CryoTel® Family
Free-Piston Stirling Cryocoolers

OPERATING INSTRUCTIONS

Model: CryoTel® GT
Controller: Gen II v1.0.0
Manual Version: 6
Effective: May, 2012

Intellectual Property Declaration

Manufactured by Sunpower, Inc., under the following patents: U.S. Pats 4,583,364; 4,602,174; 4,623,808; 4,649,283; 4,805,408; 4,864,232; 4,866,378; 4,912,409; 4,926,123; 5,003,777; 5,148,066; 5,342,176; 5,385,021; 5,450,521; 5,457,956; 5,461,859; 5,496,153; 5,502,968; 5,525,845; 5,537,820; 5,592,073; 5,642,088; 5,642,622; 5,715,693; 5,749,226; 5,775,273; 5,873,246; 5,941,079; 6,035,637; 6,038,874; 6,170,442; 6,199,381; 6,293,184; 6,446,336 B1; 6,536,326; 6,684,637; RE 38,337; 6,782,700; U.S. patents pending. Also: Australia Patents 676,805; 677,518; 680,770; 685,997; 701,785; 709,315; 753,580;754032. Brazil PI 950368-5; PI 960 8885-0; PI 9710742-5; PI 9713840-1; PI 9713840-1. Canada patent 2,184,473. EPO 0655120 1B issued in France, Italy, UK, Netherlands, Sweden and Germany (as DE 69329862.6-08). EPO 0693160 issued in Italy, UK, Netherlands France, Germany (as DE 69403468 T2); EPO 0754364 1B issued in France, Italy, UK, Netherlands and Germany (as DE 69526217.3-08). EPO 0783618 1B issued in France, Italy, UK, Netherlands and Germany (as DE 69518926.3-08). EPO 0878014 1B issued in France, Italy, UK, Netherlands and Germany (as DE 69611387.2-08). EPO 0885413 1B issued in France, Italy, UK, Netherlands and Germany (as DE 69627894.4-08). Italy 1297082. UK Patent No. 0,218,682; UK 2,334,307; UK 2,330,651. DBP No. 0,218,682 (Germany).
India Patents 177477, 178274, 185034; 185035. Republic of Korea patents 0202290; 0292453; 0301548; 0309486; 0320093. Mexico patents 184451; 194065; 197407; 201368. New Zealand Patents No. 263331; 282959; 319499; 302849; 517329. Singapore Patent P-No. 48360; 51842; 87422; 87423; 87424. Taiwan patent NI-77875.
Japan Patents

特許第３４１３６５８号

Patents pending 特許第１９６６４３８号 m, C 特許第３１００１６３号 e, 特許第３２２４１３２号 den, Brazil, Japan, Republic of Korea, India, China, Singapore.

Sunpower, the Sunpower graphic identifier, and CryoTel® are trademarks of Sunpower, Inc. and are registered in the U.S. and other countries. Other products, logos, and Company

Contents

FIGURES

Introduction

Sunpower, Inc. is pleased to present this manual with your newly-purchased CryoTel® model cryocooler. As the world leader in free-piston Stirling cryocooling, Sunpower fully supports its products and is pleased to hear of any comments or concerns from new or existing clients.

I. CryoTel® GT Operating Instructions

The Sunpower cryocooler is a precision instrument; robust in many ways but fragile in others. This operating manual provides standard-use instructions and precautions. Please post where technicians will be working with the unit. Please do not assume that if a warning or instruction is not included here, a particular test or application of this unit is acceptable. It may not be. If you have any questions about this unit, or about any tests or applications you intend to perform, please contact Sunpower support service at phone (740)-594-2221 or email info@sunpower.com

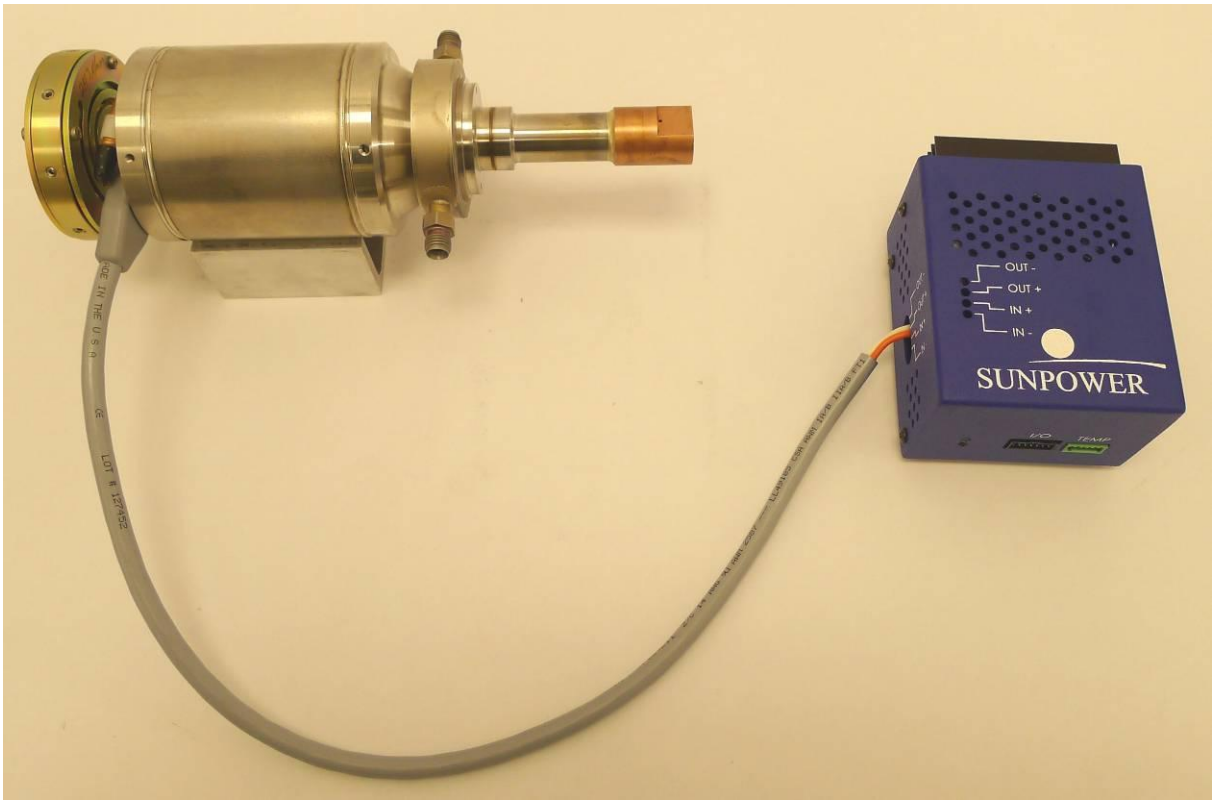


Figure 1: CryoTel® GT and Controller

CryoTel® GT dimensions: length with balancer: 260 mm (10.2 in); length without balancer: 217 mm (8.5 in); diameter: 83 mm (3.3 in);
mass: 3.1 kg

II. Precautions (Dos and Don'ts)

Although the CryoTel® GT is mechanically robust, it can be damaged if not handled properly when in operation or when removing from the packaging. The handling and operational **Dos** and **Don'ts** are listed below. Refer to the diagram of the CryoTel® GT in Figure 2.

