seen that a positive motor voltage results in increasing cart position encoder counts, and vice-versa.
Similarly, rotating the IP02 free-falling pendulum (or pendulum socket) counter-clockwise (CCW), when facing the cart, should result in a positive change in the pendulum encoder counts, which should increase at a rate of +4096 counts per pendulum revolution. Likewise, rotating the free-falling pendulum clockwise (CW), when facing the cart, should result in a negative change in the pendulum encoder counts, which should decrease at a rate of -4096 counts per pendulum revolution.

**Notes:**

You should keep in mind that some data acquisition systems do not measure in quadrature, in which case you will receive a quarter of the expected counts, resulting to a lesser resolution. Other data acquisition systems do measure in quadrature but increment the count by

0.25 (as opposed to having integer number of counts). Therefore, you should know how the system you are using operates. All Quanser counters measure a total of four times the number of encoder lines per rotation. Therefore a 1024-line encoder results in 4096 integer number of counts for every full revolution.

### 6.3.2. Troubleshooting

If one of the encoders does not measure correctly, you should:

- check that the MultiQ is functional. The red LED on the board should be lit. If it is not, the fuse may be burnt and need replacement.
- check that both signals from the encoder channels A and B are properly generated and fed to the MultiQ. Using an oscilloscope, you should observe two square waves, representing channels A and B, with a phase shift of 90ºe (between the rising edge of the two channels). If you believe that your encoder is damaged and need to be replaced, refer to Section Obtaining Support, below, for information on contacting Quanser for technical support.