CRITICAL! – Do not operate the cryocooler without adequate cooling at the heat rejection site. Overheating the cryocooler will cause permanent damage.

DON'T

- Pick up the cryocooler by the cold finger
- Set the cryocooler on the cold tip.
- Allow the cold finger to be dented. The slightest dent will render the unit inoperable.
- Drill holes, or in any other way puncture, or attempt to modify, the pressure vessel.
- Operate the unit without proper cooling. Heat must be removed from the copper heat rejection area of the cryocooler. If the cooler is provided with external cooling fins, air must be forced over the fins and the flow path should not be obstructed.
- Puncture or otherwise damage the copper service tube.
- Subject the electrical feedthroughs to mechanical stress; i.e. axial or radial movements, axial loads, blows, or the like.
- Mount the cooler by suspending it from the balance absorber mounting bolt.
- Apply clamping pressure to the pressure vessel.
- Rigidly attach the absorber stud to "ground." Instead, let the cooler "float" via a rubber bushing or other means of articulation.
- Remove the protective cover on the cold weld on the end of the copper service tube. Do not subject the cover to blows.
- Control power to the cryocooler by making or breaking the power leads between the controller and the cryocooler.
- Use an external, automatic, closed loop control system which attempts to control the cryocooler operation by varying the set point settings in the cryocooler controller.

DO

- Check with Sunpower before making any modifications to the cryocooler
- Note that if the controller is installed in an enclosure, cooling must be provided.
- If the cooler is operating in a laboratory test mode with heaters providing the thermal load to the cold tip, interlocks should be provided so that the heater cannot operate unless the cryocooler is running. This will prevent accidental overheating of the cold tip.

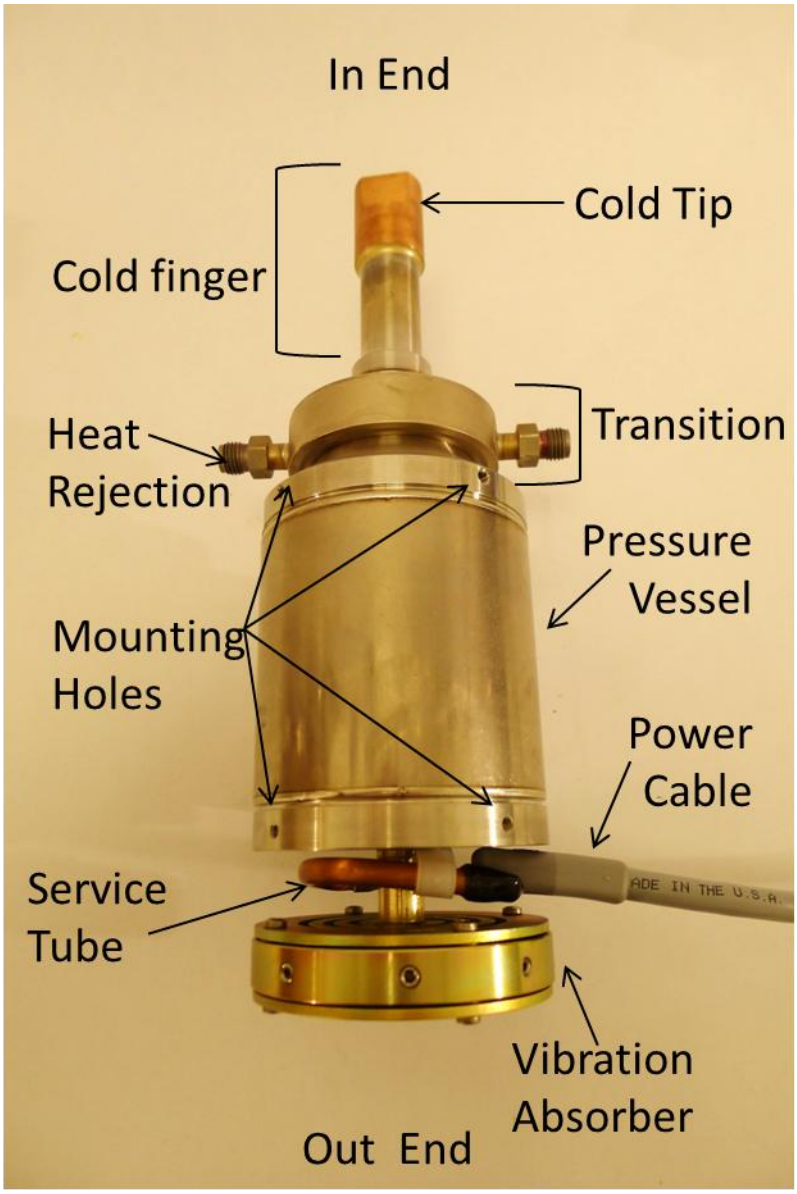


Figure 2: CryoTel® GT Cryocooler

III. Unpacking

When unpacking or handling, only hold the cryocooler by the pressure vessel or the transition (see Figure 2). The CryoTel® GT may sit horizontally on a level bench top or table, but the cooler must be supported to prohibit rolling. The cold finger must be protected from any contact as well.

IV. Mechanical Mounting

The CryoTel® GT has a thick metal end plate on the "out" end of the pressure vessel nearest the passive vibration absorber. M4 threaded holes on the outer diameter of the transition and end plate are designed for attachment of the cooler to an external mechanical structure for testing or integration into the application. These can be seen in Figure 3.

On the face of the external copper ring that rejects heat from the cooler is a stainless steel plate. The plate has four M3 threaded holes that can be used for attaching a removable NW50 or customer specified vacuum flange (see Figure 4). A vacuum flange can also be welded to this plate, but must be done with a low energy weld such as plasma or micro TIG. It is recommended that, if needed, the customer allow Sunpower to perform the welding operation. The mechanical structure including the cryostat attachment plate, heat rejection copper, and transition have been designed to allow mounting the entire assembly by the cryostat and cantilevering the cooler and vibration absorber from the cryostat in a given application.