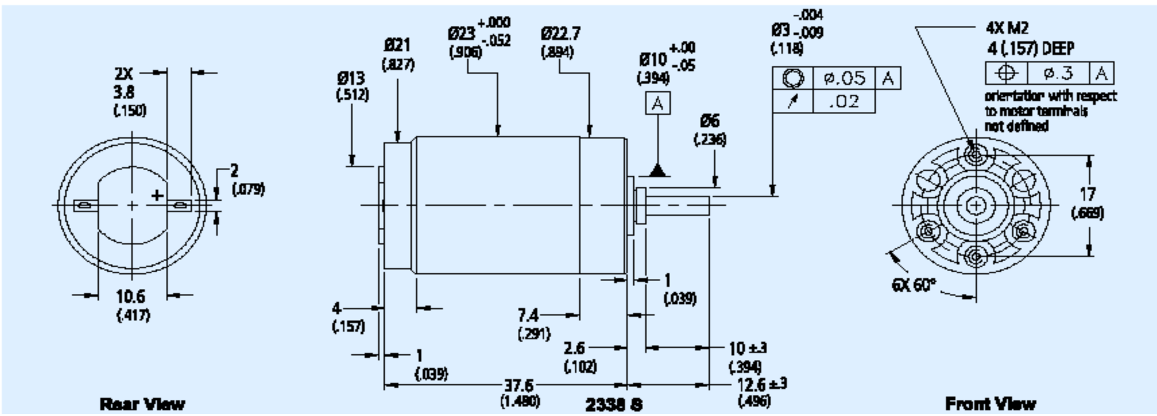
## 7. Obtaining Support

**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.

# Appendix A. DC Motor Specification Sheet

## Series 2338 ... S

| | 2338 S | | 4.5 S | 006 S | 009 S | 012 S | 018 S | 024 S | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Nominal voltage | $U_N$ | 4.5 | 6 | 9 | 12 | 18 | 24 | Volt |
| 2 | Terminal resistance | R ± 12% | 1.4 | 2.6 | 5.7 | 10.0 | 23.5 | 38.0 | Ω |
| 3 | Output power | $P_{2\ max.}$ | 3.39 | 3.23 | 3.29 | 3.31 | 3.18 | 3.50 | W |
| 4 | Efficiency | $\eta_{max.}$ | 70 | 69 | 67 | 66 | 67 | 67 | % |
| 5 | No-load speed | $n_o$ ± 12% | 7,200 | 7,200 | 7,400 | 7,800 | 7,400 | 7,600 | rpm |
| 6 | No-load current (with shaft ø 0.12 in) | $I_o$ ± 50% | 0.100 | 0.080 | 0.060 | 0.050 | 0.030 | 0.025 | A |
| 7 | Stall torque | $M_H$ | 2.55 | 2.42 | 2.41 | 2.29 | 2.32 | 2.49 | oz-in |
| 8 | Friction torque | $M_R$ | 0.082 | 0.086 | 0.095 | 0.099 | 0.095 | 0.102 | oz-in |
| 9 | Speed constant | $k_n$ | 1,650 | 1,240 | 855 | 678 | 428 | 330 | rpm/V |
| 10 | Back-EMF constant | $k_E$ | 0.606 | 0.804 | 1.170 | 1.470 | 2.340 | 3.030 | mV/rpm |
| 11 | Torque constant | $k_M$ | 0.818 | 1.088 | 1.586 | 1.997 | 3.158 | 4.107 | oz-in/A |
| 12 | Current constant | $k_I$ | 1.222 | 0.919 | 0.630 | 0.501 | 0.317 | 0.244 | A/oz-in |
| 13 | Slope of n-M curve | $\Delta n/\Delta M$ | 2,824 | 2,975 | 3,071 | 3,406 | 3,190 | 3,052 | rpm/oz-in |
| 14 | Rotor inductance | L | 100 | 180 | 380 | 630 | 1,400 | 2,600 | µH |
| 15 | Mechanical time constant | $\tau_m$ | 20 | 17 | 17 | 17 | 17 | 17 | ms |
| 16 | Rotor inertia | J | $6.797 \cdot 10^{-5}$ | $5.523 \cdot 10^{-5}$ | $5.240 \cdot 10^{-5}$ | $4.815 \cdot 10^{-5}$ | $5.098 \cdot 10^{-5}$ | $5.381 \cdot 10^{-5}$ | oz-in-sec² |
| 17 | Angular acceleration | $\alpha_{max.}$ | 38 | 44 | 46 | 48 | 46 | 47 | $\cdot 10^3 rad/s^2$ |
| 18 | Thermal resistance | $R_{th\ 1} / R_{th\ 2}$ | 3 / 24 | | | | | | °C/W |
| 19 | Thermal time constant | $\tau_{w1} / \tau_{w2}$ | 5.7 / 645 | | | | | | s |
| 20 | Operating temperature range: | | | | | | | | |
| | – motor | | – 30 to +85 (– 22 to +185) | | | | | | °C (°F) |
| | – rotor, max. permissible | | +125 (+257) | | | | | | °C (°F) |
| | Note: Special operating temperature models for | | –55°C to +125°C (– 67°F to +257°F) available on request. | | | | | | |
| 21 | Shaft bearings | | sintered bronze sleeves | | ball bearings | | ball bearings, preloaded | | |
| 22 | Shaft load max.: | | (standard) | | (optional) | | (optional) | | |
| | – with shaft diameter | | 0.1181 | | 0.1181 | | 0.1181 | | in |
| | – radial at 3,000 rpm (0.12 in from bearing) | | 9 | | 72 | | 72 | | oz |
| | – axial at 3,000 rpm | | 1.08 | | 7.2 | | 7.2 | | oz |
| | – axial at standstill | | 72 | | 72 | | 72 | | oz |
| 23 | Shaft play: | | | | | | | | |
| | – radial | ≤ | 0.0012 | | 0.0006 | | 0.0006 | | in |
| | – axial | ≤ | 0.0079 | | 0.0079 | | 0 | | in |
| 24 | Housing material | | steel, zinc galvanized and passivated | | | | | | |
| 25 | Weight | | 2.47 | | | | | | oz |
| 26 | Direction of rotation | | clockwise, viewed from the front face | | | | | | |
| | **Recommended values** | | | | | | | | |
| 27 | Speed up to | $n_{e\ max.}$ | 6,000 | 6,000 | 6,000 | 6,000 | 6,000 | 6,000 | rpm |
| 28 | Torque up to | $M_{e\ max.}$ | 0.566 | 0.566 | 0.566 | 0.566 | 0.566 | 0.566 | oz-in |
| 29 | Current up to (thermal limits) | $I_{e\ max.}$ | 1.380 | 1.000 | 0.680 | 0.510 | 0.330 | 0.260 | A |