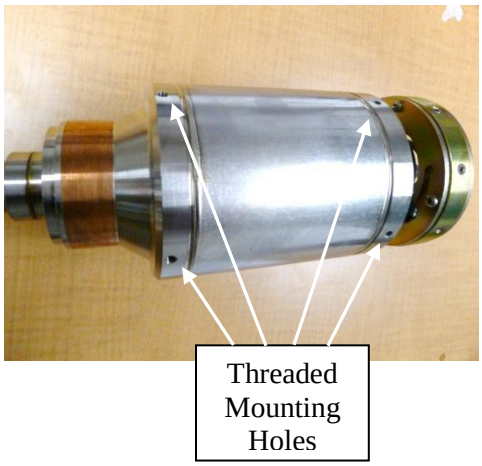


Figure 3: Pressure Vessel Mounting Holes

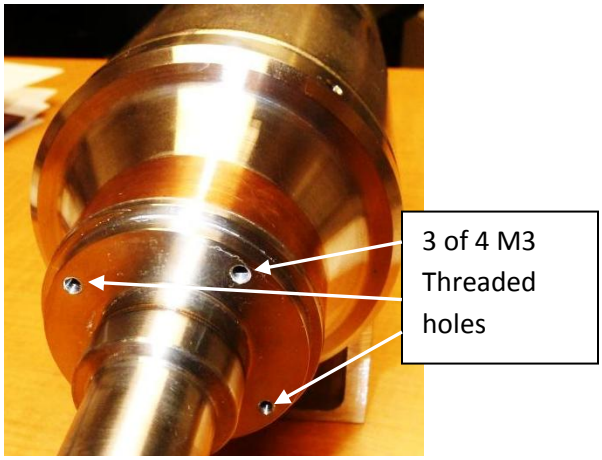


Figure 4: Weld Flange Holes

V. Attachment of Heat Load to Cold Finger

The copper cold tip at the end of the GT cold finger has a ¼"-20 threaded hole that can be used for mounting equipment to the cold tip for applications or tests (see Figure 5). The application of force to the cold tip must be handled with care and in accordance with these not-to-exceed limits:

- Cantilevered force, cooler **not** in operation: do not exceed a cantilevered force on the cold finger (static or shock) > 100 N (10.20kg).
- Cantilevered force, cooler **in** operation: do not permit the heat load apparatus to deliver force to the cold finger (static or shock) > 30 N (3.05 kg)
- Vertical loading: do not exceed a pure tension or compression load > 300 N (30.50 kg)
- Torque, cold finger: do not exceed a load >16 N*m (142 in*lbs)
- Torque-copper cold tip ¼-20 Thread: do not exceed a load of 10 N*m (88 in*lbs)

Figure 5: Cold Tip ¼”-20 Threaded Hole

VI. Cold End Vacuum

The cold finger of the CryoTel® GT operates best in an insulated vacuum. The vacuum eliminates possible loading of the cold finger from convection or condensation of elements in the atmosphere such as water vapor and nitrogen. The vacuum is created by a customer provided vacuum Dewar or cryostat. As previously noted a flange can connect the cryostat and the stainless steel vacuum flange with an O-ring seal or welded attachment (Fig 4).

When using a mechanical vacuum pump it is appropriate to seal the flange with an O-ring and clamp. The vacuum pump will remove any residual gasses released by the O-ring and continue to maintain a vacuum inside the cryostat. However, an O-ring may corrode and become brittle over an extended period of time.

For customer applications requiring long-term vacuum without using a vacuum pump, it is recommended that the cryostat be welded to the CryoTel® vacuum interface.

VII. Feedthroughs

The electrical pins on the metal plate at the end of the pressure vessel near the balance absorber are surrounded by glass, which acts as an insulator and prevents helium from leaking out of the pressure vessel. This arrangement is called a feedthrough. Because of the glass insulator, the feedthroughs should be handled cautiously. They are a permanent feature of the pressure vessel back end plate and should not be modified in any way.

The CryoTel® GT is shipped with a power cable that attaches to the feedthroughs and the controller. This cable consists of orange and white 16 gauge wires with a molded plastic connector for the feedthroughs at one end and crimp sleeves to attach to the proper terminal block on the controller at the other end. This harness is shown in Figure 6.

Figure 6: Power Cable

It is necessary to remove the balance absorber in order to install the power cable. The balance absorber is attached with the center M5 screw. Remove this screw and the balance absorber will be free from the cryocooler.

Install the power cable by aligning the cryocooler feedthrough pins with the holes in the cable connector and pressing down. Insert the retaining screw into the connector and tighten.

Install the balance absorber by re-installing the M5 screw.

Important assembly notes:
The screw heads of the four balance absorber assembly screws need to be positioned so that none of them are directly over either the power cord connector or the service tube elbow. This is to ensure that the screw head does not impact either of these features during large amplitude displacements of the balance absorber. See Figure 7 for details.

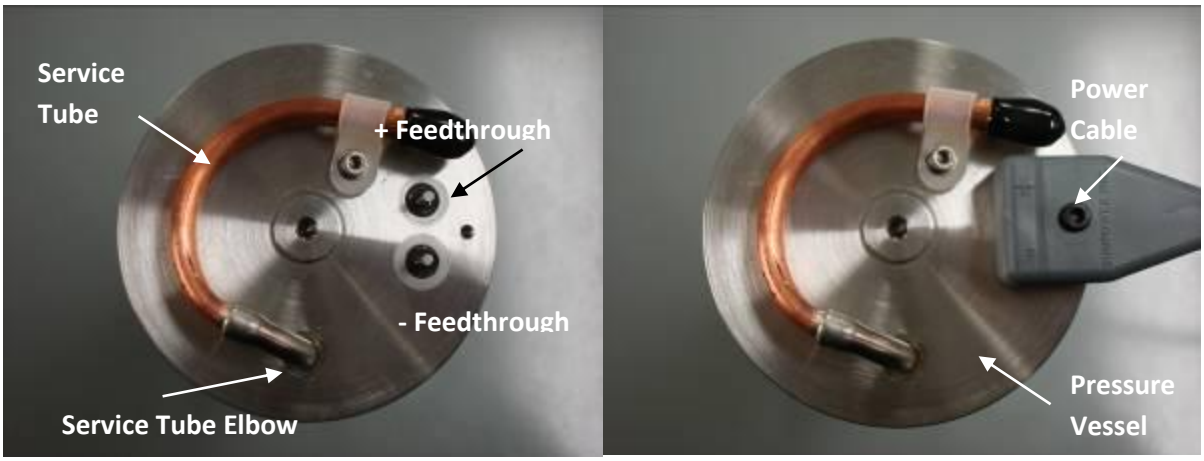


Figure 7: Rear Pressure Vessel End Plate and Power Cable Wire Harness

VIII. Temperature Sensor

For proper operation of the CryoTel® controller it is necessary to mount a temperature sensor to the object being cooled. The sensor allows the controller to measure and control the cooled object's temperature. The sensor feedback also controls the cooler's power ramp-up. If the sensor is not installed properly, the cooling capacity of the cryocooler will be severely limited and temperature control will not function.