# Appendix B. Planetary Gearhead Specification Sheet

## Series 23/1

| | 23/1 |
|---|---|
| Housing material | metal |
| Geartrain material | all steel |
| Recommended max. input speed for: | |
| – continuous operation | 4,000 rpm |
| Backlash, at no-load | ≤ 1° |
| Bearings on output shaft | preloaded ball bearings |
| Shaft load, max.: | |
| – radial (10 mm (0.394 in) from mounting face) | ≤ 612 oz |
| – axial | ≤ 540 oz |
| Shaft press fit force, max. | ≤ 540 oz |
| Shaft play (on bearing output): | |
| – radial | ≤ 0.0006 in |
| – axial | = 0.0039 in |
| Operating temperature range | –30 to +100 °C (– 22 to +212 °F) |

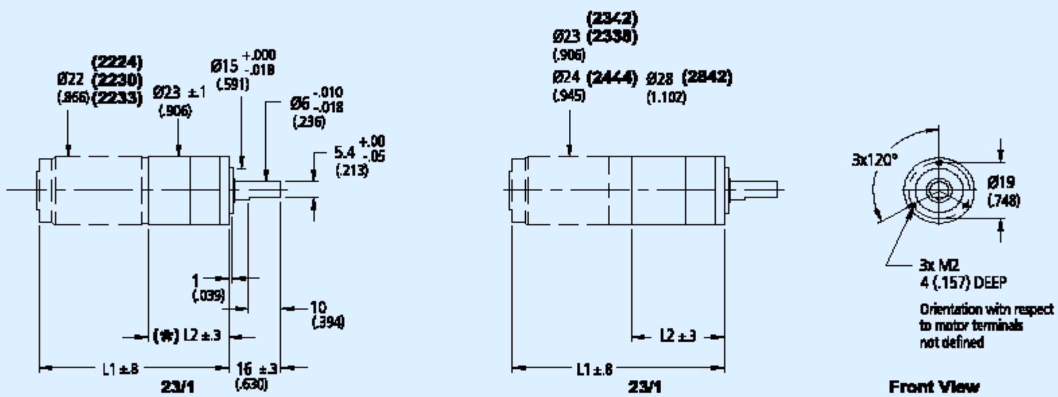
**Specifications**

| reduction ratio (nominal) | weight without motor oz | length without motor L2 mm (in) | length with motor 2224 U L1 mm (in) | 2230 U L1 mm (in) | 2233 U L1 (1) mm (in) | 2444 S L1 mm (in) | 2342 S 2842 S L1 mm (in) | output torque continuous operation M max. oz-in | intermittent operation M max. oz-in | direction of rotation (reversible) | efficiency % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 3.71 : 1 | 2.12 | 23.8 (0.937) | 44.1 (1.74) | 53.8 (2.12) | 56.6 (2.23) | - - | - - | 28.32 | 56.65 | = | 88 |
| 3.71 : 1 | 2.12 | 27.8 (1.09) | - - | - - | - - | 71.8 (2.83) | 69.8 (2.75) | 28.32 | 56.65 | = | 88 |
| 14 : 1 | 2.47 | 34.1 (1.34) | 54.4 (2.14) | 60.2 (2.37) | 63.0 (2.48) | 78.1 (3.07) | 76.1 (3.00) | 42.48 | 84.97 | = | 80 |
| 43 : 1 | 3.17 | 40.3 (1.59) | 60.6 (2.39) | 66.4 (2.61) | 69.2 (2.72) | 84.3 (3.32) | 82.3 (3.24) | 99.13 | 141.6 | = | 70 |
| 66 : 1 | 3.17 | 40.3 (1.59) | 60.6 (2.39) | 66.4 (2.61) | 69.2 (2.72) | 84.3 (3.32) | 82.3 (3.24) | 99.13 | 141.6 | = | 70 |
| 134 : 1 | 3.53 | 46.4 (1.83) | 66.7 (2.63) | 72.5 (2.85) | 75.3 (2.96) | 90.4 (3.56) | 88.4 (3.48) | 99.13 | 141.6 | = | 60 |
| 159 : 1 | 3.53 | 46.4 (1.83) | 66.7 (2.63) | 72.5 (2.85) | 75.3 (2.96) | 90.4 (3.56) | 88.4 (3.48) | 99.13 | 141.6 | = | 60 |
| 246 : 1 | 3.53 | 46.4 (1.83) | 66.7 (2.63) | 72.5 (2.85) | 75.3 (2.96) | 90.4 (3.56) | 88.4 (3.48) | 99.13 | 141.6 | = | 60 |
| 415 : 1 | 3.88 | 52.6 (2.07) | 72.9 (2.87) | 78.7 (3.10) | 81.5 (3.21) | 96.6 (3.80) | 94.6 (3.72) | 99.13 | 141.6 | = | 55 |
| 592 : 1 | 3.88 | 52.6 (2.07) | 72.9 (2.87) | 78.7 (3.10) | 81.5 (3.21) | 96.6 (3.80) | 94.6 (3.72) | 99.13 | 141.6 | = | 55 |
| 989 : 1 | 3.88 | 52.6 (2.07) | 72.9 (2.87) | 78.7 (3.10) | 81.5 (3.21) | 96.6 (3.80) | 94.6 (3.72) | 99.13 | 141.6 | = | 55 |
| 1,526 : 1 | 3.88 | 52.6 (2.07) | 72.9 (2.87) | 78.7 (3.10) | 81.5 (3.21) | 96.6 (3.80) | 94.6 (3.72) | 99.13 | 141.6 | = | 55 |

(1) For gearhead length with motor 2338 add 8.7 mm (0.343 in) to 2233 motor length column.

Note: Reduction ratios have been rounded off.
Exact values are available upon request.

(*) Subtract 3.9 mm (0.154 in) from L2 column to account for smaller mounting flange.



# Appendix C. IP01 Cart Potentiometer Specification Sheet

## 7/8" (22mm) Precision Wirewound Potentiometer

**FEATURES**

- Special Resistance Tolerances to 1%
- Rear Shaft Extensions and Support Bearing
- Non Turn Lug
- Insulating Plastic Shaft
- Special Independent Linearity to ± 0.75%
- Dual Gang Configuration and Concentric Shafts
- High Torque and Center Tap
- Special Markings and Front Shaft Extensions
- Servo Unit available and Slipping Clutch

**ELECTRICAL SPECIFICATIONS**

| PARAMETER | MODEL 533 | MODEL 534 | MODEL 535 |
|---|---|---|---|
| Resistance Range<br>Standard Values | 50Ω to 20KΩ | 100Ω to 100KΩ | 50Ω to 50KΩ |
| Capability Range | 5Ω to 60KΩ | 10Ω to 200KΩ | 5Ω to 100KΩ |
| Standard Tol | ± 5% | ± 5% | ± 5% |
| Linearity (Independent) | ± 0.25% | ± 0.25% | ± 0.25% |
| Noise | 100Ω ENR | 100Ω ENR | 100Ω ENR |
| Rotation (Electrical & Mechanical) | 0° + 10° | 0° + 10° | 0° + 10° |
| Power Rating (@ 70°C) | 1.0 watts | 2.0 watts | 1.5 watts |
| Additional Sections | 75% of section 1 | | |
| Insulation Resistance | 1000MΩ minimum 500VDC | | |
| Dielectric Strength | 1000$V_{RMS}$ minimum 60Hz | | |
| Absolute Minimum Resistance | Not to exceed linearity x total resistance or 1Ω, whichever is greater | | |
| Tempco | 20ppm/°C (standard values, wire only) | | |
| End Voltage | 0.25% of total applied voltage, maximum | | |
| Phasing | CCW end points - section 2 phased to section 1 within ± 2° | | |
| Taps | Center tap only | | |

**MARKING**

| | |
|---|---|
| **Unit Identification** | Manufacturer's name and model number, resistance value and tolerance, linearity specification date code and terminal identification |

**RESISTANCE VALUES**

| Ohms | |
|---|---|
| **533:** | 50R, 100R, 200R, 500R, 1K, 2K, 5K, 10K, 20K |
| **534:** | 100R, 200R, 500R, 1K, 2K, 5K, 10K, 20K, 50K, 100K |
| **535:** | 50R, 100R, 200R, 500R, 1K, 2K, 5K, 10K, 20K, 50K |

**ORDERING INFORMATION**

The Models 533 (3 turn), 534 (10 turn) and 535 (5 turn) can be ordered by stating

| **534** | **1** | **2** | **XXX** |
|---|---|---|---|
| MODEL | MOUNTING | NUMBER OF SECTIONS | RESISTANCE EIA CODE SECTION #N |
| | **1**. Bushing<br>**2**. Servo | | (consult factory) |