The controller is designed to us a Lakeshore PT-111 platinum RTD or equivalent. Sunpower packages the PT-111 in a copper disk so that the sensors are identical in size, shape and wiring. Figure 8 shows the sensor and the connector to the controller.

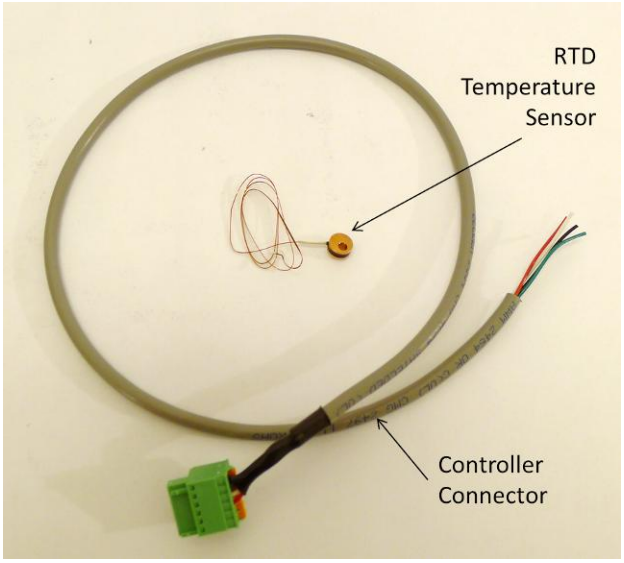


Figure 8: Temperature Sensor and cable

The temperature sensor is encased in a small copper slug. Use an M3 screw in the 3mm drilled hole to attach the sensor to object being cooled. Use a thin layer of Indium, Apiezon grease, or similar thermal grease between the sensor and the object to ensure proper thermal conduction.

Laboratory testing can be accomplished with a test cap arrangement similar to the one shown in Fig 9. The test cap is used to supply a specified heat load to the cold tip. The test cap consists of a copper cap with two resistors, a through hole with ¼”-20 clearance for connection to the copper tip, and a copper clamp ring with M3 clearance holes to clamp temperature sensors around the circumference of the cold tip. Calculate the heat load (power in Watts = current x voltage) by providing a known voltage and current across the resistors on the test cap. Mount the temperature sensor using one of the M3 mounting holes on the clamp ring. If using a second sensor, mount it to the clamp ring for independent temperature measurement. If not, simply clamp the other half of the ring snuggly with an M3 screw. Apply appropriate thermal grease to the bottom faces of the test cap and inside surface of the clamp ring in order to maximize conduction between them and the cold tip. Mount the test cap to the cold tip using the ¼”-20 threaded hole on the cold tip being sure not to apply more than 10 N*m of torque.

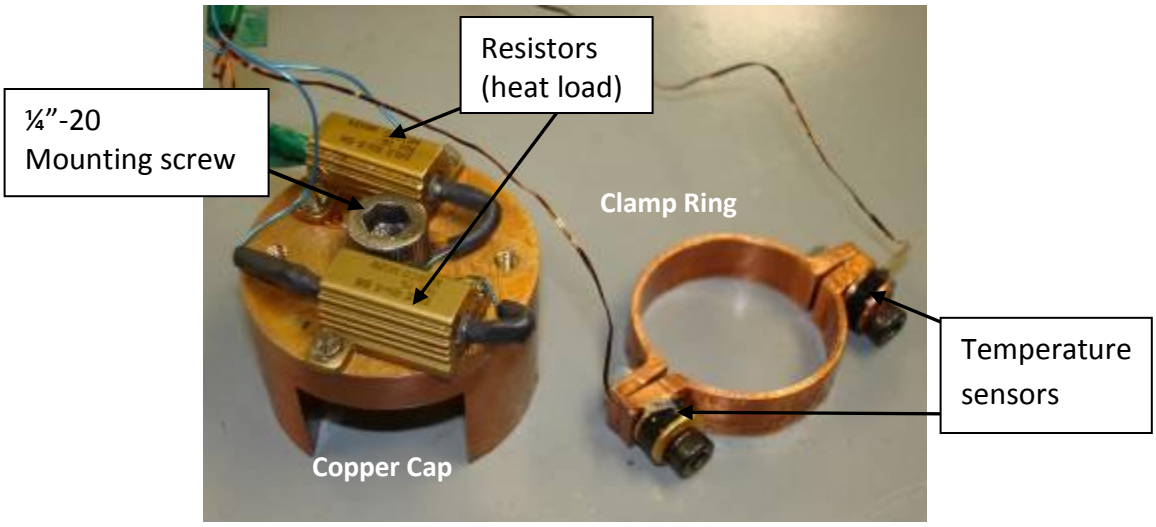
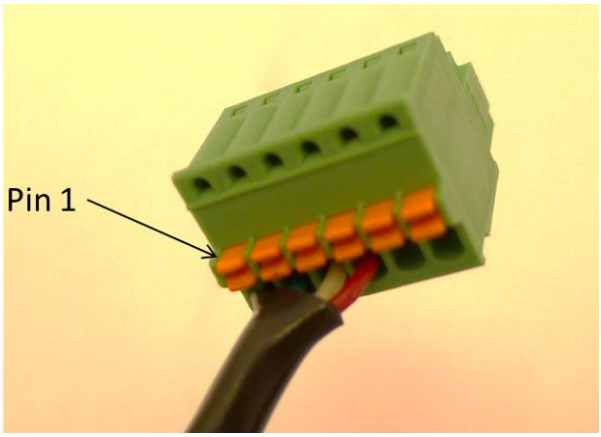


Figure 9: Test Cap Assembly

When the cold tip is contained in a vacuum vessel, use feedthroughs to connect the sensor wires to the temperature sensor connector. Use at least four conductors connecting the feed through to the control temperature sensor. Use additional feedthroughs if employing a test cap or other sensors inside the cryostat. All wires inside the cryostat should be as small as possible in order to minimize parasitic loading on the cooler. The wires of the temperature sensor are color coded to help insure proper connection. Figure 10 describes proper connections of the temperature sensor to the CryoTel® Controller.