# Appendix D. IP01 Pendulum Potentiometer Specification Sheet

## 1-5/16" (33.3mm) Low Cost Industrial Single Turn Wirewound, Conductive Plastic, Cermet

### FEATURES

- Choice of Three Elements for Broad Resistance Range
- Center Tap Available
- Continuous Rotation & Mechanical Stops Both Standard
- High Power Rating (139)

### ELECTRICAL SPECIFICATIONS

| PARAMETER | MIL-PRF-12934/MIL-PRF-39023 TEST PROCEDURES APPLY | | |
|---|---|---|---|
| | **STANDARD** | **SPECIAL** | |
| Total Resistance: Model 132 Wirewound | 5Ω to 20KΩ | to 35KΩ | |
| Tolerance: 50Ω and above | ± 3% | ± 1% | |
| Below 50Ω | ± 5% | ± 3% | |
| Model 138 Conductive Plastic | 1KΩ to 50KΩ | – | |
| Tolerance: | ± 10% | ± 5% | |
| Model 139 Cermet | 500Ω to 2MΩ | – | |
| Tolerance: | ± 20% | ± 5% | |
| Linearity (Independent) | **STANDARD** | **BEST PRACTICAL** | |
| Total Resistance (132) | | | |
| 5Ω to 20Ω | ± 1.0% | ± 0.75% | |
| 20Ω to 200Ω | ± 1.0% | ± 0.50% | |
| 200Ω and above | ± 0.5% | ± 0.25% | |
| 138/139 | ± 0.5% | ± 0.25% | |
| Noise (132) | 100Ω ENR | | |
| Output Smoothness (138 & 139) | 0.1% maximum | | |
| Power Rating | 40°C Ambient | | |
| Model 132 | 2.75 watts | | |
| Model 138 | 2 watts | | |
| Model 139 | 5 watts | | |
| | All Models derated to zero at 125°C | | |
| Electrical Rotation | **MODEL 132** | **MODEL 138** | **MODEL 139** |
| Continuous | 352° ± 2° | 345° ± 4° | 345° ± 4° |
| Stops | 336° ± 2° | 336° ± 4° | 336° ± 4° |
| Insulation Resistance | 1000MΩ minimum at 500VDC | | |
| Dielectric Strength | $1000V_{RMS}$, 60Hz | | |
| Absolute Minimum Resistance | 1.0% of total resistance or 0.5Ω whichever is greater (132 only) | | |
| Minimum Voltage | 0.5% maximum | | |
| Temperature Coefficient of Resistance | | | |
| 132 | Refer to standard resistance element data | | |
| 138 | ± 500ppm/°C maximum | | |
| 139 | ± 100ppm/°C maximum | | |

### MATERIAL SPECIFICATIONS

| | |
|---|---|
| Housing | Molded glass filled thermoplastic |
| Rear Lid | Glass filled thermoset plastic |
| Shaft | Stainless steel, non-magnetic |
| Terminals | Brass, plated for solderability, Non-passivated |
| Mount Hardware | |
| Lockwasher Internal Tooth: | Steel, nickel plated |
| Panel nut: | Brass, nickel plated |

### ENVIRONMENTAL SPECIFICATIONS

| | |
|---|---|
| Vibration | 15Gs thru 2000 Hz |
| Shock | 50g |
| Salt Spray | 48 Hours |
| Rotational Life | |
| Shaft Revolutions | |
| Model 132 | 500,000 |
| Model 138 | 2 million |
| Model 139 | 2 million |
| Operating Temperature Range | - 55°C to + 125°C |
| Moisture Resistance | – |

### ORDERING INFORMATION

The Models 132, 138 and 139 can be ordered from this specification sheet by stating. Example: **139 - 0 - 0 - 203**

| **139** | **0** | **0** | **203** |
|---|---|---|---|
| MODEL | MECHANICAL OPTIONS | OTHER OPTIONAL FEATURES | RESISTANCE CODE |
| 132, 138 or 139 | **0**. Continuous<br>**2**. Stops | **0**. Standard (End Taps)<br>**1**. Center Tap (Within 5° of Electrical Center) | **2**: 1st Significant digit<br>**0**: 2nd significant digit<br>**3**: Number of Zero's |