Temperature sensor connector

PIN	Function	Wire Color
1	V+	Black
2	V-	Green
3	I+	Clear
4	I- / shield	Red

Figure 10: Controller Temperature Sensor Connector

Mating connector for temperature interface is Digikey part number 277-1434-ND.

There is not a dedicated pin on the controller for connecting the shield of shielded temperature sensor wiring. If noise becomes an issue, grounding the shield to the controller may help. The shield can be connected to the I- wire at the controller and connected to Pin 4.

IX. Heat Rejection

Proper heat rejection is crucial to the operation of a cryocooler. Some CryoTel® heat rejection options are a water jacket, copper fins, or a conducting solid.

CRITICAL! – Do not operate the cryocooler without adequate cooling at the heat rejection site. Overheating the cryocooler will cause permanent damage.

A. Water Jacket

Sunpower can provide a permanent or removable water cooling jacket with the CryoTel® GT (Fig. 11 – *both are identical in appearance*). Use a suitable thermal grease to maximize conduction between the heat rejecter and the water jacket if using a removable unit (the permanent unit is installed at the factory and does not require thermal grease). The thermal grease should be refreshed periodically as it will dry out over time. After connecting the water supply to the water jacket for heat rejection, ensure that air is removed from the water jacket. This can be done by flowing water through the cooling system for several minutes prior to the run. If it appears that air is still trapped in the water jacket, try carefully tilting the cooler in the direction away from the cooler discharge tube. This will raise the level of the discharge tube and allow any trapped air to escape. Trapped air will decrease heat rejection and cooler performance. Water should be flowing through the jacket at approximately 15mL per second (0.24 gallons per minute).

Figure 11: Water Jacket Heat Rejection

B. Copper Fins

Copper fins are also available in a permanent or removable form. If copper fins are used for heat rejection (Fig. 12-*permanent fins are pictured*), use a fan with a rating of 100 cubic feet per minute (1.6e-3 m^3/min) for air through-flow. Sunpower recommends mounting the fan to a cylindrical shroud that can be placed around the fins in order to direct the air through the fins. Note that some heat rejection also occurs from the walls of the pressure vessel. Therefore avoid permitting any containment structure for the cryocooler to hinder the heat rejection from any part of the cooler. It is also recommended to electrically interlock the cooling fan and the controller in order to ensure that the cooler cannot operate without also turning on the fan.

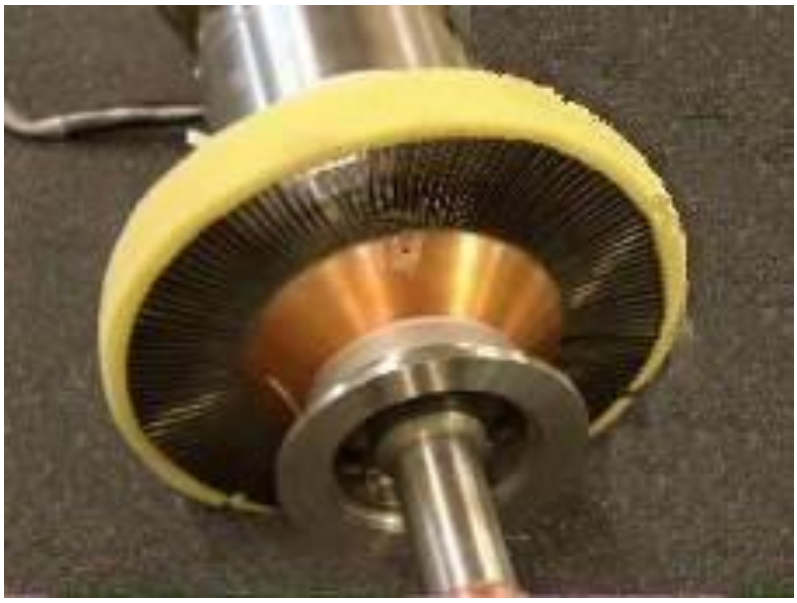


Figure 12: Cooling Fin Heat Rejection

C. Conducting Solid

Use of any other means of heat rejection necessitates ensuring that the proper amount of heat is being transferred away from the rejecter and that the reject temperature is suitable. It is recommended to involve Sunpower with the design of a conduction heat exchanger.

X. CryoTel® Operation

<u>CRITICAL!</u> – Do not operate the cryocooler without adequate cooling at the heat rejection site. Overheating the cryocooler <u>will</u> cause permanent damage.

A. Preparation

1. Attach application apparatus or test cap assembly to cold tip of cold finger.
    a. Apply a thin layer of Apiezon thermal grease or Indium to the copper tip of the cold finger in order to maximize conductivity.
2. Attach the customer-provided cryostat by appropriate means if a vacuum is required for the application.
3. If using a vacuum, make wire connections from temperature sensor and any other measuring devices inside the cryostat through Dewar feedthroughs.
    a. For maximum performance, wires should not touch the walls of the Dewar. Contact with walls will increase the heat loading (conduction) during use and will yield lower available cooling power.
4. Seal the cryostat vacuum except for the connection to the vacuum pump (if using vacuum).
5. Mechanically attach the cryocooler assembly to the customer provided mounting device.
6. Connect the wiring from the cryostat feedthroughs to the appropriate test and measurement devices.
    a. The cold tip temperature sensor must be connected to the controller's mating connector as described previously using the provided connector (See Figure 10 for controller connections).
7. Attach the vacuum pump to cryostat, start the vacuum and allow it to reach a vacuum of 10^{-4}Torr or better.

B. Beginning Operation

1. Prepare the CryoTel® GT for testing as described above.
2. Connect the cryocooler power cables for the CryoTel® GT to the controller's power terminal block. The orange wire should be connected to pin 2 (OUT +). The white wire should be connected to pin 1 (OUT -). (Controller connections shown in Fig. 13).
    a. IMPORTANT! Verify the correct polarity is observed with respect to the CryoTel® GT – orange power cable wires are positive, white wires are negative. Inversed polarity could result in damage to the Cryocooler.
3. Connect the controller to a $48V_{DC}$ power outlet. Connect +48V to the power terminal block pin3 (IN+). Connect the power return (ground) to pin 4 (IN-).
    a. IMPORTANT! Verify the correct polarity is observed. Inversed polarity <u>will</u> result in damage to the controller.
    b. Note: Crimp ferrules should be used on wire ends connecting to the terminal block. The 14 Gauge ferrules are available at Digikey PN 288-1101-ND. The proper tool for crimping the ferrules is Digikey PN 288-1163-ND.
    c. The controller has a startup sequence that positions the piston in the axial center. This sequence takes approximately 7-10 seconds once the controller is turned on.
    d. The controller then applies a 60 Hz AC voltage to the motor, creating the oscillating motion of the piston that begins the cooling process.
    e. The controller increases the power to the cryocooler based on cold end temperature. The maximum draw by the controller is approximately 300 W_E.
4. Allow cold tip temperature to stabilize at desired cold end temperature.

a. Proper operation of the CryoTel ®GT requires a minimum loading of 6 Watts. If minimum load requirements are not met, the stabilized temperature will be below 77 K.

Figure 13: CryoTel® GT Controller

C. Operation Shutdown

1. Turn off the controller.
    a. The quick rattle heard when power is cut off from the CryoTel ®is due to the stored energy in the vibration absorber being dissipated.
    b. In rare cases where the operating temperature was below 60 K, it has been observed that the cooler can energize itself during shutdown and become an engine. To prevent this, allow the cold tip to reach a temperature above 60 K before shutting down.
2. Allow the cold tip and the rest of the cryocooler temperature to rise to room temperature before opening the vacuum in order to prevent the vapor outside the cryostat from condensing and freezing on the cold tip.
    a. Applying a heat load to the cold tip during the warming process reduces the time needed to reach room temperature.
    b. Sunpower recommends using a relay in conjunction with the temperature sensor to ensure that the power supply to the heat load shuts off when the cold tip temperature reaches 300 K.

XI. LED and Digital Output 4

The two LEDs, shown in figure 14, indicate whether the cooler has reached its set point temperature or if the cooler is still in cool down mode. The red LED will be on as long as the cooler is not at the temperature setpoint. When the cooler reaches its set point temperature within the desired temperature band the green LED will turn on. The default temperature band is 0.5K. See Section XIII, page 27 for details on changing the temperature band.

Digital Output 4 (I/O Connector pin 4) will go high (5V) when the cooler is at the set point temperature. When the cooler is not at the temperature set point Digital Output 4 will be low (0V). See Figure 15 for I/O connector pin out.

If both LEDs are flashing together repetitively, the controller is reporting an error. See Section XII for details.

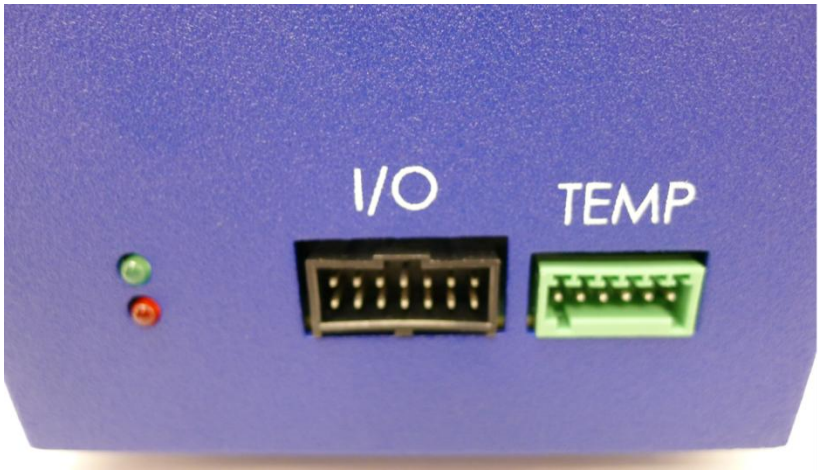


Figure 14: Controller LEDs

XII. Error Summary

If both LEDs are flashing together repetitively, the controller is reporting an error. There are two ways to check the error codes. The **ERROR<CR>** command can be issued, or the number of LED flashes can be counted.

When the **ERROR<CR>** command is issued, any errors that are present are indicated with a "1". See figure 15 for the error codes. Multiple error codes can be displayed simultaneously. For example a return of "100001" would indicate an over current and temperature sensor error. See section XIII for the serial communications reference.

To check and error code using the LEDs, count the number of flashes. Both the red and green LED will flash simultaneously. There will be a series of short flashes followed by one long flash. The long flash indicates the end of the sequence. The flash count includes both the short flashes and the long flash. If there are multiple errors only one of them will be displayed by the LEDs, but after the long flash the red and green LEDs will flash back-to back very rapidly.

Number of LED flashes	ERROR<CR> return value	Description
1	000001	Over Current
2	000010	Jumper Error
3	000100	Serial Error
4	001000	Non-volatile Memory Error
5	010000	Watchdog Error
6	100000	Temperature Sensor Error

Figure 15: Error Codes

Error Details:

1. Over Current
    a. If the controller detects an overcurrent it will immediately shut off the output to the cryocooler.
    b. Check the wiring between the controller and the cryocooler for any problems. If this does not resolve the error contact Sunpower.
2. Jumper Error
    a. Power cycle the controller. If this does not resolve the error contact Sunpower.
3. Serial Error
    a. Communication with the controller may not be possible after a serial error.
    b. Power cycle the controller. If this does not resolve the error contact Sunpower.
4. Non-volatile Memory Error
    a. Power cycle the controller. If this does not resolve the error contact Sunpower.
5. Watchdog Error
    a. Power cycle the controller. If the error occurs again contact Sunpower.
6. Temperature Sensor Error
    a. Check the wiring between the controller and the temperature sensor including the fine wire attached to the temperature sensor itself. Check if the controller is reporting an appropriate temperature. If this does not resolve the error contact Sunpower.
    b. If the temperate sensor wiring has intermittent problems, the error code will remain in the controller even if the wiring starts functioning properly again. The controller must be power cycled to clear the error code.

XIII. CryoTel® Serial Communications Command Reference

Control the CryoTel® GT with any terminal emulator program. A common choice is Hyperterminal, as it is included with Windows, (Windows 7 users may need to download Hyperterminal). The connecting cable for basic functionality is included.

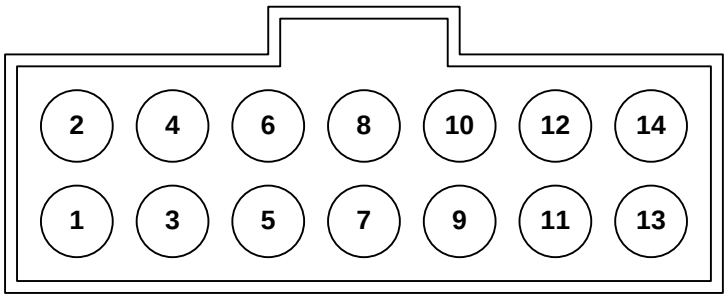
Caution: Use of an external program, such as LabVIEW™, to establish closed loop control of the cryocooler via serial communication, may cause controller malfunction. Manual set point adjustments may be made as required without problem.