Other characteristics will be standard as described on this specification sheet. If special characteristics are required such as special linearity tolerance, special resistance tolerance, non-linear functions, etc., please state these on your order

# Appendix E. IP02 Encoder Specification Sheet

## S1 & S2 — Optical Shaft Encoders

### Description:

The **S1** and **S2** series optical shaft encoders are non-contacting rotary to digital converters. Useful for position feedback or manual interface, the encoders convert real-time shaft angle, speed, and direction into TTL-compatible quadrature outputs with or without index. The encoders utilize an unbreakable mylar disk, metal shaft and bushing, LED light source, and monolithic electronics. They may operate from a single +5VDC supply.

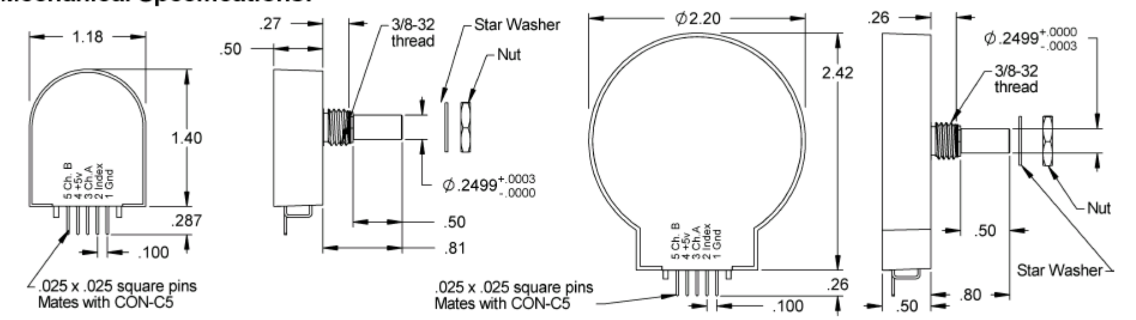
The **S1** and **S2** encoders are available with ball bearings for motion control applications or torque-loaded to feel like a potentiometer for front-panel manual interface.

**Electrical Specifications:**
B leads A for clockwise shaft rotation, A leads B for counter clockwise shaft rotation viewed from the shaft/bushing side of the encoder. For complete details see our **HEDS** data sheet.

### Features:

- Small size
- Low cost
- 2-channel quadrature, TTL square wave outputs
- 3rd channel index option
- Tracks from 0 to 100,000 cycles/sec
- Ball bearing option tracks to 10,000 RPM
- -40 to +100°C operating temperature
- Single +5V supply
- US Digital warrants its products against defects and workmanship for two years. See complete warranty for details.

### Mechanical Specifications:




### Mechanical Notes: (ball bearing)

| | |
|---|---|
| Acceleration | 10,000 rad/sec² |
| Vibration | 20 g. 5 to 2KHz |
| Shaft Speed | 10,000 RPM max. continuous |
| Acceleration | 50K rad/sec²<br>10K rad/sec² (**S2** series) |
| Shaft Torque | 0.05 in. oz. max. |
| Shaft Loading | 1 lb. max. |
| Bearing Life | $(40/P)^3$ = Life in millions of revs.<br>P = radial load in pounds. |
| Weight | 0.7 oz. |
| Shaft Runout | 0.0015 T.I.R. max. |

### Mechanical Notes: (sleeve bushing)

| | |
|---|---|
| Acceleration | 10,000 rad/sec² |
| Vibration | 20 g. 5 to 2KHz |
| Shaft Speed | 100 RPM max. continuous |
| Shaft Rotation | Continuous & reversible |
| Shaft Torque | 0.5 ±0.2 in. oz.<br>0.3 in. oz. max. (**NT**-option) |
| Shaft Loading | 2 lbs. max. dynamic<br>20 lbs. max. static |
| Weight | 0.7 oz. |
| Shaft Runout | 0.0015 T.I.R. max. |

### Materials & Mounting:

| | |
|---|---|
| Shaft | Brass or stainless |
| Bushing | Brass |
| Connector | Gold plated |
| Hole Diameter | 0.375 in. +0.005 - 0 |
| Panel Thickness | 0.125 in. max. |
| Panel Nut Max Torque | 20 in.-lbs. |