A. Serial Interface Specifications

RS-232
Baud Rate: 4800
Flow control: none
Data bits: 8
Stop bits: 1

B. Controller Connector Wiring Information

Pin Numbering for I/O connector and RS-232 connections on CryoTel® Controller



Pin Number	Function
1	Digital Out 1
2	Digital Out 2
3	Digital Out 3
4	Digital Out 4 (AT Temperature)
5	Digital Input 1 (Soft Stop)
6	Digital Input 2
7	Digital Input 3 (Thermostat)
8	Digital Input 4
9	Isolated I/O GND
10	Onboard Isolated 5V
11	Isolated I/O GND
12	Onboard Isolated 5V
13	RS-232 RX (Input)
14	RS-232 TX (Output)

Figure 16: I/O connector

Some advanced function requires adding wires to the basic cable or creating a new cable. Part numbers for the required additional parts are located below:

I/O connector Crimp Terminals
Manufacturer: Molex
Manufacturer PN: 90119-2109
Digi-key PN: WM2558-ND
Note: The above terminal is for 22-24AWG and is tin/lead over nickel. Different terminals are available from the manufacturer.

I/O connector housing
Manufacturer: Molex
Manufacturer PN: 90142-0014
Digi-key PN: WM8039-ND

I/O terminal Crimper Tool for 22-28AWG
Manufacturer: Molex
Manufacturer PN: 63819-0200
Digi-key PN: WM9028-ND

Basic Communication Functionality

CryoTel GT Terminal Emulator Commands

The following pages show an explanation of each of the terminal emulator commands and display examples. All of the parameters set will be retained in memory when the controller is power cycled unless otherwise noted.

1) Display temperature sensor value in Kelvin
   a) Command: **TC<CR> (<CR> means "press Enter key")**
   b) Returns the current temperature of the RTD in Kelvin.

```
TC
330.00
```

2) Display target temperature in Kelvin
   a) Command: **SET TTARGET<CR>**
   b) Returns the target temperature of the controller in Kelvin when in temperature control mode (Default mode).

```
SET TTARGET
077.00
```

3) Set target temperature when in temperature control mode.
   (a) Command: **SET TTARGET=<VAL><CR>**
   (b) Set the temperature the cryocooler will try to attain when in temperature control mode.
   (c) VAL corresponds to the target temperature in Kelvin.

```
SET TTARGET=86.00
086.00
```

4) Display current command power and power limits
   a) Command: **E<CR>**
   b) The top value is the maximum allowable power for the current temperature. The middle value is the minimum allowable power. The bottom is the current command power. All values displayed with this command are in watts.

```
E
230.00
070.00
170.00
```

Advanced Communication Functionality

5) Show current control mode
   a) Command: **SET PID<CR>**
   b) This command will return the current control mode

```
SET PID
002.00
```

6) Set control Mode
   a) Command: **SET PID=<VAL><CR>**
   b) VAL may be a 2 or a 0. If it is 0, the controller will maintain a constant power as commanded by SET PWOUT. If it is 2, the controller will try to maintain a constant temperature as commanded by SET TTARGET.

```
SET PID=2
002.00
```

   c) The PID mode will be reset to the default value on a power cycle. The default value can be changed using the SAVE PID command.

7) Change default control mode
   a) Command: **SAVE PID <CR>**
   b) Saves the current SET PID value as the default value. The saved value will be restored after a power cycle.
   c) The value returned is the PID value that was saved.

```
SAVE PID
002.00
```

8) Display user commanded power
   a) Command: **SET PWOUT<CR>**
   b) Display commanded power when in power control mode as set by SET PID.

```
SET PWOUT
170.00
```

9) Set user commanded power
   a) Command: **SET PWOUT=<VAL><CR>**
   b) Set command power when in power control mode as set by SET PID.
   c) VAL corresponds to the target power in watts. While any number from 0.0 to 999.99 can be input, the controller will only command a power that will not damage the cryocooler.

```
SET PWOUT=160
160.00
```

   d) The minimum power is 70W @ 77 K.
   e) The maximum power is a function of cold head temperature and increases as the cold temperature decreases.

10) Display Soft Stop mode
   a) Command: **SET SSTOPM<CR>**
   b) Returns the current Soft Stop mode of the controller.

```
SET SSTOPM
001.00
```

11) Set Soft Stop mode
   a) Command: **SET SSTOPM =<VAL><CR>**
   b) Sets the current Soft Stop mode of the controller. This command sets if Digital Input 1 or the SET SSTOP command control the Soft Stop functionality used to shut down the cryocooler.
   c) VAL corresponds to the Soft Stop mode of the controller. A 0 allows the SET SSTOP command to control the Soft Stop functionality; a 1 allows Digital Input 1 (I/O connector pin 5) to control the Soft Stop functionality.

```
SET SSTOPM =1
001.00
```

d) When in Soft Stop Mode 1, setting Digital Input 1 high will shut down the cryocooler. Setting it low or leaving it disconnected will allow the cryocooler to run. The Onboard Isolated 5V (I/O connector pin 10 or pin 12) can be used to set Digital Input 1 high.
e) The soft stop function will slowly ramp down the cooler before shut down to minimize shutdown vibration.

12) Display soft stop status
    a) Command: **SET SSTOP<CR>**
    b) Returns the current soft stop status of the controller as set in Soft Stop mode 0 or 1.

```
SET SSTOP
001.00
```

13) Set soft stop status
    a) Command: **SET SSTOP=<VAL><CR>**
    b) Sets the current soft stop status of the controller when in Soft Stop Mode 0
    c) VAL corresponds to the soft stop status. To initiate a soft stop enter 1, this will shut down the cooler but allow the controller to remain on. Entering a 0 will restart the cooler from its stopped state.

```
SET SSTOP=1
001.00
```

    d) If in Soft Stop Mode 1, this command will not control the Soft Stop functionality.
    e) The soft stop function will slowly ramp down the cooler before shut down to minimize vibration.

14) Display user defined maximum power
    a) Command: **SET MAX<CR>**
    b) Returns the maximum power as set by the user.

```
SET MAX
190.00
```

15) Set user defined maximum power
    a) Command: **SET MAX=<VAL><CR>**
    b) Sets the user defined maximum power.
    c) VAL corresponds to user defined maximum power output in Watts. Entering a value that exceeds the safe operating power of the cooler will not result in damage to the cooler.

```
SET MAX=210
210.00
```

    d) The maximum safe power is a function of cold head temperature and increases as the cold temperature decreases. The maximum cooler power will be the lowest of the safe operating power or the SET MAX value.

16) Display user defined minimum power
    a) Command: **SET MIN<CR>**
    b) Returns the minimum power as set by the user.

```
SET MIN
100.00
```

17) Set user defined minimum power
    a) Command: **SET MIN=<VAL><CR>**
    b) Sets the user defined minimum power.
    c) VAL corresponds to user defined minimum power output in Watts. Entering a value that is below the safe operating power of the cooler will not result in damage to the cooler.

```
SET MIN=120
120.00
```

18) Display user defined minimum and maximum powers
    a) Command: **SHOW MX<CR>**
    b) Returns the minimum and maximum powers respectively as set by the user.

```
SHOW MX
080.00
200.00
```

19) Display cooler power as measured by the controller.
    a) Command: **P<CR>**
    b) Returns the cooler power in Watts as measured by the controller.

```
P
170.13
```

20) Display thermostat mode
    a) Command: **SET TSTATM<CR>**
    b) Returns the current thermostat mode of the controller.

```
SET TSTATM
001.00
```

21) Set thermostat mode
    a) Command: **SET TSTATM =<VAL><CR>**
    b) Sets the current thermostat mode of the controller. This functionality enables a user to add a thermostat to the system which can be used to shut down the cryocooler.
    c) VAL corresponds to the thermostat mode of the cryocooler. A 0 disables the thermostat functionality, a 1 enables this functionality.

```
SET TSTATM =1
001.00
```

    d) When utilizing this functionality, opening the thermostat circuit will shut down the cooler. One side of the thermostat should be attached to Digital Input 3 (I/O connector pin 7). The other side of the thermostat should be attached to the Onboard Isolated 5V (I/O connector pin 10 or pin 12). Setting Digital Input 3 high will allow the cooler to run when in thermostat mode 1. If the Onboard Isolated 5V is not connected to Digital Input 3 (the thermostat opens), the cooler will be shut down.

22) Display thermostat status
    a) Command: **TSTAT<CR>**
    b) Returns the current thermostat status of the controller.

c) If in thermostat mode 1, a return of 1 indicates the thermostat is closed and is allowing the Cryocooler to run. A return of 0 indicates the thermostat is open and the Cryocooler is shut or is shutting down.

```
TSTAT
001.00
```

23) Display proportional constant of the temperature control loop.
   a) Command: **SET KP<CR>**
   b) Returns the proportional constant of the temperature control loop.

```
SET KP
050.00000
```

24) Set proportional constant of the temperature control loop.
   a) Command: **SET KP=<VAL><CR>**
   b) Sets the proportional constant of the temperature control loop.
   c) VAL corresponds to the user defined proportional constant of the temperature control loop.

```
SET KP=1
050.00000
```

   d) There may be some applications where the user may want to modify the PI constants to tune the temperature control loop based on their individual system. This would require experience in tuning PID control loops.
   e) The default proportional constant for the GT is 050.00000. KP and KI will be reset to their defaults if the RESET command is used.

25) Display integral constant of the temperature control loop.
   a) Command: **SET KI<CR>**
   b) Returns the integral constant of the temperature control loop.

```
SET KI
001.00000
```

26) Set integral constant of the temperature control loop.
   a) Command: **SET KI=<VAL><CR>**
   b) Sets the integral constant of the temperature control loop.
   c) VAL corresponds to the user defined integral constant of the temperature control loop.

```
SET KI=1
001.00000
```

   d) There may be some applications where the user may want to modify the PI constants to tune the temperature control loop based on their individual system. This would require experience in tuning PID control loops.
   e) The default integral constant for the GT is 001.00000. KP and KI will be reset to their defaults if the RESET command is used.

27) Display temperature band .
   a) Command: **SET TBAND<CR>**
   b) Returns the temperature band that the LEDS and the “At Temperature” pin on the I/O connector will function per section XI.

```
SET TBAND
000.50
```

28) Set temperature band..
   a) Command: **SET TBAND=<VAL><CR>**
   b) Sets the temperature band that the LEDS and the "At Temperature" pin on the I/O connector (Digital Out 4, I/O connector pin 4) will function per section XI.
   c) VAL corresponds to the user defined temperature band. The default band is 0.5K.

```
SET TBAND=1.5
001.50
```

29) Set user password.
   a) Command: **SET PASS=<VAL><CR>**
   b) Sets the user defined password to unlock the controller parameters.
   c) VAL corresponds to the user defined password. The default password is STIRLING. The password must be between 1 and 10 characters in length. This command will return a 1 if the password was successfully changed.

```
SET PASS=ABC123
001.00
```

   d) The controller must be unlocked to change the password. If the controller is locked and the password has been misplaced, it must be sent back to Sunpower to be unlocked.

30) Display lock state
   a) Command: **LOCK<CR>**
   b) Returns the Lock state of the Cryocooler. A 0 indicates that controller parameters can be changed. A 1 indicates that all controller parameters are locked.

```
LOCK
000.00
```

31) Set lock state
   a) Command: **LOCK=<Password><CR>**
   b) Locks all of the controller parameters from being changed. A return of 1 confirms that all controller parameters are locked.
   c) <Password> refers to the current user defined password. The Default password is STIRLING.

```
LOCK=STIRLING
001.00
```

32) Set lock state
   a) Command: **UNLOCK=<Password><CR>**
   b) Unlocks the controller parameters. A return of 0 confirms that controller parameters can be changed.
   c) <Password> refers to the current user defined password. The Default password is STIRLING.

```
UNLOCK=STIRLING
000.00
```

33) Display list of most controller parameters.
    a) Command: **STATE<CR>**
    b) Returns a list of most of the controller parameters and what they are set to.

```
STATE
MODE      =     002.00
TSTATM    =     000.00
TSTAT     =     000.00
SSTOPM    =     000.00
SSTOP     =     000.00
PID       =     002.00
LOCK      =     000.00
MAX       =     300.00
MIN       =     000.00
PWOUT     =     000.00
TTARGET   =     077.00
TBAND     =     000.50
TEMP KP   =     050.00000
TEMP KI   =     001.00000
```

34) Display controller serial number
    a) Command: **SERIAL<CR>**
    b) Returns the controller serial number.

```
SERIAL
REV4.1 V1.0.0-123456789
```

35) Display any error codes that are present.
    a) Command: **ERROR<CR>**
    b) Returns error codes if there are any present. See Section XII more information.

```
ERROR
100000
```

36) Reset controller parameters to the factory defaults.
    a) Command: **RESET=F<CR>**
    b) Resets the controller parameters to the factory defaults.

```
RESET=F
RESETTING TO FACTORY DEFUALT…
FACTORY RESET COMPLETE!
```

End of CryoTel® GT Operating Instructions Version 6